BOOK OF

ABSTRACTS

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FORESTS & SOCIETY TOWARDS 2050

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Contents

The Scientific Committee - Potpourri session

Impact of Forest Rehabilitation Programs on Soil Quality Status in Malaysia

The Scientific Committee - Potpourri session
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Abstract: The rehabilitation of forest areas is not new to Malaysia as forest replanting activities have been carried out throughout the country for years to meet the demand for woody and nonwoody products as well as to nurture degraded forestland. Thus it is important for a soil to be evaluated to ascertain the degree to which rehabilitation activities have succeeded in restoring forest health, particularly in sustaining soil quality in rehabilitated forests. This review article aims to provide a corpus of information for forest managers and related agencies who work closely with forestry. The aim is to provide an overview on the importance of soil quality in measuring the success of forest rehabilitation programs. Research articles on the evaluation of soil properties at selected rehabilitated forests in Peninsular Malaysia were included in the review. The impact of forest rehabilitation in relation to soil properties comprising soil compaction, moisture, acidity, macronutrients, cation exchange capacity, microbial count, microbial enzymatic activity, and microbial biomass is discussed. Natural forest is used as a benchmark to see the effect of forest rehabilitation programs. Our review indicates that rehabilitated forests that were established earlier and have gone through a longer period of time have better soil quality compared to the soil of forests established later. This shows that rehabilitated forests are able to restore their soil quality and achieve fertility on par with natural forests, if given longer periods of time for recovery. Soil quality analyses should be done regularly to measure the extent of success in rehabilitation programs. Evaluation of forest soil quality should not neglect any of the three important aspects of soil physical, In short, it is important to select appropriate parameters to evaluate soil quality so that one can gain a clear picture of current soil conditions to ensure proper actions can then be taken to restore the condition of problematic soils to its optimum level.

Restoration and in situ conservation of native species the Atacama Desert, Chile

The Scientific Committee - Potpourri session
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Abstract: The decade 2021-2030 has been defined as the era of ecosystem restoration. In accordance with Chile's international commitments, committing itself by 2030 to the afforestation of 200,000 ha with at least 70,000 ha of native species, the sustainable management and recovery of 200,000 ha of native forests, and the application of the National Landscape Restoration Plan which includes 1 million ha under restoration processes by 2030. These commitments at the level of adaptation to climate change and biodiversity conservation represent a huge challenge for Chile in terms of governance, implementation and long-term monitoring.

For Chile to achieve restoration goals in the coming decades, studies have identified bottlenecks that prevent the country from meeting these challenges, which include: insufficient stock and supply of seeds for the production of native plants and the need for production protocols; and the need for innovative plantation designs of native species that allow improving the deficient results in the establishment phase.

The vegetation of the arid zones of Chile plays a fundamental role in the persistence and functioning of the Mediterranean ecosystems, it is the most threatened part of the country under a scenario of global climate change, a phenomenon that accelerates the processes of desertification and erosion, affecting the populations of rare, endemic and restricted-distribution species. The native flora of the Atacama region consists of 980 species of native vascular plants, of which 9.6% are in the Endangered (EP, 26 species) or Vulnerable (VU, 68 species) category.

The objective of the study is the conservation of endemic native shrub species (10 species) and cacti (4 species) with some degree of conservation danger, through the implementation of a landscape-scale restoration plan that covers an area of 60 ha.

In a first stage, seed collections were carried out and propagation protocols were generated for the target species. The individuals were established in land with a natural distribution and irrigated by means of a technical drip irrigation system. Irrigation was calculated by analyzing the historical rainfall of the study site. After 1 year of establishing the individuals in the field, there is an average of 85% survival.

"Adjusting land use patterns in agriculture with value chains from fast-growing economic trees in a new transformed agroforestry system"

The Scientific Committee - Potpourri session

Kitipong Tangkit
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Abstract: Efforts to promote commercial economic plantation in countries with conflicting land use policies that are not hostile to agriculture have long worked with agroforestry systems. The introduction of the concept of changing the word economic tree to a new name for the economic plant has not been concretely successful when the slow growth of economic trees is an obstacle to solving the problems of smallholder farmers.

But the problem of agricultural crops such as crops grown in developing countries with short-term harvests is always pressured by market prices and production factors and is a burden that the government must directly support the price both direct and indirect.

The idea of building a fast-growing economic timber agroforestry system for farmers is a challenge as to what model can lead smallholder farmers to create stability in the short, medium, and long term. The experiment introduced fast-growing plants, such as eucalyptus, to develop and improve activities within the value chain that work together with primitive crops. Changing the cultivation behavior deeply rooted in the cultural system is challenging. Consistently improving the outcomes in activities within the value chain may be the key to success in helping smallholder farmers overcome lifestyle imbalances and reduce short-term crop input debt. Very well with the economic tree that was renamed in the original name of the bio-based economic plant.

"Delineation of Groundwater Potential Zones in Una District, Himachal Pradesh Using Analytic Hierarchy Process (AHP) and Geospatial Analysis"

The Scientific Committee - Potpourri session

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Abstract: Human activities and ecosystems cannot exist without groundwater, which plays a crucial role in supporting human activities and sustaining ecosystems. However, its availability and quality are increasingly threatened by a variety of factors, such as population growth, climate change, and anthropogenic activities. It is vital to identify and delineate groundwater potential zones in order to ensure sustainable management and use. Geospatial analysis and Analytic Hierarchy Process are used to investigate potential groundwater zones in the Una district in Himachal Pradesh. Analytic Hierarchy Processes are multicriteria decision-making techniques that evaluate different factors affecting potential groundwater zones and assign weights based on their relative importance to each parameter. The research methodology involves the selection of thematic maps of geomorphology, lithology, soil, lineament, drainage, land use, slope, aspect, and rainfall. A geospatial tool in ArcGIS software was used to convert these maps into raster data by utilizing Survey of India toposheet data, SRTM DEM data, and Liss III data of Resourcesat-2A satellite imagery. Moreover, these datasets were subject to predetermined scores and weights in the decision-making process. A comprehensive groundwater potential zone map was developed by integrating a variety of datasets, such as topographic maps, satellite images, rainfall data, soil data, and land use/land cover data. The anticipated groundwater zones obtained were classified into five categories: Very poor covering 1% (17.85 km^2) of the total area; Poor 7 % (114.89 km^2); Fair 30% (453.76 km^2); Good 36% (548.06 km^2) and Excellent 26 % (392.78 km^2). The validation process involved obtaining open well yield data and referring to the Central Ground Water Report from 2021-2022 for comparative analysis and verification. Researchers have provided insight into how groundwater managers and policymakers can develop strategies and plans that address the spatial heterogeneity of groundwater potential zones in future water management plans.

Keywords: Groundwater potential zone, Geospatial analysis, Analytic Hierarchy Process, remote sensing.

A Bayesian network model to disentangle the effects of stand and climate factors on tree mortality of Chinese fir plantation

The Scientific Committee - Potpourri session
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Abstract: Tree mortality is a complex process that not only needs to consider the impact of various factors on tree mortality, such as stand and climate factors, but also considers the uncertainty and link the various long-term effects of the factors to each other. In this study, based on the long-term spacing trials of Chinese fir in four regions of southern China, Bayesian network was used to model tree mortality in response to stand and climate factors, as well as comparing with logistic regression and random forest methods. The results showed that Bayesian network had the highest accuracy in predicting tree mortality. In addition, Bayesian network could automatically find the dependency relationship between data and provide a theoretical framework for modeling uncertainty by using probabilistic calculus and underlying graph structure. Sensitivity analysis showed high importance of RD for survival rate among stand factors, and the most relevant of MAT among climate factors, whereas stand structure (Gini) was ranked as less important. In addition, tree mortality increased with the increase of AP, N, age and Gini coefficient, but decreased with the increase of RD, MAT and WMMT. Moreover, climate factors also affected stand variables, and there was a certain interaction between stand variables. The results will provide insights into forest management of Chinese fir plantation under the background of global climate change in the future.

A framework for considering justice aspects in integrated wildfire risk management

The Scientific Committee - Potpourri session
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Abstract: Throughout history, ecosystems and societies have adapted to wildfires, but there is increasing evidence that anthropogenic climate change as well as socioeconomic development are altering the dynamics of extreme wildfire events, leading to increasing wildfire risk globally. With this increasing wildfire risk, inequalities may escalate, leading to potential new conflicts in wildfire risk management (WFRM). Managing these growing risks in increasingly complex governance settings raises important equity concerns; in particular, what is perceived as just in terms of outcomes of and processes in WFRM. Building on the environmental justice literature, we develop a framework for identifying and categorizing along the WFRM cycle (prevention, preparedness, response, and recovery & adaptation) crucial and generally applicable aspects of distributional, procedural, and restorative justice. We argue that policy and decision makers should proactively consider all three justice aspects within collaborative governance policy processes to successfully innovate integrated WFRM strategies that respond to equity concerns.

A framework for indicators of recreational values in forests

The Scientific Committee - Potpourri session

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Abstract: Tourism and recreational activities are important ecosystem services that forests provide and they continue to grow. Seventy percent of Europe's forests are available for public recreation and about six percent are primarily designated or managed for public recreation. The intensity of recreational use can be measured in million visits per year, providing an indication of how important forest are for recreational purposes. There are however several challenges to monitor and measure social values in forests. Many countries have difficulties to report valid data according to the Ministerial Conference on the Protection of Forests in Europe (FOREST EUROPE). A state-of-the-art report of social indicators in forestry in North European countries by the Nordic Council of Ministers concludes that there is a need for further development of social indicators for sustainable forest use, but a major problem in most countries is a serious shortage of reliable data about forest recreation. The current study will help to fills these knowledge gaps. The objective of this study is to develop a framework for indicators of recreational values in Sweden. It was set up as a literature-based pilot study, supported by the National Board of Forestry, where 165 documents (peer-reviewed scientific articles, reports, policy-papers etc.) were identified and analyzed through a snowball approach.

Conceptually, we propose a two-dimensional framework. The first dimension is defined as either a potential or a realized value. Recreational potentials of a forest depend primarily on the forest's characteristics, but also on the influence of the surrounding environment, the existence of recreational infrastructure and the location of the forest. The realized value is the perceived experience qualities and actual use by recreationists. The second dimension captures whether the indicator measures the recreational value provided by a specific forest, or the value enjoyed by a specific user. The study also identifies several factors that may have a significant impact on recreational values – in a positive or negative way – but have not been sufficiently studied to be suggested as indicators based on current knowledge.

A new approach to ecosystem restoration: opportunities in sugarcane plantation landscapes

The Scientific Committee - Potpourri session
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Abstract: The interest and need for ecosystem restoration increased greatly worldwide in the past years mostly targeting highly diverse regions such as the brazilian Atlantic Forest. However, land availability can be a main challenge since local landscapes consist of complex land use mosaics. Thus, increasing the efficiency of large agricultural systems such as sugarcane, can free up marginal areas and create opportunity for restoration. This work sought to find restoration opportunities by identifying and quantifying marginal areas of mechanized sugarcane production (Short Line Areas – SLA). The SLA consist on regions of short sugarcane planting lines where production costs are higher than the profits. We trained regression models using supervised machine learning algorithms to quantify the SLA in São Paulo state (Brazil) assessing two SLA thresholds: 50 and 100 meters. The models were based on 120 agricultural landscapes of 25 km² sampled throughout the state (total of 7,553), in which the SLA were manually mapped and explanatory variables that could be correlated with the presence of such regions were calculated (mean slope; drainage density; percentage of sugarcane cover, and landscape metrics applied to the crop fields). Finally, the estimates were used to investigate the potential contribution for reducing the state's deficit of legally preserved areas. The best models were created by the Random Forest algorithm. Model performance for each threshold (50 and 100 meters, respectively) was assessed using the Coefficient of Determination (0.451 and 0.634), Mean Absolute Error (0.252 e 0.932) and the Root Mean Squared Error (0.323 e 1.195). Estimates for the entire state were 174.19 km² of SLA considering the 100-meter threshold; and 39.78 km² for the 50-meter threshold. Overall, the use of SLA to reduce the state deficit of legally preserved areas can mitigate from 0.43 up to 4.83% of the total deficit. Investigating SLA showed potential to create new restoration opportunities, especially in complex landscapes. These regions can still be addressed considering incentives for voluntary commitments; corroborating the efforts, commitments, policies and projects of ecological restoration encouraged by the UN Decade of Ecosystem Restoration.

A scoping review on determinants of financial institutions' engagement in biodiversity conservation

The Scientific Committee - Potpourri session

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Abstract: Scaling up investments and finance for ecosystem conservation is recognized as an urgent and crucial response to combat biodiversity loss. Financial institutions (FIs) are now recognized as vital sources and catalysts in this endeavor, given their potential to mobilize and allocate financial resources, driving transformative action through meaningful dialogues with their stakeholders. However, voluntary investments by FIs in biodiversity conservation remain limited. We expect the role of FIs in biodiversity finance within agricultural-environmental policy frameworks to be contingent upon their motives, barriers, and available financial tools. Despite some attempts at summarizing the state of research in the grey literature, a comprehensive scoping review is lacking. To address this gap, we conduct a review of scientific literature to identify the determinants of FIs' engagement in biodiversity activities. This includes examining the contextual conditions and extent of FIs' investments in biodiversity conservation, including the challenge of assessing the measurable biodiversity outcomes resulting from such engagements. Our study defines FIs as banks, insurance companies, pension funds, and mutual funds. Specifically, we provide overviews of existing studies, encompassing publication patterns, countries, and study types, summarizing the settings, contexts, and scales of conducted research. Additionally, we explore FIs' motives for investing in biodiversity conservation, the facilitating or inhibiting conditions for their conservation activities, and the characteristics of their direct and portfolio-based biodiversity investments. Comparative analyses among different types of FIs encompass financial motivations, obstacles, tools, geographical money flows, portfolio characteristics, investment sectors, and project features. By addressing the research gap in biodiversity finance, this paper proposes enhancements in research and policy to align with the EU's biodiversity strategy for 2030 and the global biodiversity 2050 Vision and goals.

A spatial framework for investment allocation under tree-planting policies: Outcomes for costs, land use, and human equity

The Scientific Committee - Potpourri session
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Abstract: Forest expansion, or the establishment of trees on land without current or historic tree cover, has significant potential as a GHG mitigation strategy, particularly in temporal and boreal regions where forest management and timber production could provide additional value to forest expansion efforts. There is great potential for economic gains from forest expansion, but there are challenges in ensuring the best outcomes. Capturing the dynamics of forest expansion is multifaceted and relies on ecological (i.e., soil and water qualities) and economic (i.e., timber markets, implementation costs) conditions, which need to be considered when implementing forest expansion investments. Failing to account for these factors will result in inefficient use of resources for planting and lower CO_2 benefits per dollar of investment. This paper assesses simulated changes in the spatial distribution of tree planting and additional forest carbon storage on alternative land use types under different incentive structures. We develop a spatially explicit resource allocation optimization framework to assess trade-offs between multiple policy structures. We combine estimates on planting costs and potential, current land utilization, forest yields, and demographic indicators to build a forest expansion optimization framework in the contiguous United States. We compare estimated CO_2 sequestration, cost efficiency, land use change, and spatial allocation of investments under policies that seek to maximize CO_2 storage over different time horizons and budgets. Lastly, we consider a policy design that prioritizes tree planting in communities with a higher relative proportion of disadvantaged populations to understand the cost and CO_2 implications of efficiency vs. equity considerations. Preliminary projections estimate total forest expansion to be between 17.94 and 28.14 million acres, a range of 393.9 to 662.8 million tons of CO_2, and the cost of expansion ranges from $11.19 to $26.63 per ton of CO_2. We find the highest expansion and CO_2 storage in scenarios with higher budget expenditures and longer simulation periods, but the cost per ton of CO_2 increases with the budget due to higher marginal abatement costs and opportunity costs of land. These outcomes are shown to be highly sensitive to spatially explicit economic and ecological conditions, as well as incentive structure specifications.

A survey of Swedish hardwood sawmills

The Scientific Committee - Potpourri session

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Abstract: Swedish forestry could benefit from maintaining a greater proportion of broadleaved species in the otherwise conifer-dominated stands, since greater species diversity may improve forest resilience to disturbances. Furthermore, the demand for Swedish roundwood is predicted to continue increasing, with many projects and studies now focused on hardwood utilization. Despite a growing interest in broadleaved tree species, in recent years the number of hardwood sawmills has been declining and there is limited information about their locations and capacity.

In this work, 21 hardwood sawmills were surveyed to identify mill locations and details about their log inputs. Questions related to species and volumes used, where raw material was sourced from, and what end products were manufactured. Additional questions were asked about their most significant threats and opportunities and their level of optimism regarding the future of hardwood sawmilling in Sweden.

Survey respondents mainly processed oak and birch, approximately 87,000 and 42,000 m^3sub/year, respectively (combined totals for all sawmills). The beech, alder and ash volumes were in the 1,000s of m^3sub/year. All the participating hardwood sawmills were located in southern and central Sweden. The sawmills produced a range of products, including sawn timber, flooring, tabletops, fine joinery, matches and toothpicks. Most of the birch volume was used for furniture components, while oak was widely used to restore or refurbish buildings and in public outdoor environments.

The surveyed sawmills were small and source most of their inputs from nearby suppliers. Few sawmills were importing raw materials, and where imports did occur, they were generally for oak. Common issues identified when importing wood included: unreliable wood quality, high transport costs and a desire to support local suppliers.

The sawmills were optimistic about their future and the Swedish hardwood sawmilling industry. As the mills are small, they have greater flexibility and can make decisions faster, which was perceived as a competitive advantage. Sweden has a continuing demand for hardwood timber, which may encourage forest managers to invest more in broadleaved tree species.

A Systematic Literature Review on European Forest Nature Conservation Politics: Avenues for Research and Theory Development

The Scientific Committee - Potpourri session
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Abstract: Even though basic scientific knowledge on the importance of biodiversity and its conservation have been known for decades, the related issues are perceived differently by states and other actors in Europe. At the same time, numerous biodiversity indicators are showing negative trends and especially forest ecosystems are increasingly affected by biodiversity degradation. In the European Union (EU), many efforts have been taken to maintain biodiversity in forests. For instance, recent political developments such as the new EU strategies on forests and biodiversity or the proposal for an EU Nature Restoration Law aim at improving the ecological transformation of society and economy. However, to achieve these ambitious policy targets coherently, forest nature conservation policymakers must consider a multitude of involved actors, sectors and conflicts. The fragmentation of interests and values of stakeholders becomes not only apparent on the EU level but also within member states, especially in federalist countries like Germany. Consequently, the myriad of actors and their either complementary or conflicting interests pose a challenge for nature conservation policymaking and implementation. To capture this complex conglomerate, forest nature conservation needs to be also informed by social and political sciences.

This systematic literature review addresses knowledge gaps in forest nature conservation politics by focusing on conflicts and challenges, their typologies, as well as relevant actor groups and policy sectors in the EU and Germany. Hence, the review is guided by the following two research questions: What are the relevant policy sectors and actors that influence nature conservation politics both in the EU and Germany? What are the main conflicts and types of conflicts regarding nature conservation politics in the EU and Germany? Furthermore, the review will conduct a meta-analysis for identifying theories on policy change and actor networks as well as existing research gaps in these frameworks, aiming at theory development. In order to facilitate the reporting of results from the review, and thus increase reliability and validity, the PRISMA statement is used. The findings of the study provide new avenues for research on forest nature conservation politics and identify opportunities for syntheses of policy change theories.

Adapting the Tasmanian forest practices system to climate change

The Scientific Committee - Potpourri session
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Abstract: Given the increasing risk to production forests posed by climate change, the regulator of forestry in Tasmania, Australia, initiated a project to explore the ways the forest industry could adapt to climate change. The first stage of the project involved seeking feedback from local scientific experts on the expected impacts of climate change on Tasmanian production forests and potential adaptation options. Broad themes covered were carbon, forest vigour and condition, fire, soils, water, biodiversity and weeds, pests and diseases. The 52 responses were distilled into 75 potential adaptation options which varied greatly in importance and achievability. The second stage of the project was to convene a practitioner workshop to explore 'what climate change adaptation options could the forest industry start to progress?' Prior to the workshop the 30 people invited were given the background report from Stage 1 and asked to rank all adaptation options for importance and achievability. During the workshop 23 participant-identified discussions were had which aimed to identify practical actions to achieve the potential adaptation options. The third stage of the project used the information from the workshop and expert review to develop a list of targeted actions where the regulator of forestry has a direct or supporting role. Given limited resources, each action was assessed for importance and achievability, the result of which was used to identify a list of ten priority actions. These actions include reviewing the effectiveness of current erosion control measures, developing new spatial layers for planners to use and promoting research that will inform future management. This prioritisation process will be repeated regularly to ensure continual progress and to account for changes in priorities and resources.

Adaptive Natura 2000 forest conservation concepts in a climate change hotspot region

The Scientific Committee - Potpourri session
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Abstract: Climate change is inevitably leading to changes in forest structures and species communities - including the death of many trees, sparse forest structures where non-native invasive plants may become established, shift of protected species distribution, and the increased spread of pests and insects that further threaten forest biodiversity. These conditions pose a challenge to protected forest areas, such as those inside Special Areas of Conservation (SAC) as part of the Natura 2000 network. The SAC have been established under the EU Habitats Directive, which aims to preserve or restore favourable conservation status of habitat types as well as animal and plant species listed in the Directive's annexes. To date, however, there is limited knowledge about the impacts of climate change on characteristic tree and herbaceous plant species in protected forest areas. Therefore, we assess the current state of forest habitat types inside several SAC in the climate change hotspot region Upper Rhine in Germany to detect possible changes that have already occurred due to ongoing global warming. To this end, we collect data on characteristic plant species and forest health condition in 2023 and 2024 by assessing heat- and drought-induced damage to tree stands in different beech and oak dominated forest habitat types in three SAC. Based on the results, we discuss the development and implementation of measures to compensate for climate-induced losses of protected forest habitats. Furthermore, we discuss the appropriateness of habitat definitions and assessment criteria under current and expected future climate conditions and develop conservation objectives that consider the vulnerability of these forest habitat types and adaptive management measures. Our results may also be relevant to other hotspot regions that are (will be) facing similar climatic conditions.

Advances in forest variable modelling using LiDAR technology: insights from a tree breeding trial in North-West Spain

The Scientific Committee - Potpourri session
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Abstract: Forest variable modelling from LiDAR (Light Detection and Ranging) data has revolutionized our understanding of forest ecosystems and their dynamics. By utilizing the three-dimensional data collected from airborne and/or terrestrial LiDAR sensors, researchers and forest managers can accurately estimate numerous forest variables, such as tree height, canopy density, biomass, and species diversity, which have many applications in a wide range of fields of study, including tree breeding trials.

This study was performed in a *Pinus pinaster* tree breeding trial and aimed to use LiDAR data to select the family/meta-population of this species that is best adapted to the conditions of North-West Spain. For this purpose, two types of point clouds were used: (i) terrestrial, collected with a handheld scanner, and (ii) aerial, collected with a UAV-LiDAR system. The terrestrial point cloud was used to determine tree positions and measure diameter-at-breast-height and total height of each tree, while the aerial point cloud was used to calculate a set of variables associated with vegetation structure (height, coverage, crown characteristics, etc.) at the single tree level. From these data, two models were fitted to estimate volume and biomass fractions using statistical techniques. Based on this, the differences between families/meta-populations for these two variables were analysed.

The study's general results revealed significant differences in volume and biomass among the *P. pinaster*families/meta-populations assessed. Specifically, certain *P. pinaster* families exhibited higher volume and biomass, indicating a potential influence on forest productivity and carbon storage capacity. The integration of LiDAR technology provided accurate and detailed measurements, underscoring the importance of considering genetic differences in *P. pinaster* families for effective forest management and conservation efforts.

In conclusion, the study using LiDAR data successfully quantified the differences in volume and biomass among various *P. pinaster* families/meta-populations. This reinforces the crucial role of LiDAR-based forest variable modelling in guiding informed decision making for forest management and conservation strategies.

Advancing forest resilience to global changes: a pan-canadian application of the functional complex network approach

The Scientific Committee - Potpourri session
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Abstract: Global changes pose significant threats to the resilience and sustainability of forests worldwide. While climate-smart forestry and adaptive silviculture have been proposed and applied to address these challenges, they fail to adequately tackle growing social, economic, and environmental uncertainties associated with global changes.

To address these limitations, our approach embraces a comprehensive framework that recognizes forests as complex adaptive systems. It incorporates essential elements such as uncertainty, non-linearity, thresholds, and cross-scales hierarchies. Our strategy involves functionally diverse plantations as insurance against global changes. Additionally, we emphasize the utilization of functional diversity, redundancy and connectivity to increase resilience at both stand and landscape scales. To confront potential future climates, we consider assisted migration to introduce new functional traits and genes. By employing network theory, we describe the spatial connectivity of forest stands. Furthermore, we acknowledge the significance of self-regulation forces within forest ecosystems to effectively address the threats of global changes. This enables us to identify key stands in the landscape where interventions should be prioritized to promote forest resilience.

To validate this approach, we have initiated a large-scale study in collaboration with multiple universities, First Nations, industries, and governmental and non-governmental organizations, encompassing diverse forested biomes across Canada. This study involves a comparison between the functional complex network approach, business-as-usual practices, and climate-smart forestry under various future climate and disturbance scenarios. Moreover, we are diligently evaluating the socio-economic and governance implications associated with implementing both climate-smart and functional complex approaches. To ensure a holistic perspective, we actively engage social scientists, First Nations, and other collaborators in the development of realistic and socially acceptable management scenarios.

Through this project, we aim to bring the functional complex network approach into the real world, equipping forest managers with the necessary tools to determine appropriate actions and locations within the forest landscape to enhance resilience in the face of global changes. Our ultimate goal is to contribute to a paradigm shift in forest management and public perception, transforming it from an extractivist viewpoint to one where forest management actively contributes to increasing the resilience of forests to the uncertainties brought about by global changes.

Advancing Transformative Stakeholder Engagement for Inclusive Forest Restoration Processes.

The Scientific Committee - Potpourri session
Marie Vaney
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Abstract: The importance of addressing conflict around forest restoration is now firmly recognised as imperative for success in the field. So is the inclusive involvement of stakeholders in the restoration process. However, the adoption of both practices still faces challenges, also with respect to the will and readiness of forest restoration teams to do so. The experience of the EU Horizon 2020 SUPERB project offers unique insights into how twelve such teams across Europe are being encouraged and empowered to recognise and tackle conflict with and among their different stakeholders through close engagement with the latter.

SUPERB stands for *Systemic solutions for upscaling of urgent ecosystem restoration for forest related biodiversity and ecosystem services*. It is a four-year research and innovation project that runs until December 2025 and aims to develop, test and upscale effective restoration solutions in twelve diverse European forest areas. This work is embedded in an innovative framework of continuously engaging a broad range of stakeholders. As part of this framework, inclusive stakeholder engagement is advanced as a tool for identifying and dealing collaboratively with conflict to enable effective, sustainable and socially beneficial restoration outcomes. The present study discusses and assesses SUPERB's hands-on efforts to work with the project's restoration teams to mainstream such use of stakeholder engagement at the local level.

The study's central methodology is participatory research, conducted by the authors as the SUPERB partner responsible for guiding and supporting the design and implementation of the project's stakeholder engagement activities. The study draws on the direct experience of the authors working on this task. It also makes use of related project reports and feedback from the forest area partners and stakeholders involved. The study concludes that to effectively coach forest restoration teams to take on conflict through inclusive stakeholder engagement it is crucial to introduce this co-creative approach at a pace that fits each team's context and experience.

This abstract is complementary to the one submitted to T4.6 by O'Brien and Begemann. If choosing between the two, please kindly prioritise the latter.

Advocating for Forestry as a Topic in High School Curriculum

The Scientific Committee - Potpourri session

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Abstract: The Philippines has lost about 32% of its forest cover between 1990 and 2015, according to the World Bank. Many Filipinos are aware of the alarming rate of deforestation in the country, but forestry continues to be underappreciated and undervalued. One of the prevailing causes is a lack of education and awareness. This study aimed to establish a basis for high school education to include the topic of forests in the junior high school curriculum. This zeroes in on the significance of engaging the youth to protect, conserve, and manage our forests and be future stewards capable of influencing our planet's sustainability. The K to 12 Science Curriculum of the Philippines' Department of Education and the Angeles City Science High School's (ACSHS) Most Essential Learning Competencies (MELCS) for Environmental Science were analyzed and compared with other schools in Angeles City, Pampanga. These show that forest education is significantly lacking in the junior high school curriculum, with the K to 12 Science program not having any substantive forestry-related content. An online survey was conducted to determine the knowledge gap on forestry among 164 Grade 7 students, four Science teachers, and 56 alumni of ACSHS. The survey determined the respondents' knowledge on forestry and whether their behaviors take into account the current state of the Philippine forests. Data were analyzed using simple descriptive statistics. The respondents all acknowledged the importance of incorporating forestry as a topic in high school, as supported by the results obtained. The study highlights the need for intentional school activities where students can better appreciate what forests are, the ecosystem services that they provide, and the importance of participating in the protection and conservation of this undervalued natural resource. Examples of learning activities include viewing online modules and writing essays about forests, and projects such as establishing school nurseries for native tree species, tree planting, visiting protected forest areas to identify forest flora and fauna and learn about forest ecosystem protection and conservation. This study can inform policy makers to include the topic on forests in the high school curriculum to educate future generations about addressing forestry challenges.

An integrated approach for the sustainable management of forested islands of South Korea: Typology and ecosystem service mapping

The Scientific Committee - Potpourri session
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Abstract: The efficient implementation of sustainable island forest management policies requires classifying them based on specific criteria and establishing a consistent management system for the forested island types identified. Through two expert Delphi analyses, a list of ecosystem services and key ecological and socio-economic factors relevant to the management of forested islands were elicited. Using these results, a typology of forested islands was established: (type 1) connected islands with high natural vegetation cover [n=156]; (type 2) connected islands with moderate natural vegetation cover [n=16]; (type 3) connected islands with low natural vegetation cover [n=60], (type 4) unconnected islands with high natural vegetation cover [n=1,810]; (type 5) disconnected islands with moderate natural vegetation cover [n=108]; and (type 6) disconnected islands with low natural vegetation cover [n=302]. An AHP analysis conducted with forest experts enabled the identification of priority ecosystem services to be considered for the management of each island type. In areas where islands are connected, provisioning services (natural resources, medicinal plants, etc.) were considered to have greater importance than regulating services (erosion prevention) and supporting services (species diversity). In areas where islands are disconnected/isolated, especially those that lack natural vegetation, regulating services (erosion prevention) were prioritized for management to achieve ecosystem conservation goals. In particular, type 3 islands require urgent management to increase ecosystem resilience as being connected to the mainland makes island forest ecosystems vulnerable to anthropogenic impacts and invasive alien species, which may lead to disturbances to island forest ecosystems. To illustrate the application of the classification system, the land use scoring method was carried out on a forested island corresponding to type 3. The spatial distribution of prioritized ecosystem services revealed mismatches between the supply and demand of erosion prevention, freshwater supply, and habitat provision services. The results of this study are twofold—a classification framework that categorizes forested islands based on ecological and socioeconomic factors is proposed, and key island ecosystem services to be prioritized in future management are identified for each island type. The results can be used as evidence to guide island development and management policies to sustain flows of key ecosystem services.

Analysis of Land Use and Land Cover Change in the Forest Zone of Nigeria

The Scientific Committee - Potpourri session
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Abstract: Land-cover change has many environmental, physical, and socioeconomic significances. Therefore, the study investigated the consequence of Land Use/Land Cover (LULC) change on vegetation indices in the forest zone of Nigeria between 1989 and 2019 (30 years). Multistage sampling technique was used to sample three states which are Ekiti, Edo and Ondo State. In each state, three communities were purposively selected for the study, making 18 communities in the forest zones of Nigeria that was used for the study. Image processing and Geographical Information System (GIS) analysis was carried out. The result revealed that in the freshwater swamp Agricultural Ecological Zone (AEZ) of the forest zone, there was declining in areas covered by dense vegetation (69.17%) and wetland receded by 98.19% in the last 30 years. The built-up land and agricultural land increase by 152.71% and 21.18% respectively in the last 30 years. In the rainforest zone AEZ of the forest zone, there was 1689.43% increase in areas covered by sparse vegetation against 50.94% decline in dense vegetation. The study recommends that government and Non-Governmental Organizations (NGOs) should assist in formulating environmental policies that will protect the ecosystem in the study area.

Analyzing the dynamics of forest gaps in the Białowieża Forest (2015-2022) - a comparative study utilizing multitemporal data analysis of ALS and DAP

The Scientific Committee - Potpourri session

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Abstract: Gaps play an important role in ecological processes occurring in forest ecosystems, influencing forest structure, particularly in mature stands and old-growth forests. Gaps can affect tree growth, regeneration success, and contribute to the maintenance and enhancement of biodiversity. The ability to spatially characterize gaps (size, location) and track their temporal changes would be highly valuable for multifunctional and sustainable forest management, especially in forest planning and silviculture.

Modern remote sensing systems have opened up new possibilities for tree biometrics and the assessment of forest structure properties. Remote sensing technologies that provide continuous spatial information based on three-dimensional data, such as Airborne Laser Scanning (ALS) and Digital Aerial Photogrammetry (DAP), have gained much interest in last decades. Digital Surface Models generated using ALS and DAP data provide a detailed and accurate representation of the land surface and objects within a given area and provide valuable information about the characteristics of trees and stands.

The aim of the research was to determine the dynamics of gaps in the Białowieża Forest District from 2015 to 2022 using airborne laser scanning data and high-resolution aerial imagery. In addition, a comprehensive comparison was made between the utilization of ALS point clouds and image-derived Point Clouds (IPC) for spatial characterisation of gaps.

The results obtained confirm that the structural changes in the forest stands of the Białowieża Forest District are very dynamic. Moreover, the analyses carried out show that the number of gaps detected based on ALS data was significantly higher compared to the data from DAP (for data collected in the same year). It is worth noting that the largest differences in the number of gaps detected occur for small gaps (under 5 acres). Furthermore, ALS data better represent the shape of the gaps. The knowledge gained from the analysis can be valuable for the management of the Białowieża Forest area and the development of forest management concepts that resemble natural processes.

Are forests in protected areas more or less prone to climate-change induced disturbances?

The Scientific Committee - Potpourri session
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Abstract: Disturbances are an essential component of forest dynamics influencing tree mortality, growth and regeneration and, ultimately, shaping species composition and forest structure. Yet, while disturbances induced by forest management can be planned, unpredictable shifts in the regime of disturbances associated to climate change (e.g., wildfires, drought, pest outbreaks), may threaten forest conservation. Therefore, characterizing the disturbance regime is crucial to assess forest resilience. In this line, there is still a debate whether forests in protected and non-protected areas may differ in their disturbance regime, with some voices alleging that reduced forest management in protected areas makes them more prone to other disturbance types or forest decay episodes. Here we analyze the disturbance regime of Catalonian forests from 1986 to 2020 in and outside of Natura 2000 areas (40% and 60% of forests, respectively), distinguishing between two types of severe disturbances (wildfires and other disturbance types including forest harvesting), and events of lower intensity, likely associated to drought-induced forest decay. For this study, we combined different data sources: i) the National Forest Inventory, ii) historical land-use maps, iii) a remote sensing-based map of disturbances across Europe (1986-2020) and, iv) the monitoring of forest decay episodes (2012-2020). From 1986 to 2020, severe disturbances affected 19% of the forest surface in Catalonia, a trend similar to the overall 17% of Europe's forest area disturbed for the same period. Yet, while wildfires accounted for 7% of all disturbances in Europe, they represented 48% in Catalonia. Occurrence of disturbances in unprotected areas almost doubled that in protected areas (17.1% vs 9.2%, respectively), with a similar proportion in the occurrence of wildfires, other types of disturbances and forest decay episodes, regardless of the protection status. Overall, our results stress the disproportionate importance of wildfires in shaping forest landscapes in Mediterranean-type regions in comparison to harvesting activities, while they also refute that those forests included in protected areas (i.e., Natura 2000) are more prone to suffer the effects of climate-change disturbances. This research benefited from the EU projects RESONATE (GAP-101000574) and wildE (GAP-101081251).

Assessing Primary Vegetation Recovery from Earthquake-Induced Landslide Scars in Japan's Boreal Forests: RTK-UAV Approach

The Scientific Committee - Potpourri session

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Abstract: Globally, post-disturbance site formation is caused by large-scale natural disturbances. In such areas, it is necessary to restore vegetation rapidly as it regulates the outflow of sediment and water. However, the relationship between post-disturbance site vegetation recovery and environmental factors has not yet been elucidated. This study aimed to estimate the environmental factors affecting early vegetation recovery after large-scale disturbances (i.e., earthquakes). We used a novel analysis of multidimensional high-definition earth surface data derived from real-time kinematic unmanned aerial vehicles (RTK-UAVs) with high positioning accuracy to reveal primary vegetation recovery conditions, accounting for ground surface changes and environmental information of earthquake-induced landslide scars in Japan's boreal forests. A vegetation survey was conducted to understand the species composition and coverage that had recovered from earthquake-induced landslide scar in Japan's boreal forests. The herbaceous species *Petasites japonicus* subsp. *giganteus* and the woody introduced species *Larix kaempferi* were identified as the dominant species that help restore vegetation, with high frequency and plant coverage in the primary succession of the landslide scar. The reproductive characteristics of these pioneer species suggest that they have an advantage for establishment and growth, particularly on landslide scars with substantial topsoil dynamics. An optimal generalized linear model was used, which considered the distance from the vegetation inside and outside the landslide scars, ground surface change, inclination angle, annual amount of solar radiation, and the local region as explanatory variables. The ideal environmental conditions for vegetation recovery are summarized as follows: 1) Maximum biological legacy preserved inside and outside landslide scars. 2) Vegetation recovery expected in stable areas with little erosion and accumulation. 3) Vegetation recovery expected on slopes other than steep slopes or those with extremely high amounts of sunlight. The vegetation recovery conditions and RTK-UAV remote-sensing techniques used in this study can be applied to vegetation restoration zoning plans immediately after a disaster in similar environments.

Assessing the suitability of under-represented tree species for forest management – an example using economic return and biodiversity indicators

The Scientific Committee - Potpourri session
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Abstract: A shifting focus in forest management from timber production to resilience and multifunctionality in the face of changing disturbance regimes might entail altering the species composition of forests. Although the conifers Douglas fir (*Pseudotsuga menziesii*) and silver fir (*Abies alba*) currently comprise only a small proportion of Central European forests, the prospect of widespread planting of these species as a climate adaptation measure is currently widely debated by forest managers. To inform this debate objective assessments of the multi-functional value of these species is required.

Here, we introduce Pareto frontiers to objectively assess the value of tree species under competing objectives and considering uncertaion future. Using these frontiers, we explore trade-offs between financial performance and biodiversity aspects of German tree species portfolios with and without these currently rare conifers. We compare several potential biodiversity indicators (related to herbivores, saproxylic beetles, and deadwood decomposition rates) that can be derived from standard forest inventory data.

Our results indicate that optimizing the biodiversity indicators generates gradual decreases in financial performance at first, but after an inflection point soil rent declines sharply. Portfolios excluding Douglas and silver fir achieved comparable biodiversity levels, but much weaker financial performance, than portfolios that included these conifers. Our novel approach of generating Pareto frontiers that integrate uncertainty can offer useful insights into ecosystem services trade-offs in contexts where risk is unequally distributed across management alternatives.

AUTOMATIC CHARACTERIZATION OF FOREST STANDS USING A HANDHELD SCANNER: FROM POINT CLOUDS TO VALUABLE INFORMATION FOR FOREST MANAGERS.

The Scientific Committee - Potpourri session

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Abstract: Optimizing forest management practices for sustainability requires accurate and reliable information about available resources. Traditional inventory methods fall short in meeting the information needs for sustainable multipurpose management. In this regard, although terrestrial laser scanning has improved data collection efficiency, the development of automated tools for variable extraction from 3D point clouds is still necessary. By utilizing these tools, forest managers can streamline workflows and make informed decisions, thus contributing to sustainable forest management practices.

In this work, we present an example of automatic characterization of a forest stand through the processing of 3D point clouds captured with a handheld scanner. The processing is carried out automatically through a two-step mathematical algorithm. First, the algorithm calculates essential geometric variables that characterize the trees: diameters of sections along the stem, coordinates of section centres (XYZ) and total tree height. Second, it uses these variables to estimate stem shape variables, specifically maximum sagitta, sinuosity and lean of each tree.
The characterization was conducted in a Pinus pinaster breeding plot, where the algorithm calculated variables with only a small error range. That is, the approach demonstrated its robustness in estimating section centres, which are crucial for calculating shape parameters. The results obtained highlight the approach's effectiveness as an efficient alternative to traditional inventories which can automatically provide useful information for forest managers.

The approach presented here has direct applications in forest planning tasks, namely providing relevant information about forest stands which serves as the basis for informed decision-making in a wide range of tasks such as resource estimation, silviculture treatment simulations according to different scenarios, tree breeding and habitat characterization.

Bat sonotype as a novel insight into the congo basin rainforest dynamic

The Scientific Committee - Potpourri session
Yoba Alenga

Abstract: Tropical forest ecosystems are undergoing an exponential regression of their surface areas with subsequent habitat loss and fragmentation. The effects of such disturbances on bats are quite significant, even leading to a decline in populations. In order to ensure the maintenance of bat populations, it is thus important to preserve their habitats. This involves highlighting preferential habitats but also factors related to their foraging sites.

We have combined acoustic surveys and capture-mark-recapture methods to study relationships between bats and their preferred habitats and also to identify functional role of bats captured or recorded in their habitat. A total of 42 bats were captured, belonging to 13 species, including 5 species of frugivorous bats and 8 insectivorous bats.

The frugivorous bats - namely the species *Scotonycteris bergmansi*, *Casinycteris arginnis*, *Myonycteris torquata* and *Epomops franqueti* - were associated with dispersal of 16 plant species in the Yangambi Man and Biosphere Reserve (*Aidia micrantha*, *Allanblackia floribunda*, *Anonidium mannii*, *Barteria nigritana*, *Canarium schweinfurthii*, *Coelocaryon preussi*, *Dacryodes edulis*, *Mammea africana*, *Maranthes glabra*, *Microdesmis yanfungana*, *Musanga cecropioides*, *Pycnanthus angolensis*, *Staudtia gabonensis*, *Strombosia grandifolia*, *Strombosiopsis tetrandra* and *Panda oleosa*) while the species *Megaloglossus woermanni* ensures the pollination of the species *Maranthes glabra*.

Acoustic monitoring revealed the presence of 11 sonotypes namely of the following species: *Chaerephon pumilus*, *Macronycteris gigas*, *Macronycteris vittatus*, *Doryrhina cyclops*, *Rhinolophus fumigatus*, *Neoromicia nana*/*Scotophilus dinganii*, *Pipistrellus nanulus*, *Pipistrellus rueppellii*, *Nycteris arge*, *Myotis bocagii* and *Glauconycteris superba*.

The type of habitat (primary forest) significantly increases the foraging activity of bats. A medium to high density of the understorey and a medium opening of the canopy have a significant influence on bat activity and call structure. Complementarity of acoustic monitoring and capture is crucial to understand the mechanisms governing aggregation of bats assemblages in order to assess their activity and the ecosystem services they provide.

Beyond the timber legality regime: insights and implications for the newly emerging forest-risk commodity regime

The Scientific Committee - Potpourri session
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Abstract: Illegal and unsustainable land use are the key drivers of global deforestation and forest degradation. Timber supply chains are regulated through a complex of demand- and supply-side private and public policy and governance mechanisms under the transnational timber legality regime. To address regulatory gaps in not regulating transnational agricultural commodity supply chains, the European Union, United Kingdom, and United States started developing new demand-side trade rules to address agricultural expansion as the most important driver of deforestation. These new legislative initiatives to regulate agricultural forest risk commodity (FRC) supply chains build on experiences with designing, implementing, and enforcing timber legality policies. We analyse these policy changes by drawing on regulatory governance scholarship and Bernstein and Cashores (2012) four pathways of global influence theoretical framework. Our results show shortcomings in formally designed synergies between state-sanctioned trade rules (e.g., EU Timber Regulation, US Lacey Act Amendment) institutionalizing timber legality norms in hard law and market incentives in the form of development-cooperation based free trade agreements (i.e., Forest Law Enforcement Governance and Trade Voluntary Partnership Agreements) and voluntary private regulation (i.e., forest sustainability certification). Our results challenge assumed win-win synergies of policy and governance mechanisms seeking to deliver on social, environmental, and economic goals and contribute to research on the design of smart policy mixes under the newly emerging forest-risk commodity regime.

Biodiversity Assessment of Gums, Resins, and Associated tree species in Arid and Semi-Arid Lands of Northern Kenya.

The Scientific Committee - Potpourri session
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Abstract: Anthropogenic activities, especially unsustainable harvesting of tree resources and degradation, cause a decline in biodiversity in Arid and semi-arid lands (ASALs). ASALs cover 80% of Kenya’s landmass and support 36% of the population. Besides, they support 70% of the livestock and 90% of wildlife. In response, robust biodiversity loss exists, overexploitation of gums and resins tree species, and climate and land use changes, besides the emergence of invasive species. This review investigated the composition, diversity, distribution and occurrence of gums and resins and associated species in ASALs of Northern Kenya. It also explored the best conservation strategies for gums and resins-producing species by mapping their distribution which is important economic resources in these regions. Our research findings indicated a lower Simpson's biodiversity index for Mid-Tana (0.08) and Sabarwawa (0.07) landscapes. No significant differences were found using the Hutcheson t-test p-value 0.006687. Plant communities in both landscapes are sparsely diverse, Sabarwawa (0.0698) and Mid-Tana (0.08658). Results from the ß-diversity indicated a moderate species turnover process indicating a high similarity in species composition. Four gums and resins-producing species were noted: *Boswellia neglecta*, *Commiphora holtziana*, *Vachellia senegal* and *Vachellia seyal*. The relative frequency of gums and resin species was equally higher in Mid-Tana, 23.13%, compared to Sabarwawa, 22.22%. A strong positive correlation existed between gums and resins species richness and low and mid-lower altitudinal gradients. Findings from our study can provide a baseline regarding biodiversity conservation in arid and semi-arid landscapes. Notably, elevation influences the occurrence of gums and resin-producing tree species, thus, a critical factor in the growth of these species. These species are alternative sources of livelihood for theDry eco-regions and require sustainable management.

Biological Invasion by Acacia longifolia (Andrews) Willd. and Environmental Susceptibility in Temperate Regions. Determinants and Impacts in Centre-We

The Scientific Committee - Potpourri session
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Abstract: This communication aimed to: (i) define and map the global and local cores (Portugal and Brazil) invaded by Acacia longifolia; (ii) identify its impacts on coastal ecosystems; (iii) understand the relationships between the patterns and processes responsible for the proliferation and invasion of this species; (iv) and, finally, this information pretend to be a support to the future evaluation of the distribution patterns and ecological processes of the species to develop national and transnational Invasive Alien Species management. Acacia longifolia is a coastal shrub native to Australia, and shows significant invasive potential. It was introduced first in Portugal at the end of the 19th century, about a century before it was brought to Brazil. We did a global analysis of the invasive species dynamics (regarding its invasibility/invasiveness), focusing on areas invaded by the species with different natural and socio-ecological characteristics. Considering that total eradication in the short-medium term is technically unfeasible, more pragmatic management solutions are required whose adaptation to local realities greatly benefits from these global analyses.

Biopesticide potential of Melia volkensii?

The Scientific Committee - Potpourri session
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Abstract: The fall armyworm, *Spodoptera frugiperda,* and red flour beetle, *Tribolium castaneum* are insect pests of economic importance that have a negative impact on maize production and stored grains, respectively. The continued use of synthetic insecticides has been reported to cause undesirable effects and negative consequences on the environment, human and other non-target organisms leading to renewed interest in botanical pesticides as a safer alternative. In this study, we employed a bioactivity-guided strategy to isolate and identify insect antifeedants from *Melia volkensii,* an indigenous tree species native to drylands of East Africa. Laboratory screening of methanolic extracts from the bark, leaves, nuts and pulp showed that *M. volkensii* nuts and pulp extracts had higher antifeedant activity against fall armyworm and red flour beetle. Further fractionation of the nut and pulp extracts was done using solvents of increasing polarity. Biotesting of the solvent fractions showed that antifeedant activity was retained in the dichloromethane fraction, which was subsequently purified using column chromatography. The respective chromatographic subfractions were tested against the insects to identify bioactive fractions. The bioactive nut subfractions were subjected to preparative-HPLC and preparative-TLC to yield pure toosendanin. Recrystallization of the bioactive fraction from pulp yielded pure salanninolide. The limonoid compounds were positively identified using LC-MS and NMR spectroscopy. This study provides new leads for development of insect control compounds and shows that *M. volkensii* extracts could be incorporated in integrated pest management.

Bird diversity in old hinoki plantations with multi-layered canopy structure

The Scientific Committee - Potpourri session
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Abstract: Forests with a complex vertical structure (stratification) have high biodiversity including rich forest bird populations. However, there is still little knowledge about whether multi-layer forests with single conifer species can contribute to biodiversity conservation same as that consisting of multiple species (conifer and broadleaf). We investigated bird species diversity in old hinoki (*Chamaecyparis obtusa*) plantations in southern Japan, and evaluated the contributions of multi-layered canopy structure of different species composition to bird species diversity conservation.

The field survey was conducted in four forest stands: a two-layered old plantation (TC) dominated by hinoki (106-year-old canopy trees and 28-year-old understory trees), a well-developed multi-layered mixed stand (MW) consisting of old hinoki (100-year-old) canopy trees with a well-developed understory of large broadleaf trees, a developing multi-layered mixed stand (MD) with old hinoki (100-year-old) canopy trees and less developed understory of sparsely distributing broadleaf saplings, and a 99-year-old semi-natural evergreen broad-leaved forest (SB).

The broad-leaved forest (SB) had high bird diversity during both the breeding and wintering seasons, showing small seasonal and annual variations in diversity. The well-developed multi-layered mixed stand (MW) showed a trend in bird diversity similar to that of the broad-leaved forest (SB). The developing mixed stand (MD) had lower bird diversity than developed mixed stand (MW) and greater seasonal and annual variations in diversity. In the two-layered stand (TC), the bird diversity was similar to that of the developing mixed stand (MD).

We concluded that the single-species and two-layered hinoki plantation (TC) investigated in this study less contributed to bird diversity than the well-developed multi-layered mixed plantation (MW), but had a similar level of contribution as the developing mixed plantation (MD), suggesting an importance of the richness of food resources.

Blossom, place to read, shade and friend: Accounting for social and cultural values of trees outside of woodland in peri-urban and rural environments

The Scientific Committee - Potpourri session

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Abstract: Trees outside of woodlands and forests (ToW) represent a large percentage of tree cover in some countries. Recent research from England has found that 4.3% of land area is covered by ToW, compared to 14.6% covered by woodlands. For many people ToW are their main interaction with trees of any kind. This project sought to better understand the range of social and cultural values different publics associate with ToW, especially in less-studied peri-urban and rural settings. An interdisciplinary social science approach also collaborated with ecologist colleagues and drew on insights from the arts and the humanities. This led to a holistic understanding of how social and cultural values intersect with and are influenced and informed by other ways of viewing ToW. The results led to the development and testing of a theoretical framework for public values around TOW and illustrated how we might identify and measure this range of values. Our findings have implications for how we plan, establish, manage and care for this vital resource, as distinct from woodland trees. Enabling us to better account for social and cultural values as we balance goals, risks and trade-offs for ToW within policy and practice.

Bridging the human-nature divide in Forest Growth Models for Indigenous Forest Landscapes: taking the cases of Central India and Southwest USA.

The Scientific Committee - Potpourri session

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Abstract: Ecological models such as Forest Growth Models are central to decision-making for the scientific management of forest landscapes. However, applying these models to Indigenous Forest landscapes reveals a theoretical gap in knowledge. Current models inadequately represent Indigenous Forest landscapes that are characterized by complex adaptive social-ecological systems. Models fail to systematically integrate human interactions that influence ecological dynamics. These inabilities increase the human-nature divide in forestry science and often produce unwanted surprises. From a management perspective, Indigenous decision-making needs are inadequately met in these models. At the same time, there is a risk of losing traditional ecological knowledge (TEK) as the altered natural resource management regimes based on current science have created barriers to transfer TEK to future generations. Thus, there is a critical need to develop models that are theoretically capable of dealing with social-ecological systems, bridging the human-nature divide, responding to Indigenous communities' needs, and supporting TEK conservation. Based on my ongoing research with indigenous communities, I will demonstrate the development of integrated social-ecological models using participatory modeling and process-based modeling approaches that model indigenous communities' interactions with specific forest species in two contrasting landscapes. I take the example of Tendu (*Diospyros melanoxylon)* in Central India used by Gond Communities for *bidi* (local cigarette) making and Emory Oak (*Quercus emoryi)* central to the culture of White Mountain Apache in the Southwestern United States. Based on the current model development process, I will discuss how these models can become boundary objects that can be used for Knowledge Co-production, bridge the human-nature divide, empower Indigenous community decision-making for their landscapes, and preserve TEK for the sustainability of Indigenous Forest Landscapes.

Burn them all? – Analysis of the current forest bioenergy dispute

The Scientific Committee - Potpourri session

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Abstract: The intention of the EU to replace fossil fuels with renewable energy sources is one of the reasons for the increased demand for (not only) European forests. The newest Renewable Energy Directive sets up the share of the renewable energy goal for 2030 to be 40%. Another current EU renewable energy policies have the ambition to reach the share of renewable energy to 45% by 2030 (e.g. REPowerEU). There has been a heated debate about these ambitions for over a decade. Various actors present their attitudes and opinions about forest bioenergy in many newspaper articles, statements, opinion papers, letters and the forms of petitions or protests. This study focuses on the current forest bioenergy debate that often happens on different online channels and platforms applying the discourse analysis principles. It aims to analyse over 100 newspaper articles, statements and petitions to explore various actors' perceptions of the EU forest bioenergy. The analysis of the written sources is complemented by the information obtained through interviews with eight actors. These actors were selected due to their active participation in the public debate related to EU forest bioenergy. The main objective of the study is to analyse all the material to describe the discourse and determine bridges and barriers among the actors concerning forest bioenergy. It also explores the perceptions and opinions of actors about each other and the effect of the dispute on the actors' activities. It also analyses the actors' opinions about various actors' participation in the dispute. The results of the study will provide a piece of information for further facilitation of the forest bioenergy discussion and negotiations and this way to support the related policy-making. The results can also be taken into account when preparing a communication strategy for individual actors. The poster will present the pre-results of the ongoing study analysis.

Can science solve conflicts on managing forests for multiple Ecosystem services use?

The Scientific Committee - Potpourri session

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Abstract: Knowledge transfer has received increasing attention by scientists and policy makers especially in ecosystem services provision and related trade-offs between them. It is a complex process, which depends on decision makers´ ability to convince all relevant actors to accept scientific solutions for existing problems. In this way, it can help resolve conflicts in forest use and protection. The aim of the presentation is to analyse four different knowledge transfer processes in Slovakia using the RIU model (Böcher and Krott, 2016). The RIU model enables to identify which phase - research, integration, or utilization - is crucial for the overall success. We also included power analysis for deeper understanding of stakeholders´ relations. The main research methods are document analysis and semi-structured interviews. We conducted case studies on various governance levels (local, regional, national, international) to create a complex overview of different situations, guidelines, recommendations, and identified success factors. Results show that changes in political leadership can initiate changes of knowledge transfer process dynamics. Involving relevant stakeholders facilitates the acceptance of results and helps to prevent future forest use conflicts. The effect of a skilled facilitator and powerful actors or actors´ groups are crucial. Knowledge transfer differs, depending on whether it takes place at a local, regional, national, or international level, in our case it even required multi-level governance.

Carbon footprint and impacts of mechanized timber harvesting operations in the Northeastern United States

The Scientific Committee - Potpourri session
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Abstract: The US economy targets to achieve net-zero carbon emissions by 2050. Sustainably managed forests are considered a net sink rather than a source of carbon. Logging contributes remarkably to the carbon footprint of sustainable forest management. Estimating the carbon footprint of logging operations is essential to minimize the environmental impacts of the industry. The objectives of the study were to quantify and compare the carbon footprint (kgCO 2 eq) of predominant mechanized timber harvesting methods such as whole-tree (WT), cut-to-length (CTL), and hybrid-cut-to-length (Hyb. CTL) in the Northeastern USA. Life cycle assessment (LCA) was done using SimaPro software and allied database (USLCI and USEI), adhering to ISO 14040 and 14044 standards. TRACI (Tool for reduction and assessment of chemicals and other environmental impacts) v 2.1 was used for impact assessment. The system boundary was from tree stump to mill gate and the functional unit was 1 tonne of round wood. The input variables were the quantity of fuel (liter tonne -1) and lubricants (engine oil, grease, hydraulic oil, and antifreeze (kg tonne -1) obtained from the logging companies/contractors in the region. The data required to do the analysis was obtained from the logging companies. The preliminary result showed that the average global warming potential was highest for the WT (11.57 kgCO 2 eq), followed by Hyb. CTL (11.09 kgCO 2 eq) and CTL (9.91 kgCO 2 eq). A similar trend was observed for smog. Ozone depletion potential was highest for Hyb. CTL, followed by WT and CTL. These results could help forest managers to make informed decisions while selecting the harvest method, considering the carbon footprint in the forest industry's pursuit of carbon neutrality. As the green economy is gaining importance, information on the carbon footprint of the forest supply chain is necessary to ensure the sustainability of active forest management activities.

Carbon Sequestration and GHG Emissions from Cacao (Theobroma cacao L.) Cropping Systems in Davao Oriental Philippines

The Scientific Committee - Potpourri session
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Abstract: Cacao (*Theobroma cacao* L.) is a high value crop grown as monoculture or intercropped with coconut in countryside of the Philippines to maximize economic gains, however, carbon sequestration potentials and GHG emission are not realized for climate change mitigation. This research assessed carbon and GHG in cacao farms from Davao Oriental in Mindanao Island. Three cropping systems were selected: monocrop cacao, monocrop coconut, intercrop cacao and coconut across three municipalities (Mati, Lupon, Caraga) in the region. Carbon measurement was based on crop biometrics, laboratory analysis, and allometric equations. Estimated mean carbon sequestration from four carbon pools in intercropping, mono-coconut, and mono-cacao were 110-, 109-, and 22-tons ha^{-1}, respectively. Cacao in intercrop system contributes only ≈4% of the carbon stocks due to smaller stem diameter, younger age, and soil management practices. Rate of annual biomass accumulation aboveground generated was higher in monocrop coconut than intercropping and monocrop cacao ranging from 08-0.91 tons ha^{-1} yearly. Major drivers in carbon sequestration were soil management, spacing, farm management and biodiversity. Higher GHG emissions were obtained from mono-crop or intercrop cacao where 50% emissions were added when cacao is incorporated as understory. High sources of emissions were from residue and fertilizer application for cacao management. Conversion of deforestation areas into intercropping can potentially add 340,344 tons of additional carbon wins across four target provinces in five-year period. Potential carbon stocks that can be saved from averted deforestation is estimated at 1.4M tons in five years. The presence of natural ecosystems adjacent intercropping farms indicates environmental benefits like canopy layering, biodiversification, soil improvement, and creating possible corridor for wildlife. Capacitating farmers to promote carbon conservation and improvement of extension services will sustain ecosystem services while improving income. Substantial reduction in GHG emissions can be achieved if carbon wins can be integrated as part of the farming practices.

Challenges in forest commons between traditional and new uses of forests: a Q methodology study applied to an Alpine case

The Scientific Committee - Potpourri session
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Abstract: Interest for forests as providers of multiple ecosystem services, including several regulating and cultural services, is rapidly emerging in industrialized Countries, putting new pressure on forests and their managers and owners and requiring a more holistic forest management approach.

The present study is set in the northern Italian Alps, specifically in the Dolomites, where there is a centuries-old tradition of forest commons, formed by descendants of the original indigenous communities, that collectively own and manage large areas of forests and pastureland. Forest commons in such context are similar to indigenous communities of in tropical Countries or North America, but, as opposed to those, are not well studied in Europe. As other forest owners, these forest commons are now facing new societal demands for recreational uses, which are challenging their traditional approach to forest management, mostly focused on timber production. In our study area, there are 15 forest commons, that own more than 80% of the forest area (ca 20000 ha) and a similar surface of pastureland.

We aim to explore if, and how, the commoners, via their democratically elected leaders, perceive this new role as providers of ecosystem services, especially recreation. Currently, there is little knowledge on these specific types of owners. We interviewed 13, out of a total of 15, leaders of forest commons in the area and used Q methodology to explore the main viewpoints among them. Q methodology aims at analyzing human subjectivity in the form of preferences, beliefs and viewpoints. A standard set of statements representing the possible positions on the topic of forest for recreation is sorted by each respondent according to their agreement with such statements. Factor analysis is than applied to allow the reduction of the results to few key factors that summarize the main viewpoints of the respondents.

Our results aim to highlight the change of perspectives occurring in the interviewed leaders and cast light on the relevant role forest commons will play in the future as providers of recreation and other ecosystem services in the Alps.

Challenges of satellite data integration with risk-related factors for an information platform accounting for uncertainty

The Scientific Committee - Potpourri session
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Abstract: Earth observation data are trending at a growing rate of exponential proportions. New investments on space technology have resulted in more platforms and sensors looking down at our Earth. Both public and private space agencies are growing their data production, removing the gap between what was once “large data” and is now “big data”. Earth observation truly matches the multiple “V”s of big data - it is varied, comes at high velocity, with large volumes and with data of different veracity. The latter is the focus addressed in this note, as we describe the challenges of using down-stream products from satellite imagery together with other factors that concur to provide risk indicators , such as climate forecasts on a short and long term. Each measure intrinsically contains a degree of error and this must be propagated to the final products and clearly provided along with the required products. Products from satellite imagery and other means of survey cover a specific spatial and time range. If we take land cover as an example, accuracy metrics are estimated by ground truth acquisition at specific locations and time, using more reliable means, such as higher resolution imagery or in-situ knowledge. Each category of land cover must have a minimum number of test sites to provide a matrix of hits and misses and final per-class metrics, such as omission / commission errors, precision/recall etc. This part, i.e. spatialized information on uncertainty and reliability, is often overlooked, and not given enough highlight on the downstream products. We present and discuss here a proof-of-concept of a geodata platform that integrates maps with predicted flooded areas in the Sundarbans mangrove forest, from sea level rise (SLR) values estimated from IPCC forecasts. A digital elevation model (DEM) is used accounting for different degrees of confidence that depend on DEM accuracy. The resulting loss of land cover categories was mapped via remote sensing imagery (Landsat), using classification and accuracy assessment with ground key points, providing uncertainty information to the user accessing the platform.

Challenges of trees and forests managment alongside the railway lines

The Scientific Committee - Potpourri session
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Abstract: Railway traffic is extremely vulnerable to the dangers caused by the vegetation growing along the railway lines. Trees, or their parts (especially branches), as well as shrubs are very often a causing factor of the more or less serious railway accidents and incidents resulting in delays of various duration. We analysed causes of the occurences that had been recorded by the railway services in Poland during recent years to elaborate the critical conditions (dimensions, health status, age, species or others) that enhance the risk of the vegetation-caused railway accident. This is the first stage of the elaboration of the tool that enable to manage and maintain the vegetation growing alongside the railway lines to limit the danger of the accidents.

Characteristics of Tree-Based Interventions in a Uganda Refugee Settlement

The Scientific Committee - Potpourri session
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Abstract: Refugee displacement represents a global environmental challenge. Loss of tree cover is particularly concerning in areas where refugees and hosts heavily depend upon tree products—especially fuelwood and shelter-building poles. Tree-Based Interventions (TBIs) are increasingly promoted in refugee settings to reduce tree cover loss while improving the well-being of refugees and hosts. Examples of TBIs include agroforestry, community woodlots, farmer-managed natural regeneration, and tree conservation through promoting improved cookstove technology. The environmental and social benefits of TBIs in refugee settings are apparent, but their distinct characteristics are less understood. This research analyzes and synthesizes the similarities and differences of TBIs promoted by four non-governmental organizations (NGOs) within the Imvepi refugee settlement of northwest Uganda. Four NGOs are chosen as case studies due to the diversity of their offered services. These range from the distribution of tree seedlings to refugee and host households and encouraging the use of fuel-efficient stoves, to planting food forests at local schools and hospitals. Imvepi—which hosts nearly 65,000 mostly South Sudanese refugees—enables deep analysis of the scale, mission, and resources of each case NGO. Data will be collected in the form of semi-structured interviews with administrative and local NGO staff between May and July, 2023. Data will also be drawn from TBI site visits and the review of NGO reports and documents. A qualitative scenario decision support tool will be developed based on synthesized TBI characteristics to guide the selection of TBIs across a variety of displacement settings. TBIs are a valuable facet of NGOs focused on the welfare of refugees, hosts, and surrounding landscapes, yet TBIs differ based on the guiding philosophies and resources of a given NGO. This study explores similarities and differences across TBIs and synthesizes the range of TBI characteristics and activities into a single framework that can apply in varying displacement contexts.

Community Forests as an Innovative Approach to Promoting Rural Prosperity in the United States

The Scientific Committee - Potpourri session
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Abstract: Forests in the United States support livelihoods, protect environmental quality, and provide a broad range of other social and ecological benefits. Yet, their moderate market returns and provision of nonmarket goods and services that often go uncompensated can make them susceptible to degradation through overexploitation and conversion to more profitable land uses. Community forests (CFs) are a hybrid forest governance approach that enable community members and other key stakeholders cooperatively to manage local forests to produce a range of benefits. CFs have been proposed and established as a potentially promising approach to redress the imbalances between social and ecological forest benefits, and limited market returns and development pressures—issues particularly important in rural areas. However, there is limited empirical data on CFs' current status, trends, characteristics, or outcomes in the U.S., and what characteristics and conditions lead to enhanced forest retention, ecosystem services provision, profitability, and community well-being.

Our extensive research has enhanced understanding of community forests to generate and practical and policy insights for their establishment and support as an innovative approach to forest conservation and rural prosperity in the U.S. First, we conducted an inventory to characterize the broad diversity of community forests in the U.S. Second, we conducted detailed case studies using in-depth site visits and interviews of managers and stakeholders for 18 community forests across a broad range of geographies and ownerships. Results indicate a wide variety of goals and objectives, governance mechanisms, acquisition methods, financial models, outcomes, and community benefits. This talk will explore how and under what circumstances these may lead to enhanced economic opportunities and conservation successes and discuss policy implications. In particular, we explore the various financial models used and implications for financial sustainability.

Could continuous cover forestry on drained peatlands increase the carbon sink of Finnish forests?

The Scientific Committee - Potpourri session
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Abstract: Land-based mitigation measures are needed to achieve climate targets. One option is mitigation of currently high greenhouse gas (GHG) emissions of nutrient-rich drained peatland forest soils. Continuous cover forestry (CCF) has been proposed as a measure to manage this GHG emission source; however, its emission reduction potential and impact on timber production at regional and national scale have not been analysed.

To quantify the potential emission reduction, we simulated four management scenarios for Finnish forests: (i) clearcutting of nutrient-rich drained peatlands replaced by selection harvesting (CCF) and (ii) the current prevailing forest management regime (BAU), and both at two harvest levels, namely (i) the mean annual harvesting (2016–2018) and (ii) the maximum sustainable yield. The simulations were conducted with a forest simulator (MELA) coupled with hydrological model (SpaFHy), soil C model (Yasso07) and empirical GHG exchange models.

Simulations showed that the management scenario (CCF) that avoided clear-cutting on nutrient-rich drained peatlands produced approximately 1 Tg CO_2 eq. higher carbon sinks annually compared to the BAU at equal harvest level for Finland. This emission reduction can be attributed to the maintenance of higher biomass sink and to the mitigation of soil emissions from nutrient-rich drained peatland sites.

Could Developing Countries Achieve Industrial Sustainable Development? —— Take China's Forestry Industrial Policy as an Example

The Scientific Committee - Potpourri session
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Abstract: Developed countries have achieved sustainable forest industrial development to realize the forest Kuznets curve. China as the largest population developing countries, its industrial policy is help to realize industrial sustainable development since 2003. As a result, this paper first uses the text mining method to analyze China's forestry policy discourse and use PMC-Index method to measure policy effectiveness. The results show that: (1) To realize forestry sustainable industry is that develop industrial ecology in process industry such as wood process industry, paper industry, and develop ecological industry such as non-timber product, woody food and oil, under-forest product.(2)The policy general belongs to acceptable, the actor, namely, policy subject and object are poor of all first variable. (3) The evaluation is perfect that it is about paper industry and camellia industry. (4) The central government is focused on ecological construction while the sub-government concentrates on ecological construction and economic development.

Current trends in the management of Portuguese community forest areas

The Scientific Committee - Potpourri session
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Abstract: The Portuguese community lands ─baldios─ have hundreds of years of history. Since its beginnings, local rural populations have used these lands for their subsistence, which led to a progressive landscape change. This process created the local economic and social characteristics of the baldios. At the beginning of the last century, most baldios were nationalized by the State and were rapidly afforested. After the 1974 April Revolution, these territories were returned to their traditional owners ─local rural communities─ giving rise to the starting of their management and governance decentralization process. Currently, the Portuguese community forest areas occupy more than half a million hectares and are organized into more than 1100 units. Different stakeholders, such as commoners (baldios owners), Forest Services, and local authorities, are involved in their management. Their natural resources provide important support for the development of the rural economy. However, the current state and dynamics of the management processes of these lands are not sufficiently analyzed. In addition, there is almost no information about the baldios of the Portuguese Atlantic islands of Azores and Madeira.

In 2022, a round table was organized to discuss community-based forest management in Portugal. This event has contributed to updating information on Portuguese baldios and highlighted ongoing changes and current problems. Among the topics discussed were: (1) The development, potential, and challenges in the management of baldios of Azores and Madeira; (2) The legislative framework of the forest regime, its impact on the management of baldios forest areas, and the need for its reform; (3) The main risks influencing the quality of forest management in baldios; (4) New management models such as clusters of baldios; (5) and, Forest certification of community forest areas and the valuation of their ecosystem services.

This presentation at the IUFRO congress aims to discuss at the international level the topics above mentioned and to elaborate on the adequate steps to improve the management and value of the Portuguese community forest areas.

Design and synthesis of novel urushiol derivatives from the sap of lacquer (Toxicodendron vernicifluum) and evaluation of their anticancer properties

The Scientific Committee - Potpourri session
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Abstract: Urushiol, isolated from the sap of lacquer (Toxicodendron vernicifluum), is a natural alkyl phenolic compound that is a privileged structure in drug discovery, especially in the design of protein kinase inhibitors, and exhibits potent cytotoxicity against a variety of human cancer cell lines [11-12]. Structurally, urushiol contains an o-dihydroxybenzene (catechol) coupled with an unsaturated 15-carbon alkyl side chain, which makes urushiol susceptible to oxidation and polymerization, thus negatively affecting its anti-cancer activity. Intriguingly, urushiol also possesses significant inhibitory activity against HDACs and is structurally similar to SAHA, as it has a linker and a CAP region. However, urushiol does not contain a ZBG, a region that had been shown to be critical for the inhibitory activity in conventional HDAC inhibitors.

In this study, we designed and synthesized 11 novel urushiol-based HDAC inhibitors for cancer therapy. Specifically, we introduced a ZBG group by adding a hydroxamic acid group to the alkyl side chain and blocked oxidative polymerization by replacing the alkyl side chain with a methylene acetal. We also introduced different pharmacophoric groups to the 15-carbon alkyl side chain or benzene ring of urushiol to increase its inhibitory potency. It has been demonstrated that the synthesized compounds 1 –11 inhibit class I HDAC1/2/8 strongly, but not class II HDACs (HDAC6). Compounds 1-11 exhibited inhibitory activities against HDAC1/2 with IC50 of 50.1-240.17 nM, and against HDAC8 with IC50 of 16.11-41.15 nM in vitro, while against HDAC6 with IC50 of 1409.59 nM.Consistent with the in vitro assay, strong antiproliferation activity was observed in multiple cancer cell lines. six compounds showed superior in vitro anti-proliferative activity against four human cancer cell lines (A2780, HT-29, MDA-MB-231, and HepG2 with IC50= 2.31-5.13 μM) than SAHA. Analysis of acetylation levels revealed that the synthesized compounds only caused an increase in the acetylation of histone H3, but not α-tubulin. Furthermore, we demonstrated that our compounds regulated multiple tumor-related biological processes, including cell apoptosis and the cell cycle. Their administration led to MDA-MB-231 cells remarkable apoptosis and cell cycle arrest in the G2/M phase. Together with their favorable ADMET and drug-like properties, these urushiol-based compounds are promising anticancer agents.

Determinants of Forest Dependence in the Forest Communities of Southwest Nigeria.

The Scientific Committee - Potpourri session
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Abstract: This study examined the factors influencing forest dependence among households living in the forest communities of Southwest, Nigeria. Primary data was used for the study and multi-stage sampling technique was used to select 147 household living in the forest communities in Ekiti and Ondo State in the Southwest Nigeria. Data were collected using questionnaire while descriptive statistics and Tobit regression model were used for analysing data collected. Most (81.63%) of the households' sampled were males, 78.23% were married and the mean age of the respondents was 45.2 years. The average household size of the respondents was seven. The result shows that large proportion (97.28%) of the households give high priority to the provisioning and physical benefits of the forest such as supply of firewood, medicinal plants and farming activities more than the regulating, cultural and supporting benefits. The Tobit regression model shows that the factors that positively influence forest dependence were length of stay, dependency ratio, farm size and gender (male) while age, non-forest income, distance to nearest forest and credit facilities exerted negative influence. Therefore, the study recommends that medium- and long-term credit should be made available to forest households and empowerment programs should also be designed for them in forest communities to create employment aside forestry related ones to ensure successful forest rehabilitation scheme in Nigeria.

Determinants of soil field-saturated hydraulic conductivity across sub-Saharan Africa: texture and beyond

The Scientific Committee - Potpourri session
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Abstract: Soil infiltration is critical for water security and related ecosystem services. This infiltration, the ability of soils to absorb water at their surface, is controlled by the soil hydraulic conductivity. Despite recent efforts in assembling measurements of soil hydraulic conductivity, global databases and derived pedotransfer functions remain biased towards agricultural soils and lack coverage in the tropics. Here, we present soil infiltration measurements and other indicators of soil and land health collected systematically in 3573 plots from 83 100 km^2 sites across 19 countries in sub-Saharan Africa. We use these data to (a) determine field-saturated hydraulic conductivity (K_{fs}); (b) characterize K_{fs} at these locations; and (c) explore which variables best explain the variation in K_{fs}. Our results show that sand content, soil organic carbon (SOC) and woody vegetation cover had a positive relationship with K_{fs}, whereas grazing intensity and soil pH had a negative relationship. Our findings highlight that, despite soil texture being important, structure also plays a critical role in determining K_{fs}. These results indicate considerable potential to improve soil hydrological functioning through management and restoration practices that target soil structure. Promoting vegetation cover, particularly that of woody vegetation, enhancing SOC content, limiting animal stocking, and preventing soil erosion can increase K_{fs}. This evidence provides the basis to guide and design sustainable land management practices and restoration interventions for improved water security and soil health under a changing climate with more extreme weather. Our dataset expands existing regional and global databases of soil hydraulic properties, improving coverage for Africa and providing field data for underrepresented soils and land uses, including forests and woodlands. As such, we envision that our dataset can contribute to improved understanding and prediction of soil hydraulic properties and to improved Earth system and land surface models.

Developing silvopastoral system management

The Scientific Committee - Potpourri session
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Abstract: Silvopastural system is one of the effective sustainable management practices of forests, which integrates trees, livestock and pastures on the same land. Silvopastural system assists to achieve several benefits for both forests and rangelands sectors such as managing forest fires, increasing forest land fertility, controlling grazing and promoting biological diversity and wildlife habitat. As well as, enhancing rural communities' incomes which leads to limited migration. This study will be conducted in 15 sites of nine forests in southern and southwestern Saudi Arabia, two hectares per site. It aims to identify the effectiveness of silvopastural system in the region, and to determine the awareness level among the local communities in order to achieve sustainable management of forests and rangelands. Preliminary results will be obtained in the first quarter of 2024, thus there is a high potential for minimizing wildfires and negative human practices on vegetation cover, such as logging and overgrazing. On the contrary, maximizing animal production and income. Finally, this study will be accomplished by mid-2025, and its outputs will contribute to illustrating the optimal mechanism through which silvopastural system can be applied at a large scale around the country.

Development paths for Vietnamese forest and wood sector

The Scientific Committee - Potpourri session
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Abstract: Vietnam has a forest area of almost 15 million hectares of which 4.6 mill. hectares are plantations. However, only planted production forests (3.6 mill. ha, mostly acacia) are used for timber production, while logging is prohibited in natural forests. There are two million forest owners, and the mean area of privately owned stands is less than two hectares. Almost half of the plantation forests are owned by private people or communities. Plantation forests are managed by regimes aiming at pulpwood production, but logging and timber transportation have a low level of mechanization. Sawmills suffer from sawlog quality variations and inappropriate log dimensions, which results in poor sawn timber yield and challenges in productivity and profitability. This setup restricts the willingness to invest in modern saw milling capacity, while the forest resources and lumber demand of the furniture producers suggest doing so. Consequently, most harvested roundwood (>30 mill. m^3/a) is chipped and exported to Chinese pulp mills, while the extensive furniture sector relies on imported wood. Sawn timber made of Vietnamese roundwood ends up in low value applications. The country aims at developing local use of domestic timber. Here we map the pathways to develop Vietnamese forest and woodworking sectors towards a higher degree of self-sufficiency. The results, based on SWOT analysis, show that the opportunities in the forest-based livelihoods and industrial value chains should be more clearly highlighted and communicated to citizens and decision makers. The plantation forest resources allow much greater sawlog production than now. There are also risks, such as a higher probability of windfalls, associated with prolonging the rotation time of plantation forests to increase the saw log yield. Vietnamese woodworking industries, as well as public sector, are highly committed to develop the forest management and industrial, value adding processing of domestic wood towards an agile, modern, and low-risk market player and investment environment. The production philosophy should be shifted from production push to market pull, which requires better management and networking of the numerous micro scale producers, as well as integration of the large industrial producers more tightly in the forestry-wood product value chain development.

Did Lithuania manage to reach an agreement on its forests? The effect of National Agreement on Forests on conflicts in Lithuanian forest sector.

The Scientific Committee - Potpourri session

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Abstract: Forests have always played an important role in Lithuania's landscape, economy, and society. While the variety of ecosystem services provided by forests and the trade-offs between those services are preconditions for forest-related conflicts in many countries, in Lithuania, the conflicts are further exacerbated by the transition from a planned to a market economy, the "greening" of society's mindset, and the resurgence of private forest ownership.

The need to establish a consensus on the future direction of Lithuanian forest policy led to an unprecedented decision to organize a National Agreement on Forests (NAF): a co-creation process in which all stakeholder groups would be equally involved. The process lasted from mid-2021 to late 2022 and included both discussions and document preparation. The aim was to create a robust National Forest Programme for Lithuania and to resolve the most contentious conflicts.

In our research, we evaluated the NAF as a National Forest Programme using MCPFE criteria and assessed its effectiveness as a tool for resolving conflicts in Lithuania's forest sector. Although the NAF was recognized as an important step toward improving forest governance in Lithuania, thanks to its broad participation and representation of various interests, agreements were not reached on three out of the nine topics discussed. This may lead to a deepening of the respective conflicts in the future.

Distribution of Diaporthe species in native and invasive woody Fabaceae plants in Lithuania

The Scientific Committee - Potpourri session
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Abstract: *Diaporthe* spp. are widespread plant pathogens and have a broad range of hosts, including naturally growing trees. In this study 206 fungal cultures of the species *Diaporthe oncostoma* were studied. They were isolated from *Fabaceae* family plants *Lupinus polyphyllus* Lindl, *Robinia pseudoacacia* L., *Sarothamnus scoparius* (L.) W. D. J. Koch (*Cytisus scoparius* (L.) Link), which are included in the list of invasive plants in Lithuania. During the research, a total of 149 plants were collected throughout the territory of the country. In total, five loci that were used for MLSA were analysed: the internal transcribed spacer (ITS) region (primers ITS1/ITS4; White et al., 1990), the translation elongation factor 1-α (*tef1*) gene (EF1-728F/EF1-986R), the actin (*act*) gene (ACT-512F/ACT-783R), part of the calmodulin (*cal*) gene (CAL-228F/CAL737R (Carbone & Kohn, 1999) and part of the beta-tubulin (*tub*) gene (Bt-2a/BT-2b; Glass, Donaldson, 1995).

Diversifying tree species within our forests to increase resilience – an interdisciplinary approach.

The Scientific Committee - Potpourri session
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Abstract: Humans, as integral parts of social-ecological systems, can anticipate change and, through adaptive management, influence forest resilience to help ensure both current and future forests deliver a wide range of ecosystem services. A system's resilience is its capacity to absorb or withstand perturbations, essentially maintaining structure and functions. When resilience is enhanced, systems are more likely to tolerate disturbance events.

An increase in tree species diversity is often suggested as a method to increase the resilience of forests to disease and climate change. Current guidance on diversification focusses on the silvicultural requirements of tree species mixes. However, to gain the maximum benefit from the range of ecosystem services delivered by diversification an interdisciplinary understanding of diversification is required.

Here we used an interdisciplinary approach, focussing on forests dominated by *Pinus sylvestris* (Scots Pine) or *Picea sitchensis* (Sitka Spruce), but with an interest in all forest types, to address four challenges associated with species diversification of forests. First, we used interviews and focus groups to assess how forest managers and other stakeholders understand forest diversity (at different scales), and what their ambitions are in relation to resilient future forests. Second, we used DNA techniques to assess how an increase in tree species diversity influenced the leaf microbiome. We assessed if the microbial diversity increased when tree species diversity increased and whether this provided additional biological control against pathogen infections. Third, we collated records of the biodiversity associated with Scots pine or Sitka spruce and identified which other tree species will also host these species. We used this data to assess how diversification of the forest provides greater support for biodiversity and ecosystem functioning. Fourth, we assessed how to implement diversification. Using bright spot analyses, case studies and literature reviews we assessed how continuous forest cover, natural regeneration and planting of novel species increased species diversity. Throughout, the project interacted with forest managers to ensure the results were relevant and practical and liaised with them over how to communicate the results.

Diversity of Woody Species and Biomass Carbon Stock in Response to Exclosure Age in Central Dry Lowlands of Ethiopia

The Scientific Committee - Potpourri session
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Abstract: Empirical evidence on the potential of area exclosure in the restoration of severely degraded lands is crucially important. Thus, a study was conducted to examine the influence of exclosure age on vegetation structure, diversity, and biomass carbon stock in the central dry lowland of Ethiopia. Exclosures of 5, 15, >20 years old, and adjacent open grazing land were selected. Data on vegetation were collected using 20 × 20 m sampling quadrats which were laid along parallel transect lines. The result showed that 17 woody species which represent 9 families were recorded at exclosures and open grazing lands. Shannon-Wiener (*H'*) diversity index ranged from 0.74 (open grazing land) to 2.12 (middle age exclosure). Shannon evenness (*E*) index was higher in the middle age exclosure (0.80). Woody species basal area and tree density significantly ($p < 0.05$) increased with increasing exclosure age. The Aboveground woody biomass significantly ($p < 0.05$) varied from 12.60 (open grazing land) to 68.61 Mg ha-1 (middle age exclosure). Similarly, the aboveground biomass (AGB) carbon stocked was significantly ($p < 0.05$) higher in the middle (32 Mg ha-1) and old age exclosures (31 Mg ha-1). This study indicated that exclusion can restore the degraded vegetation and sequester and stock more atmospheric carbon dioxide in the aboveground biomass. Therefore, open degraded grazing land of the lowland areas can be restored into a promising stage through area exclosure land use management.

Keywords: *Acacia species, Biomass, Degraded landscape, Grazing land, Woody species, Vegetation structure*.

Do Forest Carbon Programs Align with the Needs and Values of Indigenous Communities in the United States?

The Scientific Committee - Potpourri session
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Abstract: While forest carbon programs incentivize management that enhances carbon sequestration and storage on forestlands, it is unclear how existing and proposed carbon programs align with the varied cultural values and forest management preferences of Indigenous peoples and communities in the United States. Moreover, it is also uncertain if and how the evolving forest carbon programs incorporate cultural values and Indigenous forest management practices into their protocols for carbon projects. This study uses a mixed-methods approach to assess the compatibility of forest carbon programs with forests managed by Indigenous communities and their members. More specifically, we systematically review the scientific literature as well as documentation published by forest carbon program developers and registries in the United States to analyze information related to participation and interest in forest carbon programs and protocols for forest carbon projects on lands managed by Indigenous communities and members. We synthesize findings from the literature to identify opportunities and barriers to participation in carbon programs and the compatibility of existing and proposed carbon programs with the values and needs of Indigenous communities and members.

Further, we plan to complement the review with a case-study analysis of the United States South, a 13-state region ranging from Virginia to Texas. We will use a participatory action research (PAR) approach to engage Indigenous communities in the region and related stakeholders on forest carbon programs and their preferences for research activities, including a discussion-based workshop. Utilizing the input collected, we will facilitate the workshop to foster discussion and co-production of knowledge, and future research questions and objectives. The PAR approach utilized in this study establishes a long-term framework for engagement with Indigenous communities to ensure that they have autonomy over research activities and that their cultural values and preferences are fully acknowledged, respected, and integrated in research and practices pertaining to forest carbon programs. The developed framework, which we see as a main contribution, may be adapted for future forestry research initiatives with Indigenous peoples.

Do individual PES buyers care about additionality and free-riding? A choice experiment

The Scientific Committee - Potpourri session
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Abstract: Based on a survey of the French population, this study investigates consumer preferences for forest ecosystem services (FES) provision towards efficiency and equity in the context of additionality, and differences in willingness to pay (WTP) for FES between a tax-based and a donation-based payments for ecosystem services (PES) scheme. We show that consumers prefer equity to strict additionality adherence, with this preference being significantly stronger among females. However, consumer preferences are heterogeneous and respondents with a closer connection to the forest express the opposite preference. Regarding WTP, we find no systematic difference between the two payment vehicles, but significantly different WTP depending on how respondents perceive the aspect of potential free-riding: When respondents considered that non-contributors would also benefit from a PES scheme, a small group showed a lower WTP, while a larger proportion showed a significantly higher WTP. We thus find a pronounced altruistic attitude of French society towards FES provision. We conclude by discussing the role of altruism in PES, the dilemma posed by the partial incompatibility of additionality and equity, both from an economic and legal perspective, and the environmental impact of environmental credits when credit buyers do not account for additionality.

Do Trichoderma treatments affect the Asian chestnut gall wasp (Dryocosmus kuriphilus) and its natural enemy?

The Scientific Committee - Potpourri session
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Abstract: Fungi of the genus *Trichoderma* are beneficial microorganisms with multiple positive effects on plants. They may promote plant growth and improve plant health through the stimulation of plant defense responses to various pests, such as fungi, nematodes, and insects. Although these beneficial fungi have been mainly investigated for their antimycotic properties, recent studies focus on their effectiveness also against insect pests. Indeed, some *Trichoderma* species affect insects directly, through the parasitization or the production of bioactive compounds with insecticidal, repellent, or antifeedant effects. *Trichoderma* may also act indirectly, for example by mycoparasitizing insect-symbiotic fungi or stimulating the plant in producing defense compounds and even volatiles attractive to pests' natural enemies.

Considering the growing demand for eco-friendly tools to control plant parasites, an increase in the use of *Trichoderma*-based products is expected. Therefore, it is critical to understand the multiple, yet unexplored, interactions between *Trichoderma* and plant parasites. In this regard, a novel case study is represented by chestnut groves, where *Trichoderma* treatments may contribute to the control of numerous fungal diseases, but at the same time, they may affect the main chestnut insect pest, the Asian chestnut gall wasp (ACGW) and its natural enemy, *Torymus sinensis*. This hymenopteran parasitoid has been largely employed in Italy and other European countries in ACGW biological control, generally with good results.

In this study, two chestnut groves were treated by endotherapy with the BITE® tool in June. Trees were injected with a conidial suspension (1 x 10^7 conidia/mL) of *Trichoderma* spp. (*T. viride*, *T. atroviride* e *T. harzianum*). Three types of samples were collected before and after the treatment, both on treated and control trees: buds and ACGW withered galls in winter; ACGW fresh galls in June. In the laboratory, buds and galls were counted and dissected to verify the presence and health status of the ACGW and *T. sinensis*. Results indicate that the treatment did not have direct negative effects on *T. sinensis,* as its mortality percentages on treated and untreated chestnuts were not statistically different. The hypothesis that *Trichoderma* fungi, by their endophytic properties, affected ACGW and *T. sinensis* interactions is discussed.

Dynamic modelling of social-ecological resilience in two forest harvesting systems.

The Scientific Committee - Potpourri session

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Abstract: Forest harvesting is currently one of the main drivers of local change that has impacts on the structure, ecological functions and ecosystem services provided by forests around the world. The concept of resilience has become a key concept for natural resource use and resolution of socio-ecological conflicts arising from ecosystem management practices. Conceptualising and measuring resilience remains a challenge. We propose the operationalisation (propose a measurement framework and apply it to a case study) of resilience for social-ecological systems under forest harvesting in Mexico. The main results are the identification of the social and biophysical structural elements of the forest SES model; we describe three dynamic feedbacks: governance (social processes), ecosystem services (ecological processes) and forest management (social-ecological processes); we analyse the effects of drivers of change and propose a social-ecological resilience strategy based on the literature review. We find that climate change can reduce species richness and diversity and negatively affect soil properties, which triggers a positive feedback process that reduces the possibilities for diversification of economic activities. The adaptive response is to implement mixed forest plantations and nurseries with native and quality plants as an alternative to cope with climate change. On the other hand, globalised markets favour the intensification and specialisation of timber production, thus reducing the conservation of other resources and diversification of economic activities. Among the main adaptive capacities, they should promote multipurpose forest use to maintain harvesting and safeguard other ecosystem services simultaneously. This work identified elements that promote ecosystem resilience such as polycentric governance, the maintenance of biodiversity and the control of slowly changing variables such as the recycling of nutrients in forest soils.

Economic valuation of landscape and biocultural heritage: an alternative for conservation and restoration

The Scientific Committee - Potpourri session

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Abstract: In the current context, the conservation and restoration of the landscape and biocultural heritage have become imperative to guarantee the sustainability of natural and cultural resources. This research focuses on exploring economic valuation as an alternative to promote the conservation and restoration of these assets.

The main objective of this study was to evaluate the feasibility and effectiveness of economic valuation methods in the context of landscape and biocultural heritage. To achieve this, different economic valuation approaches were applied, such as the travel cost method and the contingent valuation method.

The results obtained revealed that economic valuation can be an effective tool to assign monetary values to the benefits provided by landscape and biocultural heritage. By applying these methods, it was possible to determine the society's willingness to pay for the conservation and restoration of these assets, which provides valuable information for decision-making.

In addition, key factors that influence the economic valuation of landscape and biocultural heritage were identified, such as the degree of deterioration, accessibility, the perception of benefits and the level of public awareness. These factors can have a significant impact on the effectiveness of conservation and restoration policies.

In conclusion, the economic valuation of landscape and biocultural heritage offers a solid alternative for conservation and restoration, by providing a quantitative basis for decision-making and promoting the proper allocation of resources. However, a multidisciplinary approach and the active participation of all stakeholders is required to ensure the effective integration of economic values in the planning and management of landscape and biocultural heritage.

This study highlights the importance of considering economic aspects in conservation and restoration, which can contribute to greater awareness and support for the protection of these valuable assets.

EFFECT OF SUCCESSIONAL CLASS IN COMPETITION AMONG TREES

The Scientific Committee - Potpourri session
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Abstract: Competition indices are frequently used in single-tree models, especially in natural forests. Although there is a wide variety of competition indices developed over time, there is currently no consensus as to which index or which group of indices is the most appropriate. Furthermore, each competition index varies according to the number of neighbours or the area selected to compose it. This makes an accurate estimate of diametric increment even more difficult. However, these indices do not consider characteristics such as species or successional group of the target tree or neighboring trees, nor the quantification of this relationship for each species or group. We aimed to adapt a distance-dependent and an independent index to incorporate the successional group and quantify the influence of each group on diametric growth in a fragment of a mixed rainforest located in Paraná state. We tested BAL and Tomé & Burkhart competition indices. The successional group was added by including a parameter for each combination of target and neighbor tree. The pioneer, secondary, and climax groups were defined, in addition to a group for exotic species. The adapted indices identified the most influential groups among themselves. Exotic species most influence the growth of other individuals, followed by neighboring trees in the same successional group. This effect was better observed in the distance-dependent index, which restricts the neighborhood of each target tree by approximately 3.5 times, compared to the distance-independent index.

Effects of natural and anthropogenic factors on mammal distribution in Htamanthi Wildlife Sanctuary, Myanmar

The Scientific Committee - Potpourri session
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Abstract: Assessing and monitoring wildlife is crucial for biodiversity conservation and protected area management. This study aimed to investigate the potential effects of physical environmental features on the distribution of mammal species at both community and individual levels in Htamanthi Wildlife Sanctuary, Myanmar. From 2014 to 2019, camera trap surveys and ranger patrols were conducted. Data analysis focused on mammal records within individual grid cells (4 km x 4 km). Using a negative binomial generalized linear model, we identified the key predictors contributing to the richness of different mammal species communities and the distribution of mammal species communities. Results indicate that the distance from gold mining activities, the protected area boundary, main streams, old timber roads, villages, and slope were important factors influencing the richness of mammal species communities. Additionally, the distance from gold mining activities, main streams, old timber roads, and villages played significant roles in explaining the of mammal species distribution. Distance from main streams emerged as a major determinant of species richness in different mammal communities, except for large body-sized mammals, omnivores, and insectivores. Slope significantly influenced the richness of medium-sized mammals and insectivorous species. Anthropogenic factors also played a role, as distance from villages affected the richness of insectivorous and primate species communities. At the individual species level, Asian palm civets, clouded leopards, guars, leopards, red muntjaks, and wild boars were more frequently detected near main streams. Tigers and boars were more abundant away from gold mines. Red muntjaks and clouded leopards showed higher distribution around old timber roads. Events involving tigers, leopards, and wild boars increased closer to villages. The distance from the protected area boundary affected leopard distribution. Elevation influenced leopard and sambar distributions, while slope gradient influenced Asian palm civet, red muntjak, sambar, and elephant distributions. These findings emphasize the importance of considering natural and anthropogenic factors

in wildlife assessment and management. Understanding the environmental features that influence mammal distribution can inform effective conservation strategies and preserve biodiversity in protected
areas.
Key words: Camera trap, ranger patrol, Htamanthi Wildlife Sanctuary, Mammals, Myanmar, Physical
environmental features

Effects of wood ash application on seedling growth and soil properties in a young Cryptomeria japonica forest, Japan

The Scientific Committee - Potpourri session
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Abstract: Wood ash application in forests is effective for promoting tree growth in organic soils of regions with cool temperatures such as Scandinavia and North America. However, data regarding wood ash application to forest soils in temperate zones are still lacking. Extensive research is required to elucidate how this application affects tree growth and forest soils to ensure its effectiveness and the sustainable site productivity. Although the amounts of wood ash generated from biomass power plants have increased since the introduction of the feed-in-tariff in Japan, majority of the wood ash containing some nutrients is not effectively utilized. To elucidate the effects of wood ash application on tree growth and soil properties in temperate forests, we investigated the growth of sugi cedar (*Cryptomeria japonica*) seedlings and the variations in soil properties after treatment in a forest located in Kumamoto Prefecture, southwest Japan.

After applying 5 Mg ha^{-1} of wood ash, soil pH and concentrations of exchangeable base cations, such as calcium, magnesium, and potassium, tended to increase in surface soils, demonstrating the effects of liming and recharging exchangeable cations. Conversely, the increase in pH and concentrations of exchangeable cations in the subsoils, and in concentrations of total carbon and nitrogen in surface and subsoils were unclear by the application of wood ash. Moreover, the sugi cedar seedlings in the treated plot grew either as much as or less than those in the control one. No significant differences in the gene copy number of bacteria and fungi were observed between the both of the plots. These data suggest that the effects of wood ash application on forest soils are limited to surface soil, and it is difficult to promote seedling growth using this treatment without including nitrogen. Therefore, for promoting tree growth and maintaining site productivity, wood ash should be performed in combination with nitrogen fertilizer, avoiding areas affected by high precipitation and steep slopes to prevent nutrient loss.

EFFICACY OF Hura crepitans TREE EXTRACTS AS BIO-PRESERVATIVE AGAINST WOOD BIO-DETERIORATIVE AGENTS

The Scientific Committee - Potpourri session

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Abstract: The use of plant-based, eco-friendly and environmentally sustainable preservatives for wood protection as an alternative to synthetic preservatives has great potential. Extracts from the back, leaves, roots, seeds and the wood of *Hura crepitans* tree were used to treat five less suspectible wood species. Distilled water, ethanol, toluene and ethanol-toluene were used for the extraction. Chemical analysis of the extracts were carried out using Gas Chromatography-Mass Spectrometry (GC-MS) after derivation using N,O bis (trimethyl silyl) acetamide. More than one hundred and eighty compounds were identified from the extracts. The main groups of compounds identified from extracts are fatty acids, hydrocarbons, phenolics, sterols, sterol ketones, sterol esters and waxes. Extracts obtained were concentrated using rotary evaporator before they were used to treat the five susceptible species at 12% (weight/weight) retention level. The samples were weighed, labelled and treated by deep soaking in the concentrated extracts for 72hrs. Treated samples were removed, weighed to determine the level of retention before drained and oven dried at 60^0C for 48hrs until a constant weight was achieved. The sample were weighed before taken to timber graveyard for six months. Another set of untreated wood samples was weighed and taken to the timber graveyard for the same number of months to serve as control. Visual assessment was carried out weekly during this period to determine the rate of attack. After six months the experiment was terminated and samples were removed, cleaned and oven dried for 18hrs at 60^0C. After conditioning to equilibrium moisture content (EMC) of 12%, samples were cleaned of soil debris before the final weight was taken and the percentage weight loss for individual test samples were determined. The results was analyzed using factorial experimental design to determine the level of significance. It was observed that the extracts improved the resistance of these susceptible wood species to bio-degradation more than 75% when compared with the controls. It was also observed that extracts gotten using ethanol-toluene were more potent when compared with other extracts. It can be concluded that the extracts from *Hura crepitans* trees contribute greatly to the protection of wood against bio-degradation agents.

Efficiency Measurement of Ecological Conservation and Restoration from the Perspective of Multi-objective and Multi-factor Analysis

The Scientific Committee - Potpourri session
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Abstract: This paper proposes an ecological protection and restoration assessment theoretical framework based on multi-objective outputs and multi-factor inputs from the perspective of ecological efficiency evaluation. The Super-Efficiency SBM model was used to measure the social and economic effects of ecological resource consumption transformation in Heilongjiang Province, China from 2006 to 2019, and the standard deviation ellipse method and convergence analysis method were used to evaluate and test the impact on regional sustainable development. The results show that the stability of land use structure is insufficient, the conversion rate of resource consumption is low, and the mean ecological efficiency of the region is only 0.343, which belongs to the non-effective ecological efficiency region. The investment in forestry ecological restoration funds has a significant impact on the efficiency of ecological resource transformation, and the implementation of the Chinese ecological restoration project of mountain-river-forest-farmland-lake-grassland promotes the improvement of the ecological efficiency level of the community of life.The spatial distribution pattern of the ecological efficiency center of gravity is unstable. In the main years when forestry investment increased, the center of gravity of ecological efficiency showed a large movement range. This article proposes the following suggestions: improve the social and economic development level of regions with low ecological efficiency through technology transfer and diffusion and experience imitation in environmental regulation, and ultimately make the ecological efficiency of different regions converge to the same steady-state level. The focus should be on local conditions to reduce resource consumption intensity and improve the efficiency of fund utilization, form a comprehensive and systematic ecological environment governance system through reasonable enhancement of regional environmental regulation, increased investment in technological progress and ecological protection and restoration funds. This study is helpful to provide a basis for promoting the coordinated development of the social, economic and ecological aspects of the community of life and for evaluating the social and economic effectiveness of global ecological protection and restoration.

Enhancing resistance against decay and improving fire safety of Cross Laminated Timber (CLT)

The Scientific Committee - Potpourri session
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Abstract: Bio-based building products are considered key in our future socio-economic environment, since they are a very relevant nature-based solution (NbS) to climate change. The statement of President von der Leyen (European commission) to turn the construction sector into a carbon sink is critical in this respect: bio-based materials should be used on a larger and more targeted scale in the future. The long-term use of materials is therefore very important since we need to improve the lifespan of renewable materials to increase its carbon sink potential.

Hence wood is increasingly considered as a main building material. Service life aspects are critical in relation to the EU Construction Products Regulation (CPR). Traditional treatments to protect against fungal decay and the impact of fire are not always performing adequately and often environmental impact has been an important consideration. The option to enhance wood properties using innovative technologies can be combined with better definition of the expectations and requirements. Besides focusing on combined innovative treatments of the wood matrix, also envelope treatments similar to the use of coatings are envisaged. CLT has become a commodity construction product for green building and hence options are explored to cover alongside standard product use also enhanced performance based on material properties and a range of technology tools. Enhanced performance is often related to fire safety and extending service life under conditions with more risk of longer time of wetness, use classes 2 and even 3 according to EN 335.

Since CLT is often based on wood species with some refractory properties in relation to impregnation. Impregnation and penetration of active components is valid for many fire and decay protection methods of solid wood. Pathways for liquid transport have been explored using micro-CT scanning. The performance of treatments using different water-based treating solutions can be linked to the ability to reach anatomical structures.

Selected references

Environmental Human Right Defenders – Change Agents at the Crossroads of Biodiversity, Climate Change and Cultural Heritage

The Scientific Committee - Potpourri session
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Abstract: Environmental human rights defenders (EHRD) fight for political, social and environmental rights alike, while often facing intimidation and violence for their work and activism. This paper summarises first results from a new inter-disciplinary project where we investigate with qualitative methods to what extent EHRD serve as important agents of change for the management of forests in the global South.

We first develop an overarching conceptual understanding of EHRD that can be applied to different political and regional contexts. We then establish a theoretical framework to identify major socio-environmental discourses that underlie the motivations and goals of EHRD, their understandings of forest ecosystems and the ecological and social crises they seek to address.

We apply this conceptual and theoretical framework tothree regional study areas in forested areas in post-conflict Colombia. The country has become the most dangerous country worldwide for EHRD with more than 400 killings recorded since 2016. Colombia has also undergone a recent governmental change with a considerable shift in both rhetoric and laws towards EHRD protection.

In addition to the EHRD themselves, we include the groups and communities they belong to or represent - and we scrutinize the degree of political legitimacy the EHRD have as defenders of forested habitats and leaders within and beyond these groups.

Altogether, our analysis is guided by the following research questions:

1. Which major motivations, goals and underlying discourses inform EHRD and their understandings of the cultural, biocultural and climate change crises they seek to address?
2. Which practices and strategies do EHRD employ tostrengthen their leadership and legitimacy and topursue their goals?
3. Which successes and obstacles – including implications for their vulnerability and the vulnerability of the forest ecosystems they seek to defend – have EHRD faced in Colombia since the signing of the peace agreement in 2016?
4. Which lessons can be learned with a view to supporting and protecting EHRD and forest ecosystems in Colombia across scales?

Our expected findings seek to contribute to better understanding and supporting different groups of EHRD, through informing international and Colombian policy makers, civil society organizations and academics.

Erwinia leaf blight and dieback disease on Eucalyptus Species in Western Kenya: A New Threat to Commercial Growing of Eucalyptus in Kenya

The Scientific Committee - Potpourri session
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Abstract: Eucalypts are the most preferred plantation species in Africa and account for half of tree plantations in East Africa. Their growth has faced challenges of insect pest invasions mostly emanating from their native habitats in the Australopacific region. Important diseases such as canker (*Chrysoporthe cubensis*), rust (*Puccinia psidii*) and Ceratocystis wilt (*Ceratocystis fimbriata*) have also been identified on eucalypts. Reports indicate that the occurrence of bacterial pathogens on eucalypts started in the early 1980s, with minor incidence, becoming more expressive from the mid-2000s with outbreaks of *Rasltonia solanacearum* and *Xanthomonas* spp. Eucalypts in community nurseries in Western Kenya have been attacked by a new disease which is not recorded in their area of origin. The Disease is quickly spreading with incidences upto 100% observed in nurseries and plantations (upto 60%). Symptoms on infected seedlings from nursery and field observations at Migori in Western Kenya, included water soaked lesions on the leaf parenchyma, blights, die back and mortality of seedlings and saplings. Isolation and culturing of the pathogen was carried out using standard laboratory techniques identified the causative agent identified to be bacteria. Bacterial colony morphology was studied on standard media and their shape, elevation, colour and diameter described.

Preliminary laboratory studies report point to the gram negative *Erwinia* species as the potential cause of the observed symptoms on eucalyptus seedlings. This disease could pose serious threat to the productivity of commercial plantations of Eucalyptus and related species in Western Kenya. For appropriate management of the disease detailed genetic characterization of the specific bacterial strains responsible for the disease is being undertaken in the laboratory. We recommend testing of conventional bactericides for quick management of the disease in nurseries together with frequent surveillance to map out the spread and factors predisposing seedlings to the infection by the bacteria.

Key words: Erwinia, Eucalyptus seedlings, commercial plantations, genetic characterization

Estimating Above Ground Biomass of Dry Afromontane Forests with Remote Sensing Imagery and Machine Learning Models

The Scientific Committee - Potpourri session
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Abstract: The application of remote sensing imagery and machine learning algorithms for analysing various characteristics of vegetation has gained significant popularity due to the increasing availability of satellite data and cloud-based computing in recent years. In this study, we utilize Multispectral band reflectance data extracted from Landsat 8 and Sentinel-2B satellites, along with seven vegetation indices, to estimate the above-ground biomass (AGB) of dry Afromontane Forest in Northern Ethiopia. By employing a comprehensive set of machine learning models, including Light Gradient Boosting Machines (Light GBM), Extreme Gradient Boosting Machine (XGBM), Random Forest (RF), and Structure Vector Machine (SVM), we aim to accurately estimate the AGB of the mentioned forest region. Additionally, we employ simpler regression-based machine learning models with regularization techniques to identify robust patterns in the data, prevent overfitting, and improve the generalization capabilities of the models. The models' performance is evaluated and compared based on their prediction accuracy using metrics such as mean absolute error (MAE), root mean square error (RMSE), and cross-validated root mean square error (CV-RMSE). The findings of this study indicate that the tuning of hyperparameters in gradient boosting models significantly enhances their predictive performance compared to the simpler regression-based machine learning models. On the other hand, models without tuned hyperparameters tend to suffer from overfitting. Notably, Light GBM and XGBM with hyperparameter tuning exhibit lower RMSE values and superior predictive capabilities compared to regular GBM, which is more susceptible to overfitting. The predictions generated by these optimized models demonstrate higher accuracy and stability in comparison to conventional gradient boosting machines, RF, SVM, Lasso, and Ridge models. The utilization of machine learning models and the insights derived from this research hold great relevance for forest conservation and management decisions, particularly in developing countries where financial constraints and security impediments limit the feasibility of field surveys and data collection.

Europe's Forest Sink Obsession

The Scientific Committee - Potpourri session

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Abstract: The focus on the net carbon uptake in the forest dominates the European decision to reverse the declining land carbon sink. This decision has been made, however, without considering the consequences for the circular bioeconomy. Moreover, since the benefits of the circular bioeconomy are only indirectly recorded as "*reduced emissions"*, and not as forest benefits, the benefits of forest use are not even acknowledged. LULUCF (Land Use, Land Use Change and Forestry) accounting thus fails to balance LULUCF emissions/removals with the forest-based substitution effects recorded in sectors. The focus on carbon sequestration in standing forests is likewise disassociated from the past century's experience with forest use. Several Member states have managed to continuously increase the annual forest increment, harvest ever larger amounts of forest, and, simultaneously, to increase net forest removals, leading to a continuous increase in forest carbon stocks. Closer scrutiny suggests *avoided emissions*, the *net flux in forest-based emissions/removals ("net removals*"), and *renewed forest growth*, provide important contributions to the global carbon budget. Reducing forest use intensity (i.e., raising the forest reference level, FRL) may thus conflict with forest-based climate change mitigation strategies. Moreover, micro-level incentives in the EU LULUCF policy framework may be incompatible with the private and public sector investment goals which could otherwise underpin forest growth potential. Failing to encourage the kind of forest investment momentum required to achieve genuine progress, the current emphasis on reforestation and protection has provided only marginal contributions to the European forest carbon budget. Though significantly greater contributions are routinely provided by Managed Forest Lands (MFL), these remain under-mobilized and even heavily restricted in the LULUCF policy framework. A more strategic approach is therefore required to strike a balance between the need for protected, biodiverse-rich forest environments, on the one hand, and promoting societal and investment interest in the many benefits (mitigation, adaptation, human livelihood, consumption, etc.) forests and forest-based resources can provide.

Evaluation of forest biodiversity using a machine learning technique in Mt. Gariwang, South Korea

The Scientific Committee - Potpourri session
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Abstract: Forest fragmentation, degradation and climate change are major causes of rapid biodiversity loss. In biodiversity conservation strategy, it is essential to develop indicators to reasonably compare and evaluate biodiversity between/among regions. The purpose of this study is to develop quantitative and objective biodiversity indicators and to suggest evaluation methodology using machine learning techniques. In order to achieve this research purpose, this study was conducted on five forest types of Mt. Gariwang in South Korea. A total of 60 plots (20×20m2) were surveyed for woody and herbaceous plants. Taxonomic, phylogenetic, and functional diversity factors were calculated using plant data. In addition, abiotic factors such as topography (i.e., elevation, slope, topography position index, topography wetness index), climate (i.e., mean annual temperature and precipitation), and normalized difference vegetation index (NDVI) factors were used as explanatory variables to estimate biodiversity factors. RandomForest as a machine learning approach was used to analyze the relative importance of each abiotic factor on the biodiversity factors of plant groups such as total, woody, and herbaceous plants. Machine learning techniques are used to reasonably estimate the aggregation and selection of biodiversity indicators. As a result, elevation was the main variable to evaluate the biodiversity of Mt. Gariwang, including both woody and herbaceous plants. Moreover, climate factors showed high importance values for the total and herbaceous plants. On the other hand, woody plants are controlled mainly by topography and NDVI factors. The results of the study suggest that when calculating forest biodiversity indicators, it is necessary to separately analyze woody and herbaceous plants. In addition, our study emphasizes that it is essential quantitatively to calculate biodiversity indicators for sustainable ecosystem conservation. Finally, this study is significant in that it selected objective indicators by using machine learning analysis between forest monitoring data and spatial data.

Evaluation of the temporality of occupations in Permanent Preservation Areas in the state of São Paulo

The Scientific Committee - Potpourri session
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Abstract: The current brazilian environmental law (nº 12.651/2012) defines legally preserved areas (LPA) for native vegetation in both rural and urban lands. Different types of LPA target specific situations such as springs and river buffers, hilltops or very steep regions. However, it was the approval of the previous environmental law (7511/1986) that increased LPA sizes according to each situation and therefore major adjustments should have occurred to meet legal requirements. São Paulo state environmental agency uses a temporal principle to define whether the LPA must be restored. In another words, if the current LPA anthropic land use consist on buildings, the landowner is exempted of performing adjustments as long as it was built before the implementation of the law (1986). Thus, the goal of this work was to estimate how much of each LPA type in the state of São Paulo was considered to be regular due to the temporal principle. Land use and land cover data from MapBiomas, as well as LPA polygons from the Brazilian Foundation for Sustainable Development (FBDS) and the Secretary of Infrastructure and Environment of the State of São Paulo (SIMA), were used for the analysis. Land use classes were reclassified to Natural Formations, Agriculture and Livestock, Anthropized Areas, and Water Bodies. The Anthropized Areas class, which is entitled to temporal regularization, is composed by Urban Infrastructure, Mining, Other non-vegetated areas, and Aquaculture. Results showed that LPA in São Paulo state sum up to 29,337 km². In 2020, around 52.36% of the total amount had native vegetation, while 47.64% were degraded, with 40% being occupied by agricultural uses since 1985. Only 0.82% of the degraded LPA can be considered regular using the temporal principle as they were built/occupied since 1985. In 2020, 4.71% of the degraded LPA had native vegetation in 1985, showing a vegetation net increase of 1,606 km² in LPA. Finally, these results can be highly relevant for public administration and for the state environmental agency since it points out LPA exempted of regularization.

Evidence of natural hybridization between Pinus brutia and P. halepensis in regenerating planted forests

The Scientific Committee - Potpourri session
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Abstract: Interspecific hybridization increases genetic diversity, which is essential for coping with changing environments. Hybrid zones, occur naturally in overlapping habitats of closely related species, can be artificially established during afforestation. Interspecific hybridization can promote sustainability in man-made forests, particularly in regions facing degradation due to climate change. However, there is limited evidence of hybridization during forest regeneration. Here, we studied the frequency of *Pinus brutia* Ten. x *P. halepensis* Mill. hybridization at three stages of the forest regeneration process in five planted forests: seeds before dispersal, emerged seedlings, and recruited seedlings at the end of the dry season. We found hybrids on *P. brutia*, but not on *P. halepensis* trees, due to asynchronous flowering phenology. Using 94 single-nucleotide polymorphism (SNP) markers, we demonstrated that all stages included hybrids, most of which were hybrids of advanced generations. The hybrid proportions increased from 4.7±2.1 to 8.2±1.4, and to 21.6±6.4 percent, from seeds to emerged seedlings, and to recruited seedlings stages, respectively. The increased hybrid ratio implies an advantage of hybrids over *P. brutia* during forest regeneration. To test this hypothesis, we measured seedling growth rate and morphological traits under semi-controlled conditions and found that the hybrid seedlings exhibited selected traits of the two parental species, which may contribute to the fitness and survival of the hybrids during the dry season in the forest. This study highlights the potential contribution of hybrids to sustainable-planted forests and contributes to the understanding of the genetic changes that occur during the regeneration of man-made forests

Finnish Forest Happiness

The Scientific Committee - Potpourri session

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Abstract: Humans have a symbiotic relationship with forests which has evolved over time. This intricate relationship has a profound impact on human well-being, which is widely acknowledged as a key indicator of national prosperity. One crucial aspect of human well-being is experiencing happiness. There is an indication that happiness benefits from spending time in green spaces that have been linked to reduced stress levels measured at the physiological level. However, the previous works have not adequately addressed forest-specific happiness that has broader societal implications.

In this study, we aim to understand the concept of 'Forest Happiness' from the world's happiest nation by exploring the sociocultural values and experiences associated with forests in Finland. We developed a multilingual (Finnish, Swedish, English) web-based questionnaire survey based on the existing knowledge of social values associated with Finnish forests. The questionnaire with open-ended and closed questions covers topics related to the aspects of the forest that make people happy, how people perceive forest happiness and forest-related issues that may decrease perceived happiness. Data analysis combines qualitative content analysis with multivariate techniques.

After less than two months since the launching of the survey around 808 responses were collected. From the preliminary analysis, it appeared that about 63% of the respondents reported that they would be considerably unhappier without their relationship with forests. Above 55% associated social values such as silence and tranquillity, space and freedom, contact with nature, scents, sounds, colours and shapes of the forests as their most preferred Finnish forest features which made them happy. However, 50% of the respondents reported that the Finnish forests can occasionally decrease their happiness due to factors like clearcutting, changes in land use, intensive forest management activities and littering. In the further analysis of this data, we aim to identify the main types of forest happiness in Finland.

Overall, the results show that Finnish forests have a profound impact on experienced happiness. Beyond the perceived attractiveness of the Finnish forests, the people value the serenity and liberation they experience in the forests. Addressing specific forest management issues is essential for maintaining and amplifying Finnish forest happiness.

Fir beetles (Pityokteines vorontzovi and P. curvidens) associated fungi and their functional roles

The Scientific Committee - Potpourri session
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Abstract: The role of bark beetle associated fungal symbionts in tree mortality, potentially through nutrient provision and protection, has long been acknowledged. A few bark beetle species (*Pityokteines vorontzovi, P. spinedens, P. curvidens*) recently emerged as threats to drought-stressed fir (*Abies alba*) stands in some parts of Europe. The fungal associates of these fir bark beetles remain poorly studied, however, and there are no studies on their functional roles for the beetles.

In this study, the fungal community associated with two common fir beetles (*P. vorontzovi* and *P. curvidens*) were investigated in the Black Forest region of Southern Germany. Using isolations from emerging adults, we identified 30 fungal species and subsequently focused on five core symbiotic fungi (*Geosmithia sp, Ophiostoma piceae, Cladosporium oxysporum, Penicillium bialowiezense, and Graphilbum fragrans*) to assess the attractiveness of these fungal volatiles to these beetles. Employing a novel behavioral bioassay, the responses of fir beetles to the volatiles and gustatory cues of the selected fungi were examined. We found that beetles responding to fungal volatiles also exhibited a significant preference for boring into media colonized by three putative fungal mutualists (*Geosmithia sp, Ophiostoma piceae, and Cladosporium oxysporum*). This behavior suggests the beetles' recognition of specific fungal nutrients and/or detoxification products of plant-defensive compounds. Building upon these findings, our ongoing research aims to elucidate the potential benefits that fungi confer to fir beetles.

Forest-based land reform partnerships in rural development and the sustenance of timber markets. Learning from two South African cases

The Scientific Committee - Potpourri session
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Abstract: In South Africa, although implementation of government and forestry industry's embraced forest-based land reform partnership governance models, rural development and community beneficiaries' access to timber or wood products markets independently remain a challenge. This study assessed the perception of community beneficiaries on the sales and leaseback and community managed enterprise forest-based land reform public-private partnership (FBLR PPP) models on the provision of wood product end-use alternative. Two communities (Amabomvini and Cata) were purposefully selected for the study, in which 140 and 175 household beneficiaries were randomly sampled, respectively. Focus group discussions were also conducted with key informants from both communities' registered legal entities. The chi-square results showed a significant ($p \leq 0.001$) relationship between the household beneficiaries' responses regarding the recommendation of pulp and paper and fuelwood as preferred wood products end-use alternatives from both communities. Binary logistic regression analysis revealed that household beneficiaries who are not educated are significantly less likely to influence wood usage for building material ($p \leq 0.038$) and sawn timber ($p \leq 0.033$) compared to those who are educated, respectively. Most household beneficiaries in Amabomvini recommended pulp and paper (63.6%), while those from Cata community (84.6%) recommended fuelwood. Additionally, the study shows that the provision of wood product market for the community-managed enterprises would be vital for the sustainability of their forest-based business. Furthermore, prioritizing access roads could assist in construction of new or nested markets for timber products trade and improving their well-being and socioeconomic status. This would ensure that community beneficiaries value the economic role forest, forest products and the significance of strengthening community governance structures in an endeavour to reduce conflicts amongst beneficiaries. Most importantly, government support towards strengthening of community beneficiaries' institutional arrangement or governance of the legal entities is critical to create an enabling environment for the community beneficiaries.

From event to regime, disruptive affections in postwildfire landscapes.

The Scientific Committee - Potpourri session

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Abstract: Wildfires are the main disturbance affecting the Mediterranean area (Pyne,1997; Pausas, Vallejo et al.2003). The fire regime has changed mainly due to climate and human activity. (Marlon et al. 2008; Pausas and Keeley 2009). The international community specialized in wildfire management recognizes the inability to solve and deal with the problem strictly from the field of emergencies. The classic prevention model is being questioned, since it is not an issue of extinction capacity or economic resources destined to extinction, but an issue of landscape's ability to integrate and modulate disturbances.

The relationship between the severity of wildfires and human agency calls into question wildfires as a matter alien to society that falls on it, but rather as a matter of social and political responsibility (Latour, 2017) Going deeper into what is perceived or what is communicated as disruptive broadens the pre-established limits by entering the field of the affective. Postwildfire images that describe landscape a few days after the fire allow us to perceive the sublime, which disturbs and connects us with feelings beyond reason, which are in the realm of the material and the sensitive.

Risk communication recognizes that risk images have the capacity to convey to people the emotional consequences of natural hazards, in addition to stimulating the risk experience. John Dewey describes that the perception of change transforms the observer into a participant. Representation has the capacity to transmit an aesthetic and emotional experience transforming the observer into a participant. The representation that transmits an aesthetic experience of postwildfire landscapes in different temporalities, beyond the "0" day, transcends the dualistic positioning of the creative or destructive and redefines the disturbance. The aesthetic experience allows us, through affection, to recognize capacities beyond appearance and the standards of beauty, incorporating the disruptive. The representation of the operability of the disturbances and certain intrinsic aspects of it, such as transformability, have the capacity to transmit affect, generating a disruptive aesthetic experience that integrates the disturbance in postwildfire landscapes.

Fungi Among Us: Fungal Hitchhikers and Animal Couriers

The Scientific Committee - Potpourri session
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Abstract: Fungi are extremely important decomposers, symbionts, pathogens, and a food source in various ecosystems. While many fungal species rely on wind, water, or direct contact for dispersal, the spread of fungi by animals is often overlooked. Animals, including mammals, birds, insects, and arthropods, have been found to serve as effective carriers, facilitating their dispersal over large distances and across diverse habitats. Fungal dispersal can contribute to promoting biodiversity and ecosystem resilience. For instance, mycorrhizal fungi play a vital role in nutrient cycling and plant growth, and their dispersal by animals can enhance plant community composition and ecosystem functioning. This can profoundly impact wildlife.

Understanding the mechanisms and patterns of fungal spread by animals is crucial for both conservation efforts and ecosystem management. By identifying the key animal species involved in fungal dispersal, their movement patterns, and ecological interactions, targeted interventions can be developed to mitigate the spread of harmful fungal pathogens or promote the establishment of beneficial fungal symbioses.

Investigating the impact of environmental changes, such as habitat fragmentation or climate change, on fungal-animal interactions, can provide insights into potential alterations in fungal dispersal dynamics and disease transmission patterns.

This study summarizes the current understanding of fungal dissemination by different groups of animals, highlighting the mechanisms involved, the ecological implications, and potential impacts on forest health.

Governing by Numbers: Actors, power and technocratic forest governance in Cameroon

The Scientific Committee - Potpourri session
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Abstract: International relations in the forest sector of the Congo Basin are a field where collaboration between North-South actors reveals a permanent power struggle. This game is even more visible within the implementation processes of international forest governance instruments such as the Voluntary Partnership Agreement on Forest Law Enforcement, Governance and Trade (VPA-FLEGT). In Cameroon, the implementation and the success of the VPA-FLEGT were conditional on the operationalization of an advanced version of the *Independent Forest Monitoring* (IFM)-type system, namely SIGIF-II. Within the framework of the VPA-FLEGT process, IFM-II should, on the one hand, guarantee the timber tracking and, on the another hand ensure the storage, analysis and archiving of all forest-related information in order to contribute to better monitoring the production and the marketing of legal timber produced in Cameroon. From the public policy analysis perspective, this article aims to analyse the agenda setting and the developing process of the IFM-II as an instrument of technocratic governance of forests in Cameroon. Its proposes to map the main North-South actors involved and their interests vis-à-vis the IFM-II project, and then questions the problem of inequalities underlying the strategies of domination and resistance between these actors. We mobilise the Advocacy Coalition Framework (ACF) to understand what underlies the game, strategic and political actions of actors in the political conflict that drives the IFM technocratic reform process. We argue that (i) the IFM-II developping process has induced formal and informal interests that actors involved are keen to preserve at the expense of the effective implementation of this instrument; (ii) the politicisation of the IFM-II project has resurfaced various resentments of (neo)colonial and imperialist inequalities in a North-South power struggle between the European Union and the Cameroonian Government in the forest sector and (iii) finally that, the elaboration and the validation of this data management tool and the tensions generated reveal a new form of confrontation that shifts the globalization of tropical forest governance from the modalities of access to forest resources to the norms of production and control of data on these resources.

Keywords : *International relations, data governance, forest policy, inequalities, domination, resistance*

Hcanopy, a new site index to describe mature and irregular forests productivity: the case of old growth beech stands

The Scientific Committee - Potpourri session
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Abstract: Forests of Western Europe have long been shaped by economic considerations, far removed from the way natural ecosystem's function. Monocultures, regular stands, and the promotion of a few commercially interesting species are all choices that have influenced forest management in the past. In the 21st century, the full force of global change is making those involved in forestry rethink their approach to silviculture. In response to these changes, continuous cover forestry regeneration has been encouraged, using natural regeneration, and leading progressively to uneven-aged stands. Although this type of stand offers greater forest resilience, it is difficult to characterise, particularly in terms of productivity. Indeed, most of the indicators in the literature have been calculated for even-aged, often planted, and homogeneous stands, far from the definition we have given to the resilient forest of tomorrow.

In this context, we developed a new indicator to assess the productivity level of these uneven-aged stands using a variable that is stable over time: the maximum canopy height (Hcanopy). The aim of this study was twofold:

(1) To identify the dendrometric parameter, based on easily available remote sensing data, that best represents stand productivity and allows for stands comparison, provided that the canopy consists of mature trees.

(2) To assess which ecological parameters influenced the value of this indicator.

We focused on beech (*Fagus sylvatica*), and especially on mature and uneven-aged beech stands in old-growth temperate forests of Western Europe. These forests were divided into polygons characterized by homogeneous abiotic conditions. For each polygon, topographic, soil, climate and silvicultural data were extracted from raster layers, to analyse their effect on Hcanopy.

The analysis shows that the average maximum canopy height (Hcanopy), corresponding to the average height of the ten tallest trees per hectare, is the best indicator to describe the productivity level of this type of stand. The value of this indicator, calculated for each polygon were highly and significantly different between forest site types. A multivariate analysis is currently underway and should identify the variables that most influence Hcanopy.

Heterogeneity matters: The impact of forest heterogeneity and tree diversity on predation pressure of pest insects in semi-natural boreal forests

The Scientific Committee - Potpourri session

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Abstract: Plant diversity favours top-down control of pest insects from natural enemies in agricultural environments. Accordingly, tree species diversity has been expected to benefit top-down control of pest insects in forests as well. However, results concerning pest suppression by natural enemies are not unequivocal, and studies about the importance of mixing tree species in forestry for pest control show differing results. Even forests with low tree diversity have been shown to maintain a high degree of habitat heterogeneity, providing niches for natural enemies. To date, there are few experimental studies in semi-natural boreal forests about the underlying mechanisms of natural regulation of pest insects.

Previous studies of the pest insect *Neodiprion sertifer,* a specialist herbivore on *Pinus sylvestris*, has shown that forest heterogeneity is a better determinant of predation pressure than tree species diversity. Therefore, we investigated the relationship between forest heterogeneity, tree species diversity, and the predation pressure of *N. sertifer* as a specialist herbivore together with plasticine models as a proxy for generalist herbivores. We measured a wide range of heterogeneity factors in mixed forests and monoculture forests in semi-natural boreal forests in central Sweden. Larvae of *N. sertifer* and plasticine models were placed out on experimental trees, and around each experimental tree we measured tree species diversity and structure, type and structure of understory, structures of dead wood and boulders, and presence of ants.

Our results showed that tree species diversity did not increase predation pressure at stand level. However, ant presence, tree and understory structures, dead wood and the presence of boulders did affect predation pressure directly or indirectly within the stands. We conclude that local heterogeneity is more important than tree diversity at stand level, and that the influence of boulders on the outcome of predator-prey interactions is underemphasized. Future studies are needed to investigate the impact of heterogeneity, and especially boulders, on arthropod predator-prey interactions, which would allow assessing their contribution to overall ecological processes.

Identification of wood by-products use patterns in Slovakia

The Scientific Committee - Potpourri session
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Abstract: Renewable resources, considered inevitable part of the issue of the circular economy, are increasingly recognized as a key factor in environmental protection, sustainable development, and economic prosperity. The circular economy emphasizes the utilisation of wood resources and reutilisation of these resources and waste streams into value added products. Successful implementation of wood utilisation in various industry sectors serves as a driving force for building a sustainable society. The analysis of wood flows takes into account not only the utilisation of wood as a material, but also by-products and waste generated by the production to be used as inputs for further uses in construction, wood processing or energy sectors. The study deals with the analysis of actual wood use patterns in Slovakia with a focus on wood by-products management following the wood cascading principles. The obtained data are the basis for the calculation of a cascading coefficient to optimise the use of wood in the whole chain of its processing and utilisation. At the present time, the most important producer of wood by-products is the sawmilling industry, consuming approximately 40% of the total volume of industrial wood used in Slovakia. Moreover, the results describe some specific wood flows focused on possibilities of using wood by-products and recycled wood for the production of products with a higher added value.

Ilyonectria and Dactylonectria species from Pinus radiata in New Zealand

The Scientific Committee - Potpourri session
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Abstract: *Ilyonectria* and *Dactylonectria* species have been associated with diseases in agricultural, horticultural and forestry crops causing cankers, root rots and black foot disease (BFD). These genera are ubiquitous and are found in soil, plant roots or woody tissues, and can act at saprobes, endophytes, or weak and latent pathogens. They have *Cylindrocarpon*-like anamorphs and produce conidia that are spread through soil and water. Many species produce chlamydospores allowing them to survive in the soil for extended periods of time. Species in these genera have been associated with severely reduced yields and crop losses. *Dactylonectria* and *Ilyonectria* species have been identified from diseased *Pinus radiata* submitted to Scion's Forest Health Reference Laboratory (FHRL). These samples were showing symptoms of root rot and most often sampled from nurseries or from recently planted stands. A delimiting study was carried out to determine what *Ilyonectria* and *Dactylonectria* species are associated with symptomatic *P. radiata*. Using ITS 1/4, only four of the 19 isolates studied aligned phylogenetically with currently described species. The remaining 15 isolates could be separated into six distinct phylogenetic clades. Three further gene regions were used to determine how these isolates might be related to known *Ilyonectria* species. However, our analysis revealed that the isolates were phylogenetically distinct from the known *Ilyonectria* species we used in this study. Further validation and descriptions of new species is being undertaken to improve our understanding of distribution, host associations, and pathogenicity to *P. radiata* and other forestry and horticultural hosts.

Impact of non-native tree species in Europe on soil properties and biodiversity: a review

The Scientific Committee - Potpourri session
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Abstract: In the context of global change, the integration of non-native tree (NNT) species into European forestry is lively debated. While native tree species are increasingly limited by higher frequencies of hot drought spells, previous forest services such as protection in mountainous areas or wood production are questioned. One option is to integrate more drought-resistant tree species – among them NNTs – in our stressed forests, another is to do without NNTs and accepting a loss of growth, i.e. a reduction in wood production.

The ecological consequences of increasing use or spread of NNTs in European forests are highly uncertain, as the scientific evidence is either constraint to results from case studies with limited spatial extent, or concerns global assessments that lack focus on European NNTs. For both cases, generalisations on European NNTs are challenging to draw. Therefore, we compiled data on the

impacts of seven important NNTs (*Acacia dealbata*, *Ailanthus altissima*, *Eucalyptus globulus*, *Prunus serotina*, *Pseudotsuga menziesii*, *Quercus rubra*, *Robinia pseudoacacia*) on physical and chemical soil properties and diversity attributes in Europe, and summarised commonalities and differences.

From a total of 103 publications considered, studies on diversity attributes were overall more frequent than studies on soil properties. The effects on soil properties varied greatly among tree species and depended on the respective soil property. Overall, increasing (45%) and decreasing (45%) impacts on soil occurred with similar frequency. In contrast, decreasing impacts on biodiversity were much more frequent (66%) than increasing ones (24%). Species phylogenetically distant from European tree species, such as *Acacia dealbata*, *Eucalyptus globulus* and *Ailanthus altissima*, showed the strongest decreasing impacts on biodiversity. Our results suggest that forest managers should be cautious in using NNTs, as a majority of NNT stands host fewer species when compared with native tree species or ecosystems, likely reflected in changes in biotic interactions and ecosystem functions. The high variability of impacts suggests that individual NNTs should be assessed separately, but NNTs that lack European relatives should be used with particular caution.

Impacts of COVID-19 Pandemic on Private Forest Landowners in the Southern United States: Challenges and Opportunities

The Scientific Committee - Potpourri session

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Abstract: The Southern United States (or simply "the U.S. South") includes 13 southeastern states from Virginia to Texas and contains approximately 100 million hectares of the most dynamic, diverse, and productive forestlands in the nation; responsible for about 60% of national timber production. As with the rest of the economy, the forestry sector in the U.S. South was disrupted by COVID-19. The pandemic interrupted the production and supply chains of manufacturing industries. For example, it produced an increase in the price of Southern softwood composite lumber, mainly caused by labor shortages and stay-at-home policies. However, the average saw timber prices were lower in 2020 compared to previous years. The pandemic also increased demand for finished wood products (for example, packaging and shipping materials for online shopping). However, this did not mean higher prices for standing timber. Since around 87% of the forestland in the U.S. South is privately owned, the pandemic may have shaped the future of forestry in the region by changing landowners' objectives, approaches, and plans related to forest management along with new challenges and opportunities. This research aims to evaluate the impacts of the COVID-19 pandemic on private forest landowners and to explore the challenges and opportunities in post-pandemic forest management in the Southern United States. We will collect data from a sample of private forest landowners in 13 states in the U.S. South with a survey instrument that elicited information about the COVID-19 impacts, forestland revenues, communications networks and education, forest management, and landowners' future plans for forest management. Our survey instrument is designed to reveal both contemporaneous and lasting impacts of the pandemic. We will evaluate the impacts of COVID-19 from a comparison of landowners considering variables such as location, size of land, and ownership. We will also develop models of landowner decisions to adopt new approaches and practices of forest management. The findings from this study will provide insights into the severity of COVID-19's impacts on several aspects of forest management to identify which effects of the pandemic were fleeting and which were more long-lasting to learn lessons toward a more robust forest-based rural economy.

Implementation Gaps and Challenges in Sokshing Forest Land leasing Policy: A Case Study in Bhutan's Forestry Sector

The Scientific Committee - Potpourri session

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Abstract: For centuries, sokshing (leaflitter forest) has been an integral part of rural livelihood in Bhutan, serving as the indigenous knowledge system for sustainable forest resource management. The farming community utilizes sokshing by collecting leaflitter as cattle bedding material, which is then combined with cattle excreta to produce farmyard manure. In 2007, Bhutan's Land Act resulted in the nationalization of sokshing land, deleting the legal household ownership records and mandating the leasing of reverted sokshing from rural areas to agriculture-dependent households. Thus, this research focuses on the implementation of the sokshing forest land leasing policy in Bhutan, aiming to assess the extent of policy adoption and its impact on forest management practices. To examine policy implementation, interviews were conducted with various policy actors at the national, regional, and local levels, including government officials, non-governmental organizations, traditional leaders, and local communities. A combination of qualitative and quantitative methods, such as interviews, surveys, and analysis of policy documents and field data, was employed in this study. The findings reveal prevalent deficits in the implementation of the sokshing leasing policy within Bhutan's forestry sector. Notably, none of the farmers have received leasehold titles for sokshing land, leading to concerns among local communities regarding ownership rights. Poor implementation of the 2007 land act and a lack of clarity regarding land property rights contribute to this ambiguity. The study identifies a lack of intersectoral coordination and communication, inadequate institutional and financial capacity, and insufficient sensitization and awareness of leasing procedures as the main barriers to sokshing lease implementation. Therefore, addressing this ambiguity and ensuring effective implementation of the sokshing lease policy necessitates improved communication and coordination among government units and stakeholders, allocation of sufficient resources, and the harmonization of policies and legal frameworks. By implementing the formulated policies, stakeholders can mitigate the concerns and challenges surrounding sokshing lease, fostering a more sustainable and inclusive approach to forest resource management in Bhutan.

In vitro Regeneration of Thick Walled Edible Bamboo Species (Dendrocalamus asper) from Seed Originated Explants

The Scientific Committee - Potpourri session
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Abstract: *Dendrocalamus asper* known as rough bamboo, giant or sweet bamboo is a thick walled tropical bamboo grown commercially in China, Thailand and Malaysia mainly for edible shoots and structural construction. However, there was no report on growing of this bamboo species for edible shoot production or any other purposes in Bangladesh. The present research project has therefore been carried out to develop efficient in vitro regeneration protocol for this bamboo species from seed originated explants. Deglumed seeds of *D. asper* were surface sterilized with 0.1% $HgCl_2$ for 0, 5, 10, 15 or 20 min and germinated in vitro in MS media without any PGRs. Germinated shoots were cultured in MS media supplemented with four concentrations (0, 1, 3 and 5 mg/L) of BAP in liquid media for shoot generation. Newly generated shoots were then cultured in semi-solid MS medium supplemented with 0, 1, 3 and 5 mg/L BAP combined with 1mg/L or 2 mg/L Kinetin for shoot multiplication. Disinfection time of seed with 0.1% $HgCl_2$ significantly enhanced the germination percentage of *D. asper* seeds in the MS media. The concentration of BAP suggestively affected the duration of shoot induction, rate of shoot proliferation and the number and growth of shoots in both the liquid and solid media. MS medium supplemented with 3mg/L BAP in combination with 1mg/L Kn showed the maximum shoot proliferation. Increasing the number of shoot from 1 to 5 in the bunch used as explants also significantly increased average number of shoots in explants cultured in the media supplemented with 3 mg/L BAP and 1 mg/L Kn. In vitro generated shoots were elongated in the MS media supplemented with 2 mg/L GA_3. The highest percent of root induction and maximum number of root per shoot was recorded from half-strength MS media supplemented with 2mg/L IBA. Survival rate after 30 days was 90 in the greenhouse environments.

Indigenous and Small-scale Natural Resource Management in the Great Lakes Region of the United States

The Scientific Committee - Potpourri session

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Abstract: This presentation will review small-scale and indigenous natural resource management trends in the Great Lakes region of the United States. Drawing from in-depth semi-structured research interviews, we will describe perspectives of natural resource professionals who work with Indigenous communities. They identify what these communities believe are driving natural resource challenges, possible solutions, and share their perspective on knowledge co-production (whether it is happening or driving their work). Three main themes include climate change adaptation, tribal capacity, and wildlife management issues. We will also review survey data on small-scale forest management, including several family forest owner surveys to explore emerging topics like interest in conservation programs, the link between forest ownership and wellbeing, knowledge and awareness of threats, and awareness and uptake of agroforestry practices. Weaving together these many data sources, we will describe what opportunities may exist for outreach and engagement of this important forest ownership category and discuss how this region may be similar or different from other U.S. regions and the global of small-scale, community, and indigenous forestry communities.

Initial growth of forest species in an experimental plot for Forest Landscape Restoration

The Scientific Committee - Potpourri session
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Abstract: Forest Landscape Restoration is a process that facilitates the recovery of a forest environment that has been partially or completely degraded, damaged, or destroyed (FAO 2017). The success of Restoration projects largely depends on the initial establishment of forest species. That is why this study intended to evaluate the initial growth, at 15 months, of tree species in Forest Landscape Restoration plots. The study area corresponds to an experimental plot of Itaipu Binacional, located in the district of Hernandarias, Alto Paraná department, Paraguay.

An experimental plot of 5.9 hectares was established using a completely randomized block design with 5 replications and 8 treatments. Each experimental unit has a total area of 1,800 m2. A total of 30 species were planted, including both cover and biodiversity species for the conservation strip, and native and exotic species for the exploitation strip.

The species that showed the higher growth in diameter at breast height and height were clones of *Eucalyptus urophylla x E. camaldulensis* and *Eucalyptus urophylla x E. grandis*, and among the native species, *Mimosa bimucronata* (DC.) *Kuntze var. bimucronata* stood out. In terms of canopy area, in addition to *Eucalyptus urophylla x E. camaldulensis* and *Mimosa bimucronata* (DC.*) Kuntze var. bimucronata*, *Solanum granulosum-leprosum Dunal was noteworthy*.

In both analyzed variables, the exotic species (*Eucalyptus sp.)* and two of the native species exhibited the highest values due to their great adaptability to these conditions and environments.

Initial performance evaluation of two hybrid eucalyptus clones in the Experimental Plot for Forest Landscape Restoration, Alto Paraná, Paraguay.

The Scientific Committee - Potpourri session
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Abstract: The association in the early stage of Forest Restoration with native species and economically valuable fast-growing species such as Eucalyptus spp. can reduce the initial costs associated with what, in addition to generating economic returns during the early years of the process. That is why this study intended to understand the initial performance of 2 hybrids of Eucalyptus spp. In a forest landscape restoration trial located in the Alto Paraná Department, Paraguay, on a property owned by Itaipu Binacional. The trial consists of two treatments and 5 randomly distributed blocks, where both treatments have a strip of exploited species and a strip of conservation species. The difference between both treatments lies solely in the exploited species strip, where treatment 1 (T1) consists of the association of Eucalyptus urophylla x E. grandis for timber purposes, with a spacing of 3x3 m, and treatment 2 (T2) consists of the association between Eucalyptus urophylla x E. camaldulensis for energy purposes, with a spacing of 3x2 m. In T1, pruning up to 9 m is planned, as well as two thinning operations and final harvesting at 10 years, whereas in T2, harvesting is planned at 5 years after plantation. The plantation was established in May 2021, and the dendrometric variables, diameter at breast height (DBH), total height, and crown coverage, were recorded at 12 months. The results showed an average DBH of 627 mm for T1 and 74.56 mm for T2. As for the average height variable, T1 yielded 417.3 cm, while T2 yielded 496.4 cm. In contrast, the average crown area variable resulted in 3.28 m2 for T1 and 4.63 m2 for T2, respectively. These data reflect significant initial performance of T2 with the aim of obtaining an important economic return.

Integrating Deforestation Risk for Fairness REDD+ Benefit Sharing in Indonesia: A Case Study of Jurisdictional-based REDD+ Program in Jambi Province

The Scientific Committee - Potpourri session

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Abstract: In order to distribute REDD+ benefits effectively, efficiently and fairly to beneficiaries in subnational jurisdiction, two distribution criteria proposed i.e.: historical emissions (tCO_{2e}) and forest cover (ha). Forest cover is proposed to accommodate beneficiaries who have protected forests in their area which has relatively smaller historical emissions as a result of protecting and maintaining the forest for years compared to beneficiaries whose areas are not preserved, deforested and degraded but are implementing REDD+. Interestingly, a simulation result of the jurisdictional-based REDD+ benefit sharing in Jambi province for 2018 using the two criteria, indicate an imbalance in the benefit allocation, where the forest areas managed at national level (national parks, nature reserves, etc.) received greater benefits than others, mainly Forest Management Units (FMUs) under subnational government's control. This is due to the fact that the national park areas cover over one third of the jurisdiction, an imbalance which will be a source of dispute from the subnational perspective. This paper explores the possibility of integrating deforestation risk as one of the main criteria to determine REDD+ benefit sharing along with the existing indicators. Using a deliberation, the appropriate local determinants for deforestation risk determined to be included in the construction of the risk criterion. Ultimately, the paper delivers a set of recommendations of what are the best criteria for the calculation of REDD+ benefit sharing. Although this paper takes the case study of Jambi province, paper also explores the feasibility of such results to be applied in other regions in Indonesia

INVESTIGATION OF PUBLIC PERCEPTIONS AND PREFERENCES REGARDING RECREATIONAL FORESTS: exploratory study in the Ukrainian Carpathians

The Scientific Committee - Potpourri session
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Abstract: For the post-war recovery of Ukraine, including restoration of its natural capital, it is important to understand public preferences and expectations concerning forest ecosystem services. Although today a significant part of the forests in the Ukrainian Carpathians is of artificial origin, we cannot say that they were designed and managed with a clear vision of arising challenges and intention to maximize multiple benefits generated by forest ecosystems. Growing local demand for recreation in the Carpathian Mountains gives rise to new challenges related to the need for formation of recreationally attractive forests. In recent decades in Europe, many studies have been conducted on public perception of recreational forests, and preferences concerning their attributes. However, studies conducted recently in Ukraine, considered forests as a generalized concept, without attention to forests' attributes. In this exploratory study we investigated public perceptions and preferences, both stated and revealed, regarding attributes of recreational forests and recreational objects in the Ukrainian Carpathians. People's willingness to travel to enjoy a forest with appropriate attributes and their revealed behavior were analyzed, with a focus on species mixture, age structure, presence of deadwood, distance, location distance etc. Set of techniques, like non-parametric statistics, choice experiment method and travel cost method were applied to provide an insight into the research question. Integration of the revealed perceptions and preferences regarding recreational forests and objects into innovative forest decision-making enables synergy of benefits like an increasing attractiveness of recreational forests and forest landscapes, improvement of forest resistance to climate change, satisfy a local demand on wood biomass and strengthen fire resistance of recreational forests.

Is climate change exacerbating national park---community conflict: A case study of Qilian Mountain National Park, China

The Scientific Committee - Potpourri session

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Abstract: Access restrictions for natural resource use of local people induced by the establishment of national parks, often result in conflicts, thus jeopardizing conservation goals. Meanwhile, communities have also been severely challenged by climate change since the 21st century, and whether this exacerbates local animosity towards the national park. By taking a community resilience perspective, this paper furnishes a renewed look at how climate changes affect the tendency of conflict. For this purpose, this study conducts an in-depth qualitative study based on semi-structured interviews with local communities in Qilian Mountain National Park. It will be ascertained that the conflict between the national park and locals tends to exacerbate under the threat of climate change, and community resilience capacity mediates the relationship. Communities of interest have higher community resilience compared to communities of geography. Communities of geography inability to adopt adaptation strategies to help them adapt to the adverse effects of climate change, leads to stiffer conflicts with the national park directorate. It also discusses measures to strengthen the resilience of communities to adapt to changing socio-economic conditions. The study highlights the importance of community resilience in achieving a harmonious balance between nature conservation and the well-being of local communities.

LOCAL COMMUNITY PERCEPTION ON THE ECOTOURISM POTENTIALITIES OF THE DELTA MONO BIOSPHERE RESERVE IN SOUTHERN BENIN

The Scientific Committee - Potpourri session
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Abstract: Ecotourism contributes to conserving natural resources and promoting natural and cultural resources stewardship. However, without the strong support and involvement of local people, it is not easy to achieve the stated goals. This study aimed to understand the local people's perception of the ecotourism potentialities of the Delta Mono Biosphere in order to inform policymakers. We conducted a semi-structured interview of 120 respondents from *Lokossa, Houéyogbé* and *Athiémé* districts surrounding Delta Mono Biosphere Reserve. We also did 104 km of transect survey to assess the diversity of the wildlife in the reserve. Our findings confirmed the presence of 08 mammalian species, 32 species of birds and 3 species of reptiles which were also recognized as a potential for ecotourism by the local population. This Biosphere Reserve provided several ecosystem services and the most cited by the respondents were provision (27,32%), support (25,85%) and cultural (23,41%) ecosystem services. Among the cultural ecosystem services, it highlighted many sacred forests and other traditional activities (fishing and small game hunting) valuable in ecotourism. The respondents call for support from the government to organize community-based ecotourism. The main threat to the conservation of these resources is the low motivation of the local communities who don't perceive all potential positive impacts of the Biosphere, if well managed. Detailed understanding and consideration of socioeconomic and demographic characteristics can contribute to effective outreach and planning processes, potentially resulting in the higher promotion of ecotourism.

Keywords: wetlands, ecosystem services, biodiversity, ecotourism potential, Benin

Mapping the Distribution of the Eurasian Hoopoe Upupa epops and the Pine Processionary Moth in Lebanon based on a Citizen Science Approach

The Scientific Committee - Potpourri session

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Abstract: The Pine Processionary Moth (PPM) has long been attacking Mediterranean forests. In its defense strategy, Lebanon was focused mainly on pesticides, more recently on biocontrol, leaving natural predators as an understudied field. Add to that an inherited lack of forest inventory, biological diversity assessment and a broad gap when it comes to avifauna and its link in the natural control of forest pests.

For the first time ever in Lebanon, this study aims at understanding the status of the Eurasian hoopoe, all while assessing the damage caused by the PPM, in an attempt to explain the relationship between the two species and their relation to other factors. Based on Citizen Science (CS), the data of the two species covering the years 2017 to 2022 resulted from various sources: a Google Form shared nationally among individuals, groups, NGOs, pages, ministries and more; Passive data collected from Facebook groups and individual posts; Personal communication with key people; and eBird.

After filtering the data, distribution maps were developed on ArcMap, and an attempt was done on Statistica software using an Analysis of Variance (ANOVA) test to correlate the PPM and the Eurasian hoopoe. However, due to many inconveniences and disparities in the results, no statistically valid correlation between the two studied species was found at this stage. As a result, research guidelines with the required experimental procedures to reveal the underlying correlation between the two studied species were offered.

Additionally, based on a “Responsible Hunting Areas” map developed by a local NGO, the varying damage from the PPM between Cazas was linked to Important Bird Areas (IBAs), highlighting the importance of multiple birds, including the Eurasian hoopoe, as natural predators of this pest.

This paper was concluded with a conservation roadmap and based on its findings, a set of recommendations for each stakeholder was proposed.

Having depicted completely understudied species in Lebanon, this paper serves as a stepping stone in the field of biodiversity conservation, as it sets the path for future researchers willing to work on the same urgent topic, in a context of Climate Change and increased pest outbreaks.

Marine climate regulation mechanisms also drive terrestrial moth populations

The Scientific Committee - Potpourri session
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Abstract: Time series data analyses were used to compare trends and changes in the biomasses of Subarctic moth (1971–2017) and northern Baltic Sea zooplankton (1966–2019) as well as to analyse how both groups were affected by climate variables.

There were no significant changes in total moth biomasses unless the outbreaking species *Epirrita autumnata*, with slightly increasing biomass, was included into the analysis. Biomasses of species flying every year, overwintering as eggs, feeding on both herbaceous and woody plants and generalists feeding on three or more plants increased significantly. In contrast, biomasses of species overwintering as larvae, feeding on something else than living plants, feeding on sprout or root, feeding on just herbaceous plants and specialists feeding on one plant only, remarkably decreased. Regarding zooplankton, the biomasses of all zooplankton groups decreased. Decreases of marine and brackish water species were the most obvious.

The driving role of NAO and observed regime shifts in the Baltic and North Seas were studied regarding both invertebrate groups. In addition, regarding moths, the role of growing season temperature sums and precipitation were studied. Mostly the spring (March–May) NAO index, which correlated positively with temperature, best explained biomass changes and trends in moths. The spring NAO negatively affected species which flew every year, which overwintered as larvae and species which used more than three nutrition plants. Species eating herbaceous plants had a bigger biomass during the first regime in 1972–1975 but concerning other groups regime shifts were not important for moths. Additionally, temperature sum until 15th of June had a significant negative effect on moths which overwintered as larvae.

Winter (December–March) NAO index was relevant for zooplankton. It was a significant factor for cladocerans, whereas observed regime shifts (1976 and 1990) best explained marine (1976 and 1990) and brackish (1976) copepod biomasses. Additionally, the effect of ice-covered period on zooplankton was investigated and it best explained biomass changes in freshwater copepods.

Our results indicate significant effects of climate change on moths and zooplankton, but the climatic regulation mechanisms affect these invertebrate groups differently, for instance due to phenological and ecosystem related differences.

Migration, Traditional Ecological Knowledge, and Biodiversity Conservation in Sacred Forests: A Case Study of Igbo Olodumare, Nigeria

The Scientific Committee - Potpourri session

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Abstract: Sacred forests are globally recognized as a form of community-based conservation for their role in protecting biodiversity within and outside the global protected area network. However, the existence of sacred forests in many cultures and societies were not primarily for conservation purpose but rather for cultural and religious purposes. In many cases, the traditional ecological knowledge (TEK) which is integral to the existence of sacred forests continues to face significant threats. In this paper, we draw from primary data collected from survey questionnaires, focus groups and participant observations in Igbo Olodumare sacred forest in the Southwest region of Nigeria. We examine threats facing the sacred forest to determine how such threats could impact the long-term conservation of biodiversity in the forest. We found that there are two main threats to the long-term biodiversity conservation in Olodumare sacred forest: (1) the increased presence of migrant farmers who are unfamiliar with TEK, and (2) the knowledge vacuum resulting from the migration of local elders who are custodian of TEK to cities. When compared with other sacred forests in southwest Nigeria with fewer immigration, we found that the biodiversity conservation status of sacred forests is heavily dependent on threat levels and degradation. Our findings highlight the adverse impact of migration (from rural-urban and vice versa) on sacred forest conservation and offer suggestions to strengthen traditional ecological knowledge through engaging multiple stakeholders within and beyond the forest community.

Modelling tree height-diameter and biomass growth relationship of planted Melia volkensii (Gurke.) stand in drylands of Kenya

The Scientific Committee - Potpourri session
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Abstract: *Melia volkensii* tree growing in drylands of Kenya have a potential of reversing environmental degradation and at the same time improved farmer's livelihoods through sale of high quality timber. Melia planted on-farms support smallholder farmer's livelihoods and play an important role in global carbon cycle because of it short rotation. However, reducing emissions of greenhouse gases from deforestation and forest degradation (REDD) require stringent carbon measuring, reporting and verifying methods which is lacking especially for indigenous species. This study aims to evaluated the distribution of above- and below-ground-biomass and carbon socks of *Melia,* an important indigenous species that is being promoted for reforestations of degraded lands by developing robust allometric equation for estimating biomass and carbon using easy to measure growth parameter like diameter at breast height (DBH) and height . Five to ten trees were sampled and there height, DBH and aboveground biomass destructively harvested from trees of ages 5, 7.9 and 11 in Kibwezi site and 10, 12, 14 and 25 in Tiva site. Roots from sampled trees were subsequently excavated and weighed for estimation of root biomass. At Tiva site, 14 years Melia tree had at attained a height of 10.0m, a DBH of 20.0cm, and accumulated total biomass of 252 kg DM kg/tree and 125 kg carbon/tree which is equivalent to 157 tons DM/ha and 78.68 tons carbon/ha respectively at tree density of 625 tree/ha. At Kibwezi site, 11 year old Melia had at attained a height of 8.6m, a DBH of 23.4cm and accumulated total biomass of 274 kg DM kg/tree and 136.8 kg carbon/tree which is equivalent to 171 tons DM/ha and 86 tons carbon/ha respectively. Belowground to aboveground ratio was 0.21. Diameter at breast height alone provided reliable prediction of belowground biomass (R^2=0.97), aboveground biomass (R^2=93) and total biomass (R^2=0.94). This study recommends diameter at breast height as the basis for estimating biomass in drylands landscapes for estimating carbon sequestration potential of Melia planted on farms. Reforestation degraded farmlands with Melia can contribute climate change mitigation and REDD++ initiative

Monitoring of Forest Phenology (1982 - 2023) in the Western Ghats, India: Integrating Landsat and PhenoCam Data

The Scientific Committee - Potpourri session

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Abstract: Monitoring forest phenology is crucial for understanding climate change as it provides insights into the timing and duration of key biological events, such as leaf emergence and flowering. These events are sensitive to climate variations and can help assess the impacts of changing environmental conditions on ecosystems. The Western Ghats in India holds immense importance due to its exceptional biodiversity, encompassing nine different forest types that support numerous endemic species. Each forest type possesses a distinct set of species and ecological processes. In the context of climate change, comprehending the impact of climate on forest phenology in this highly biodiverse hotspot becomes imperative. This study aims to investigate the changes in forest phenology over the past four decades (1982-2023) in various forest ecosystems of the Western Ghats, using Landsat data. The obtained results will be validated by incorporating available ground and PhenoCam data. Furthermore, this study will explore the drivers that regulate phenological dates across different forest types, shedding light on the factors influencing the timing of crucial biological events in response to climate and environmental conditions. By examining the phenological changes in diverse forest types within the Western Ghats, we can evaluate their resilience and vulnerability to climate change. Ultimately, this research will contribute to a comprehensive understanding of forest phenology in the Western Ghats and its correlation with climate change. The findings will aid in assessing ecosystem responses to climate variability and provide valuable insights for devising conservation and management strategies for preserving the region's unique biodiversity.

Morphological Taxonomy and Distribution of Dodder (Cuscuta species) in Kenya

The Scientific Committee - Potpourri session
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Abstract: Dodders are parasitic plants that attack other plants. In Kenya, reports on Dodder have identified *Cuscuta reflexa, Cuscuta campestris,* and *Cuscuta kilimanjari* however, other observations and reports of other Dodder species infestations indicated that several species may be widespread in the county. The weed poses a threat to this region's ecosystem and biodiversity with adverse environmental impacts. Currently, the identity of the species causing havoc in the Kenyan ecosystems is not known. Data on accurate information on the extent of parasite spread and damage caused by dodders on plants as well as the magnitude of their socio-economic impacts is also lacking. A national survey was carried out to identify sites with Dodder infestations using transects to taxonomically identify species in Kenya, their distribution and infestation. Dodder samples were collected from the infested areas and characterized morphologically. Host weeds was also determined. Known road transects were used in the collection of samples at a distance of 1km apart. Identification was done by examining the morphological features such as colour and floral characteristics and compared with known keys. Western and Rift Valley were the most affected areas while Eastern and Coastal areas had moderate infestations. Six species of Dodder were identified and their occurrence documented. The species identified were: *Cuscuta kilimanjari* (85.4%)*, Cuscuta suaveolens* (5.4%), *Cuscuta campestris* (4.3%) *Cuscuta planiflora* (3.7%) *Cuscuta epilinum* (0.5%) and *Cuscuta australis* (0.5%). *Cuscuta kilimanjari* was the most widely distributed species and had a wide host range. It was the dominant species in the Eastern Kenya region. *Cuscuta suaveolens* and *Cuscuta australis* were only found in Central Kenya region. *Cuscuta planiflora* was found in both Central and Nyanza. *Cuscuta campestris* was found in both the Central and Rift Valley regions. *Cuscuta epilum* was only found in Rift Valley on *Bougainvillea gabra.* The major species attacked by *Cuscuta sp.* are *Thevetia peruviana* followed by *Lantana camara* and *Senna siamea*. The *Cuscuta spp* were found to affect different plant species including high agricultural crops and trees. The findings of the study have expanded the distribution and host range of Dodders in Kenya.

Keywords: *Cuscuta spp, Taxonomy, Morphology, Distribution, Kenya*

Natural regeneration of Pinus sylvestris and Betula spp. onto carbon-rich soils drives net ecosystem carbon losses

The Scientific Committee - Potpourri session

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Abstract: Forest restoration is proposed to address the joint biodiversity and climate crises. However, tree establishment onto carbon-rich podzolic soils can drive soil carbon losses, via ground preparation such as mounding or ploughing. These soil carbon losses can exceed tree biomass carbon gains at the timescale relevant to 2050 net zero targets. Thus, reforestation via natural regeneration has been proposed as a solution, as soil carbon losses via ground preparation would be avoided.

However, we hypothesise that soil carbon losses via tree-soil interactions following natural regeneration onto carbon-rich soils could still drive net ecosystem carbon losses at timescales relevant to net zero. Thus, to quantify soil carbon losses in the absence of ground preparation, we investigated the ecosystem carbon stock changes that follow natural regeneration.

In the Cairngorms, Scotland, we identified sites of 25-30-year-old *Pinus sylvestris* and *Betula* natural regeneration onto *Calluna vulgaris*-dominated moorland with podzolic soils. We measured tree, vegetation, and soil carbon stocks at intervals along an eight metre transect from single naturally regenerated trees into uncolonised moorland.

Soil carbon stocks were lower in the rooting zone of the trees, compared to eight metres away in open moorland. Overall, total soil carbon stocks decreased 2.7 t C/ha per metre from the tree. On average, 0.5 t C/ha of soil carbon was gained in the upper layers of the soil, where litterfall occurred, with each metre from the tree, although this varied between tree species due to different litterfall masses and chemistries. Yet, on average, 3.2 t C/ha of soil carbon was lost in the lower layers of the soil, where tree rooting occurred, per metre from the tree, and this was consistent between the tree species. This suggests the role of tree-soil interactions in driving soil carbon losses. At the ecosystem scale, soil carbon losses exceeded tree carbon gains, resulting in net ecosystem carbon losses following natural regeneration onto carbon-rich soils.

Thus, when evaluating the contribution of naturally regenerated forests to climate change mitigation, soil type and potential soil carbon losses should be considered relative to tree carbon gains, especially at the timescale relevant to 2050 net zero targets.

Notes on the Pollination Dynamics of Smooth Narra (Pterocarpus indicus Willd. forma indicus) in Laguna, Philippines

The Scientific Committee - Potpourri session
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Abstract: Smooth Narra (*Pterocarpus indicus* Willd. forma *indicus*) is an important indigenous tree found in the Philippines. The pollination dynamics of smooth narra were studied from March to April of 2017 during its peak flowering at the College of Forestry and Natural Resources Campus of the University of the Philippines Los Banos. Its pollination syndrome, floral developmental stage, and associated floral visitors and possible pollinators were elucidated under field conditions. The floral development of smooth narra was described. A total of 13 taxa of floral visitors were recorded. Bees such as *Xylocopa*, *Tetragonula,* and *Apis* were observed foraging on the inflorescence. *Tetragonula* has the highest Index of Visitation Rate (IVR) of 412.09 while the weevil Curculionidae yields the lowest IVR of 0.04. Smooth narra has some notable floral visitations and potential insect-mediated pollination may occur. However, more studies are needed to better understand the role of insects as pollinators for *Pterocarpus indicus* and to explore the potential implications for its reproductive success and genetic diversity.

OCCURENCE OF ARMILLARIA RHIZOMORPHS IN PEAT SOILS

The Scientific Committee - Potpourri session
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Abstract: *Heterobasidion* and *Armillaria* spp. are the most important root-rot-causing pathogens of conifers. *Armillaria* species primary spread by rhizomorphs and occasionally can cause severe economical losses in spruce stands. High incidence of Heterobasidion root rot has been observed in some spruce stands on peat soils in Latvia whereas the prevalence of *Armillaria* sp. in peat soils is largely unknown. The aim of the current study was to evaluate occurrence of *Armillaria* rhizomorphs in six Norway spruce stands on peat soils infected with *Heterobasidion*.

Armillaria rhizomorphs were found in 60 out of 90 soil samples. The total length of rhizomorphs per sample (volume – 2355 cm^3) ranged from 5.2 to 763.9 cm (49.6 cm on average). *Armillaria cepestipes* was detected in 85% of samples, and *Armillaria borealis* in35%. The total length of *Armillaria* rhizomorphs per square meter of soil at a 3 cm depth was on average 6.2 m. Obtained data indicates that peat favours development of *Armillaria* rhizomorphs.

Organic carbon storage, soil respiration and nutrient elements under Prosopis trees

The Scientific Committee - Potpourri session
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Abstract: Background and objectives: In arid and semi-arid ecosystems, the relationship between tree species and
habitat is fragile due to environmental stresses. The role of native trees in carbon storage and change in
soil biological properties is important. (Prosopis cineraria (L.) Druce) is one of the most important native
species in the Sahara-Sindhi area, which has a good ability to establishment. The non-native species of
(Prosopis juliflora (SW) DC) is widely planted with fast growth. Trees in these areas can have a range of
different effects on the soil of under canopy.
Materials and methods: To measure basic and induce respiration, OC, N and P, 24 soil samples were collected from 0-30 cm depth randomly from under and outside canopy of both species. To calculate SOC with the cylinder in a 1×1 m 2 plot, sampling was done of soil to obtain the BD and OC. For measuring SOC in litter and grass cover, were collected and their weight was recorded. Finally, 120 samples were taken in south of Iran, Assaluyeh.
Results: The results of analysis of fragmented plots showed that the effect of species as the main factor
on basic and induce respiration was significant and it was in Prosopis cineraria 2.73
and 22.47 mgCo 2 in day and hour and in Prosopis juliflora 0.9 and 15.57 mgCo 2 in day and hour, respectively was more in Prosopis cineraria. The interaction effect of species in the sampling location on
available P was significant and its value was 23.68 ppm under canopy. The effect of sampling location was significant for all variables studied and under canopy was more.
Conclusion: Due to the positive effect of native species on soil respiration is very vital and negative effect of non-native species on soil respiration can reduce microbial activity. It is recommended to use
native species for natural forests and avoid entry of non-native species into.
Keywords: Available phosphorus, Organic carbon, Sahara-Sindhi, Total nitrogen.

Participatory Forest Management shortfalls! A review of Twenty Years of process implementation in Kenya

The Scientific Committee - Potpourri session
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Abstract: Participatory Forest Management (PFM) was introduced in Kenya as a result of local and national pressure by communities and civil society organizations to reduce forest destruction. This was to be a departure from the government-centered approach to community based approach premised on the benefits witnessed in Nepal and India. Despite, the successful piloting of the approach there were concerns that it had not transferred adequate powers to communities nor contributed fairly and equitably to improved community livelihoods. A was undertaken through household's case study approach in Arabuko Sokoke, Kakamega, Kereita and Gathiuru forests through household surveys, expert discussions, Focus group discussion and key informant interview to determine if the challenges were policy, institutional, human or practice based. Results of the study indicated that PFM has fairly contributed to conservation and livelihood improvement. The process had introduced diverse livelihood sources for households and an opportunity for community participation in forest management and decision making, led to the formation of community organizations and multi-stakeholder forest management teams. The organizations have become fund raisers, forest managers and nexus for rural development. It was clear that livelihood improvement is not being adequately achieved in high biodiversity indigenous forests. This calls for innovative alternative community livelihood improvement activities. Moreover, although the community indicated that they have done their best to conserve the forest, the government has not provided adequate support to conservation. Moreover, CFAs are faced with governance challenges such as poor leadership, lack of accountability and transparency, non-adherence to their constitutions requirements and lack of established physical offices which have hindered the effective performance of CFAs. The study recommends continuous PFM awareness and training which should be phased and target all stakeholders and their categories of officials. Adequate resources should be allocated for PFM implementation process to ensure fair, just and equitable benefit sharing mechanism. There is need to provide incentives for community participation in PFM. In order for PFM to be institutionalization, improve livelihoods and create wealth and ensure good governance, PFM by-laws/subsidiary legislation to facilitate PFM implementation at station level and to support national uniformity will have to be enacted.

Patterns of Species and Functional Diversity along Environmental Gradients of Yayu Coffee Forest Biosphere Reserve Zonation, Southwest Ethiopia

The Scientific Committee - Potpourri session

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Abstract: In current ecological research, there is an urgent need to have trait based functional information at local as well as at global scales for effective forest landscape restoration. In this study functional diversity of Yayu Coffee Forest Biosphere Reserve (YCFBR) Southwest Ethiopia was quantified to enhance knowledge of these dynamic mechanisms using trait based diversity. Data was collected from 90 proportionally distributed plots along disturbance levels from core, buffer and transitional zones of YCFBR. For functional trait diversity estimation, traits relevant to plant-life strategy, competition ability and response to disturbances and climate change were selected. Multiple regression model was performed to test the response of species diversity and functional diversity along disturbance and environmental gradients. Also, mixed effects model was used to test the effects of environmental variables on functional diversity using R software. The results revealed that, a total of 83 plant species from 67 genera and 42 families were identified in the YCFBR. Functional diversity showed a linear decreasing pattern with increase of disturbance intensity and environmental factors in the YCFBR. From this, anthropogenic disturbances and environmental variables were the most important factors influencing the species diversity and functional diversity of YCFBR, which may affects ecosystem processes. This findings can be used in decision-making by policy makers for conservation and restoration of biosphere reserve. Further studies should be conducted to predict the relationships of species diversity with forest ecosystem services for climate change mitigation and the effects of climate change on forest biosphere reserve of Southwest Ethiopia.

Keywords: Biosphere reserve; Functional diversity; Southwest Ethiopia; Yayu coffee forest biosphere reserve; zonation.

Perspectives, Impacts, and Management of Stakeholder Groups on Forest Conflicts: A Case Study of Taitung Anshuo Region in Taiwan

The Scientific Committee - Potpourri session

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Abstract: From 1945 to 1975, the Taiwan government implemented a policy of leasing forest land to the public for reforestation in order to restore forests that had been previously deforested or abandoned. However, since 1990, due to environmental, economic, and legal factors, most leaseholders have adopted a passive management approach. In recent years, there have been some leased land in the Anshuo area of Taitung, administered by the National Property Administration, planning for logging activities. It has raised concerns among environmental groups due to the presence of endangered species such as *Pasania chiaratuangensis* and *Pasania shinsuensis* listed in the Taiwan Red Book of Vascular Plants. This study aims to examine the attitudes of leaseholders towards conflicts between forest management and ecological conservation, and to explore the feasibility of implementing the payments for environmental services (PES) approach through the design of a "Fagaceae Conservation Fund" (FCF).

This study employed in-depth interviews with a total of 17 stakeholders. The findings revealed that inadequate communication was the main cause of forest conflicts in the Anshuo area. Whether there is a forest management plan and the intensity of logging were identified as significant factors contributing to conflicts. Distrust among environment protection groups, leaseholders, and government agencies also played an important role.

Regarding the feasibility of the FCF, the study indicated that when the fund's operation is entrusted solely to leaseholders, the feasibility decreases. Instead, it is suggested to develop a cooperative model between leaseholders and universities. While leaseholders provide the forest land management rights, the practical management is implemented by external entities, such as forestry companies or schools. This managing model was believed to be more acceptable to leaseholders. However, respondents from environmental protection groups expressed concerns about potential ecological damage resulting from the collection of fruits of Fagaceae. The study suggests that in order to address these concerns, face-to-face communication between individuals holding different positions should be facilitated, allowing for a more direct understanding of each other's perspectives.

Phenological mapping of understory invasive species residing in forest realm using machine learning algorithms

The Scientific Committee - Potpourri session
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Abstract: Forests, crucial sources of living are being threatened by invasive plant species since past decade. Growth phase of these invasive species have affected the biodiversity, effectively replacing the rich and endemic species in forest realm. In past few years it has been noticed that invasion can become uncontrollable if necessary measures are not incorporated. Therefore, mapping and monitoring invasive plant species in forest realm is becoming a topic of such a prime importance. To map understory invasive plant species from forests has always been a task. In this paper, phenology plays vital role to study temporal curve for different vegetation indices affecting in growth and senescence period. Phenology has prime importance in separability analysis of inter and intra species discrimination. Multispectral images from Sentinel-2 dataset is used for forest and invasive species discrimination which is easily available and accessible around the globe. Mostly high spatial resolution dataset is used to map invasive plant species but this technique can be proved effective for above stated problem with multispectral images. Further, machine learning algorithms were incorporated to understand the most effective algorithm in pixel-based classification. In broad category, regression tree-based algorithms (CART and SVM), decision tree-based algorithms (RF and GTB) and probabilistic algorithm (GMM) were implemented to understand the best technique for above mentioned problem. Decision tree-based classifiers were most effective ones where accuracy of RF and GTB were 92.33% and 93.99% respectively. Results obtained so far shows that machine learning algorithms are still most effective for pixel based classification. Thus, this study has shown a technical procedure to follow to segregate invasive plant species from forest area.

Plantations of native tree species in Africa: a synthesis of tree survival and growth across plantation methods in the Guineo-Congolian region

The Scientific Committee - Potpourri session
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Abstract: In the Guineo-Congolian region, forest plantations of native tree species were established and tested with different silvicultural itineraries and objectives in several countries. The results of these tests remained scattered, hampering our ability to identify the key drivers of plantation performance.

We then conducted a systematic literature review to gather, in a single dataset, records of planted tree survival and growth for the different planted tree species. From 37 studies, we compiled records of tree age, survival, mean height and diameter of 70 native tree species in 394 plantations across 8 countries of the Guineo-Congolian region. We modelled tree survival, height and diameter increments using linear mixed-effects models.

We found that the mean annual survival rate was 89.0 ± 15.2% in plantations whose mean age was 11.8 ± 14.7 years. The survival rate significantly varied with plantation methods, forest type, composition and differences in annual rainfall at plantation sites. Mean height growth was 90.9 ± 57.1 cm $year^{-1}$ and was higher for pioneer species (102.1 ± 63.2 cm $year^{-1}$) and in evergreen forests (126.1 ± 63.5 cm $year^{-1}$). Variation in height increment was significantly related to plantation age, forest type, species guild and leaf phenology. Plantation methods did not explain the differences in height increments. Stem diameter increment was 12.4 ± 7.5 mm $year^{-1}$ and slightly higher for pioneer species (13.2 ± 8.4 mm $year^{-1}$). This increment depended on plantation method and was the highest after clear-cutting (15.5 ± 6.8 mm $year^{-1}$). On average, the evergreen species showed a higher diameter increment (14.8 ± 7.6 mm $year^{-1}$) than the semi-deciduous species. We found high between-site variability for height increment and survival rate, but to a lesser extent for diameter increment.

These results helped identify the factors driving plantation performance and could guide foresters in choosing the best silvicultural itineraries for tree species.

POLICY AND LEGAL FRAMEWORK FOR FOREST MANAGEMENT IN ECUADOR: A MULTISECTORAL APPROACH TO STRENGTHEN GOVERNANCE

The Scientific Committee - Potpourri session

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Abstract: Ecuador is a megadiverse country and its forests cover 51% of its territory. Despite the consolidation of legal instruments for land management and planning in the past decade, the annual net deforestation rate in 2016 went from 61,112 ha (-0.48%) to 87,535 ha (-0.76%) in 2020. The main drivers of deforestation were land use change for animal husbandry and agricultural activities, infrastructure development, and extractive activities (e.g., oil and mining). This situation is aggravated by conflicts among the different sectors as the contribution of forests to the national economy is underestimated compared to other productive sectors that generate higher income such as oil or agriculture, but that don´t have long-term sustainability goals and fail to achieve national objectives to reduce deforestation. The study analyzed the fragmentation of conflicting policy and regulatory frameworks in land management from 2010 to 2023 through a multi-sectoral implementation approach that facilitates forest management and contributes to reducing deforestation and strengthening governance. We used a qualitative content approach through the selection of sectoral policies and legal frameworks related to forest management and interviews with key stakeholders. Legal and policy instruments were assessed focusing mainly on national and decentralized public institutions including aspects related to land management, impacts between productive sectors and environmental policies. The results show gaps and ambiguity in the regulations that generate problems of implementation and effectiveness in the territorial planning of forests and their long-term management. Policy instruments should be constituted by the different institutions and decentralized governments with a multisectoral approach to regulate and recognize the importance of forest management and planning. Finally, policy and regulatory alternatives for land use management are presented, as well as proposals for legal reform to facilitate forest management.

KEWORDS: Forest patrimony, forests, territorial planning, management, governance.

POTENTIAL OF HYPHOLOMA SPP. TO IMPROVE EFFICACY OF PHLEBIOPSIS GIGANTEA AGAINST HETEROBASIDION ROOT ROT

The Scientific Committee - Potpourri session

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Abstract: Heterobasidion root rot caused by the fungal pathogen *Heterobasidion* spp. is responsible for significant damage in conifer stands. The spread of the pathogen can be limited by using chemical and biological control agents. The commercial biological preparation Rotstop® containing a single strain of the fungus *Phlebiopsis gigantea* is widely used to treat conifer stumps in Latvia and other countries of Central and Northern Europe. It is important to consider the use of other fungi in the biological preparations to reduce the potential negative impact of using a single *P. gigantea* isolate on the biodiversity of stump colonizing fungi in the long-term.

The antagonism of *P. gigantea* and *Hypholoma* spp. against *Heterobasidion* spp. has been demonstrated in various experiments. However, no studies have been conducted to assess and compare the efficacy of individual isolates and mixed suspensions of these fungi in limiting the spread of *Heterobasidion* spp. in wood of *Pinus sylvestris* and *Picea abies*.

The results of the experiments show that *Hypholoma* spp. isolates in mixed suspensions with *P. gigantea* favour the development of *P. gigantea* mycelium in *Pinus sylvestris* wood. The origin and wood surface colonization rate of *P. gigantea* isolate have a significant effect on the efficacy of mixed suspension against *Heterobasidion* spp. Wood treatment with *Hypholoma* spp. isolates had no negative effects on the natural *P. gigantea* establishment and spread.

Keywords: *Heterobasidion*, *Hypholoma*, *Phlebiopsis gigantea*, biological control, root rot.

Preliminary risk assessment of invasive forest pest: Climatic suitability for established non-native insects in Korea

The Scientific Committee - Potpourri session
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Abstract: The increase in international trade and climate change have provided an opportunity for numerous non-native insects to be introduced and eatablished in non-native regions around the world. These non-native insects are currently considered as invasive forest pests, so it is important to prevent new introduction of these non-native insects that is likely to eatablish and cause damage. This study aims to evaluate whether climate suitability can serve as a predictive indicator for potential invasive pests. Geographic information of presence points for 74 non-native insect species, already established or reported in Korea, were obtained from the GBIF database. Climatic suitability of each species was estimated using bioclimatic variables provided by WorldClim. The presence data and randomly generated pseudo-absence data were used to georeferenced the bioclimatic variables to build climatic niche models. The climate suitability for each species was predicted by Classification Tree Analysis (CTA), Boosted Regression Tree (BRT), and Random Forest (RF) algorithms, which were subsequently integrated into an ensemble model. The final models for each species showed high predictive performance. Notably, the ten species known as major forest insect pests in Korea exhibited distinctly higher climatic suitability compared to the remaining species. Therefore, to estimate of climatic suitability of non-native insects can be used to evaluate the invasiveness of the insects that may become future invasive forest pests. In addtion, such information can be used to prepare a list of non-native insect species that can establish and become pests when introducing Korea.

Regeneration of forest ecosystems in heavily contaminated and disturbed habitat conditions - a case study of afforested post-sulfur mine sites

The Scientific Committee - Potpourri session

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Abstract: Referring to the discussion at the European Union forum on biodiversity and ecosystem restoration at climate change, the threat of drought, and extreme weather events, it seems important to consider different scenarios for ecosystem regeneration in disturbed site conditions.

Quite well example for studying the reaction of forest ecosystems and their resistance to extreme conditions are reclaimed and afforested post-industrial areas. The area of the former sulfur mine is characterized by high sulfur and acidity concentration, therefore plants exist under environmental stress. A comprehensive study of soil properties, plant reactions to excessive sulfur concentration, and surface water chemistry in the restored forest ecosystem of a former sulfur mine (southern Poland, 50°32′N; 21°47′E) was made.

Sulfur contamination of topsoil (0-20 cm), the spatial distribution of contamination, surface water chemistry, growth reaction, vitality, and mineral supply of Common birch (*Betula pendula* Roth.) and Scots pine (*Pinus sylvestris* L.), as well as the chemical composition of this and wood small-reed (*Calamagrostis epigejos* L.) were investigated on an area of over 200 ha of an afforested ecosystem after borehole sulfur mining.

It was found that hot-spots with high sulfur concentrations in soil reaching even 45,000 mg kg $^{-1}$, pH below 2.0 were still reported, however, it occupied hardly 2% of the researched area. Surface waters were characterized by an excessive concentration of sulfate ions (average 935.13 mg$\cdot$L^{-1}) and calcium ions (up to 434 mg$\cdot$L^{-1}), which was connected with the sulfur mining process and sludge lime used in neutralization. Wood small-reed was found to adapt well to the conditions of elevated sulfur concentration. Observations of plant reactions and changes, e.g. chemistry, taking place in small/local ecosystems are very important to learn about plant reactions to severe stress and apply knowledge in the context of ongoing environmental and climate changes.

Representation of peatlands in G4M-X model

The Scientific Committee - Potpourri session
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Abstract: Despite constituting a mere 3% of the Earth's terrestrial surface, peatlands represent uniquely carbon (C) rich ecosystems that contribute significantly to global soil C stocks. Their remarkable ability to sequester C underlines their integral role in the global C cycle and necessitates accurate representation in Integrated Assessment Models (IAMs) and land use models (LUMs) to leverage their contribution to climate mitigation pathways.

Nevertheless, existing LUMs often lack peatland representation or simplify the complex nature of peatlands by assigning them a fixed grid cell fraction associated with predefined soil attributes. Such a methodology overlooks the fact that soils exhibit a spectrum from mineral to organic types, with the thickness of the organic layer over the mineral soil varying considerably, substantially affecting the total peatland emissions. Moreover, peatland soils are dynamic entities where the thickness of the organic layer and its properties change over time.

The limited scope of the prevailing LUMs fails to satisfactorily capture the wide range of soil types and inherent dynamics characteristic of peatlands. As such, it is imperative to improve the representation of peatland soils in these models, to more accurately simulate these crucial ecosystems. This improvement will facilitate a deeper understanding of their influence on climate dynamics and contribute towards a more comprehensive representation of the global C cycle.

In this study, we introduced modifications to the original soil C dynamics of the RothC model as implemented in the G4M-X model. These changes provide a more realistic representation of organic C and its dynamics within the modified soil layers enhancing the representation of soil organic depth and enabling its representation in the land use model GLOBIOM. We subsequently evaluated these novel developments against data from 216 sites where peatland C measurements were available. The results indicated that the model effectively reproduces the accurate distribution of the soil organic layer at the observed depths. This advancement signifies a substantial step towards understanding the role of peatlands in the global terrestrial C cycle and mitigation efforts.

Role of Forestry in Circular Green Economy

The Scientific Committee - Potpourri session
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Abstract: Science had already accepted Climate Change as one of the major global issues which humanity is facing. Since 1990 world's forest area has shrunk by 178 million ha. Highest rate of net forest losses is recorded in Africa, and South America, but on the brighter side, during the last decade forest area increased in Asia, Oceania and Europe. On the whole total forest carbon stock is decreasing with declining forest area. (GFRA 2020)

In recent years, the concept of circular green economy (CGE) has been emerging as an important intervention that can provide several solutions to climate change through the adoption and changes of various strategies of manufacturing, production systems and consumption patterns.

Economies are being based on the end of waste, reducing environmental damage through smart designing, alternative materials which are less resource consuming, materials use and comprehensive regenerating systems with a closed loop of entire production cycle/system for re-use of basic materials. CGE is based on SDG 12, Sustainable consumption and production. EU Green Deal is a real example towards strengthening steps in this direction.

CGE offers a strong strategy that has the higher-level potential to generate more revenue if applied systematically at the country level as well as the global level to achieve climate change and sustainable development targets. It will strengthen interlinkages between private sectors and government policies and promote the adoption of modern science and data-based concepts in national policies.

The paper sought to explore the following areas of circular economy in the forestry sector
1) Explore the number of viable options/models/designs based on existing literature and case studies to achieve CEG in the production process for various industrial value chains such as Design/models for renewable materials, waste management, functionality, recyclability, circularity, circular business models, and design for long-life use of products by reuse, repair, and refurbishment.
2) Ways to achieve the different components of CGE under various sections of the sectoral and national policies directly related to Indian private as well as government sectors by emphasising the role of the circular green economy (CGE) to achieve sustainable development of forest/ToF sector.

Soil Organic Carbon and Nitrogen Storage Under Different Vegetation Types and Reclamation Treatment on Carboniferous Rocks on Coal Mine Heaps

The Scientific Committee - Potpourri session
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Abstract: Abstract

In this paper, we present the relationship between vegetation type (woodland, forbland, and grassland) and reclamation technique (with topsoil vs. without topsoil and cultivation vs. succession) on soil organic carbon (SOC) and total nitrogen (TN) in developing soils on carboniferous rocks on coal mine heaps. Soil samples were collected from the litter layer (Oi+Oe horizons) and the A horizons (0–10 cm). The results indicate that SOC and TN were significantly affected by vegetation type and reclamation method. Woodland exhibited higher SOC and TN in the Oi+Oe horizons than the other vegetation types. Reclamation with topsoil and cultivation resulted in the highest SOC_{stock} and TN_{stock} values in the A horizons (0–10 cm) under woodland and forbland compared to succession on bare carboniferous rock without topsoil with the same vegetation. In grassland, there was no significant difference in SOC_{stock} under topsoil application and cultivation; however, significantly higher TN_{stock} was observed in areas with 0–10 cm of reclaimed topsoil. Based on the results, topsoil reclamation is recommended to improve SOC accumulation if the mining site is restored using woodland. Conversely, grassland accumulates the same amount of SOC with or without topsoil reclamation. Considering the difficulty of obtaining topsoil, we suggest that grasses are optimal for SOC accumulation at mining sites, followed by forbs.

Keywords: reclamation, topsoil, succession, coal mine, soil organic carbon

Spatial Modelling for Assessment of Sub-tropical Forest Health in World's Oldest Hills Range (Aravalli) India under Changing Climatic Conditions

The Scientific Committee - Potpourri session
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Abstract: In India's semi-arid climatic zone, the Aravalli hills range is an ecotone between the Thar Desert and the Gangetic plain, covering about 10% of the forest cover of Western India. Notably, the upper range of the hills has a high population density; this range has encountered substantial areal transformation in the last five decades. However, we believe that the enhancement of green cover within this range has occurred primarily due to discontinuous degradation within the entire range, without geographical alteration. We use MODIS products to compare and contrast spatiotemporal ecological dynamics between different sub-ranges (upper, middle, and lower) of Aravalli between 2000 and 2021. Specifically, we adopt seven eco-biophysical parameters that include EVI, LAI, PTC, PNTV, ET, NPP, and LST. Also using stationed based rainfall, average temperature, T_{min} and T_{max} as well relative humidity datasets of study period. Pixel-based seasonal time-series trend evaluation for MODIS imagery composite within the GEE platform, using the Ordinary Least Square (OLS) regression method identified that forest enhancement is experienced in some parts of different ranges. We also observed some human-induced factors and natural stressors that could possibly be responsible for forest health dynamics. The results will provide valuable insights into the vulnerability and resilience of these forests to climate change and help inform future conservation and management strategies. Thus, we suggest sustainable planning and policy changes for people who are under anthropocentric stress; this we believe would help management practices.

Spatio-temporal variation in deep soil water use patterns of overstorey and understorey layers in subtropical plantations predicts community assembly

The Scientific Committee - Potpourri session
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Abstract: Deep soil water utilization allows plants to cope with drought stress. Identifying patterns of deep soil water utilization in forest ecosystems has important implications for understanding adaptations to changes in the terrestrial hydrologic cycle and resistance of forests to future expected anomalous droughts and heat waves. However, little is known about the roles of the understorey layers in driving spatio-temporal variations of deep soil water in forests and how the patterns of deep soil water use among life-forms contribute to community assembly processes. We assessed the spatio-temporal patterns and determinants of deep water utilization of tree, shrub and herb layers in subtropical coniferous plantations and investigated associations between deep water use parameters and dominance and richness of understorey vegetation. We found that the understorey layer had a higher reliance on deep soil water in the dry season, a larger seasonal plasticity of deep soil water uptake, but lower spatial variability in deep soil water utilization than the tree layer. We showed that greater reliance of the tree layer on deep soil water was associated with decreased shrub layer diversity, whereas greater reliance of the shrub layer on deep water was associated with increased herb layer diversity. Our results highlight the roles of understorey layers in driving the temporal dynamics of deep soil water in forests and improve our understanding of how deep soil water use patterns among life-forms shape community assembly in forests. Because higher deep water reliance of the tree layer was associated with decreased shrub layer diversity, we hypothesize that regions with modest droughts that reduce the shallow soil water pools may increase the deep soil water utilization of trees thereby decreasing shrub diversity.

Test abstract

The Scientific Committee - Potpourri session
Test Presenter

Abstract:

The carbon balance of a continuous cover forest in relation to clear-cutting forestry

The Scientific Committee - Potpourri session
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Abstract: Today more than 80% of the Swedish forest is managed by clearcutting (CF), with C losses during the clearcut phase. After harvest, it takes 15% of the rotation period before the regrowing forest turns into a C sink on annual basis again. Another 15% pass before the C losses of the clearcut phase are compensated by consecutive C uptake, i.e., before the forest is "C neutral" and becomes a C sink again in the perspective of a rotation period. Consequently, the mean annual C uptake during several rotation periods is ca. 65% of the maximum annual C uptake, i.e., the periodic annual C uptake at the forest's most productive age.

In continuous cover (CCF) forests, on the other hand, no clearcut phase ever leads to C losses. Instead, the C uptake is assumed to be more or less in steady state, with variations caused by periodic selective harvests. Regeneration is mostly natural, with less silvicultural options than in CF. The climate benefits of CCF compared with CF are determined by the mean annual C uptake in relation to the amounts of harvested biomass.

In a pioneering project, we are studying the C balance of a CCF forest in southern Sweden by continuous measurements of ecosystem CO_2 fluxes by the Eddy-covariance technique. The well-documented forest has been managed without clear-cutting for generations, and 10% of the stems are harvested selectively on a decadal basis. During the 4-years project period, one such selective harvest is carried out. First results indicate a large potential C uptake by CCF.

The measured annual C budgets are compared with mean annual C uptake in CF forests, determined by chronosequences. In addition, the maximum annual C uptake of a CF forest in the same geographical region is determined. This provides a solid ground to determine the C sequestration potential of CCF in relation to CF.

Analyzes of soil C and soil respiration in both forest types are used to study C allocation and components of the C balance. Even aspects of biodiversity and C stored in harvested products are considered in the study.

The case of the conservation of the elephant corridors in the Western Ghats in Tamil Nadu, India

The Scientific Committee - Potpourri session

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Abstract: Increasing population, along with the supporting agriculture and infrastructural developments and the rapidly increasing tourism sector have resulted in the fragmentation of the forest habitats in the Western Ghats, especially in the Nilgiris Biosphere Reserve situated in the state of Tamil Nadu in India. This paper specifically focusses on the Singara - Bokkapuram elephant corridor, which falls under the Mudumalai Wildlife Sanctuary, which lies in a crucial location in the Western Ghats connecting the state of Tamil Nadu with Karnataka and Kerala, enabling the movement of wild elephants.

This region, being a tourism-based economy, has been rapidly implementing various infrastructure projects to support the increasing tourist influx. Providing connectivity to the various tourist centers through roads and rails has resulted in the fragmentation of these landscapes imposing a threat on the elephant corridors. Besides, many revenue villages around this corridor depend on them for their resources including cattle grazing, fuel wood collection and collecting other non-timber forest products as well. Such disturbances have resulted in the habitat degradation and have become a major threat these corridors. As a result of all these human interventions, the continuity in such corridors is disturbed and an increase in the cases of human-elephant conflict could be observed.

This paper highlights the risks of these forests not adapting to these conflicts, as the expecations in terms of the role of these forests for different stakeholders is highly divergent. Hence, the conservation of these corridors would require a comprehensive understanding of the social, cultural, ecological and economic factors involved.

The study emphasizes the need for a collaborative and participatory approach to forest management that involves all the stakeholders, including the local communities, government agencies, NGOs, and private sector actors. The paper recommends implementing conservation agreements, sustainable forest management practices ensuring ecological, social and economic sustainability, promoting agroforestry practices, and sustainable tourist activities to ensure the long-term conservation of the Singara - Bokkapuram corridor and other vital forest habitats.

The Comparison of Smallholders' Economic Profitability in the Management of State Forests and Private Forests, Java Island, Indonesia

The Scientific Committee - Potpourri session

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Abstract: Java Island is the most populous island in Indonesia, where population pressure and poverty among the people living around the forest pose challenges to forest management. The state forests are managed using the *tumpangsari* system (*taungya*), in which smallholders have no opportunity to cultivate the land after the annual cropping period ends. While privately-owned forests have disintegrated land management with scattered areas. To compare the economic profitability, the state forest in Ngawi, East Java, and the private forest in Paliyan, Yogyakarta, were selected as areas of interest. In this research, private forests were divided into: 1) *tegalan* (trees along border) and 2) *alas* (woodlots). Focus group discussions with three forest farmer groups for each location were done using the Land-Use Profitability Assessment (LUPA) framework by World Agroforestry (ICRAF). The economic values gained by farmers from the state forests were the lowest, with a net present value (NPV) of 490.51 USD ha^{-1} and an equal annual equivalent (EAE) of 119.98 USD. The gross income was only profitable in years 1-3, then decreased by 54% and 45% in years 4 and 5. In private forests, the *tegalan* had the highest NPV and EAE, 3079.66 USD ha^{-1} and 250.93 USD, respectively, while the alas had an NPV of 2658.04 USD ha^{-1} and an EAE of 216.57 USD. Regarding the workforce in the state forest, *tegalan* and *alas* were; 79, 74, and 12 laborers per year, respectively. The state forests with a *tumpangsari* system have the lowest economic benefits but the highest labor absorption. On the other hand, in the private forests, the *tegalan* has the highest NPV and EAE and has high manpower, while the *alas* is only oriented towards long-term savings. Farming in state forests is seemingly the least profitable compared to private forests. Hence, permanent intercropping using shade-tolerant species after the annual cropping period can be introduced to elevate the income of smallholders in state forests.

The Concept of the Human-Forest Relationship (HFR) – Definition and Potentials for Forest Conflicts Mitigation

The Scientific Committee - Potpourri session

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Abstract: Human attitudes and practices play a major role in forest conflicts. This abstract introduces the concept of human-forest relationship (HFR) and its potential for understanding, mitigating, and resolving forest conflicts.

Individuals, as societal actors, maintain and change the ways forests are perceived, valorized and managed. The HFR concept's potential lies in its ability to identify and describe the processes by which people's forest-related meanings, such as beliefs, emotions, and values, as well as practices are formed. These meanings and practices are a result of people's personal experiences, life and family histories, cultural and societal backgrounds, and the forest that surrounds them.

The HFR is the conceptual approach identifying and describing the roles that forests play in people's daily lives and identities. The concept enables analyzing people's relationships with forests, that is individual meanings and practices attached to forests. It also highlights the reciprocal relation between meanings and practices.

The HFR concept depicts, firstly, what different benefits and functions of forests are valued by whom and, secondly, what decisions and forest management regimes are accepted or opposed and why. Besides past and present forest-related meanings and practices, HFR also possesses the future dimension. Conflicts arise when one's vision or expectation of the current or future state of forests and their affordances are threatened.

In conflict dynamics, the various HFRs – forest related meanings and practices – affect the emergence and escalation of conflict. The HFR concept aims to clarify various drivers and causes for forest conflicts. Knowledge and understanding of the different human-forest relationships offer options for mitigation and resolving of these conflicts.

The effect of afforestation on soil respiration and methane flux at cutaway peatlands

The Scientific Committee - Potpourri session
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Abstract: In Finland, afforestation has been the main after-use for cutaway peatlands, but only a few studies have been conducted on the climate impacts of afforestation. Here, we studied the effect of afforestation on soil carbon dioxide (CO_2) and methane (CH_4) fluxes, litterfall and vegetation C stocks at cutaway peatlands.

The study was conducted at five cutaway peatlands in Central Finland in 2021–2023. CO_2 and CH_4 fluxes were measured with closed chambers from 14 sample plots, along with measurements of water table level (WT) soil temperatures, above ground litterfall, and tree stand C stocks. CO_2 efflux was measured from vegetated and unvegetated points to separate total (Rtot) and heterotrophic (Rhet) respiration. Forest stand age varied from 0-57 years and peat layer thickness from 10 to over 100 cm.

The mean fluxes of Rtot and Rhet varied between 0.15 and 0.59 g m^{-2} h^{-1} and 0.15 and 0.35 g m^{-2} h^{-1}, respectively (2021-2022 data). Soil temperature and forest stand age correlated positively and peat layer thickness negatively with soil respiration. WT did not have significant effect on soil respiration.

The mean CH_4 fluxes from the vegetated points varied between -51.3 and 129.8 µg m^{-2} h^{-1} (2021-2022 data). Forest stand age and peat layer thickness correlated with CH4 flux, whereas WT did not. Non-afforested sample plots acted as methane sources and the sample plots with the more mature forest acted as methane sinks.

Based on this study, afforestation increases soil respiration and decreases methane emissions. However, the suitability of afforestation as an after-use method based on greenhouse gas emissions cannot be concluded based only on these results. Ecosystem level results with litterfall and changes in vegetation C stocks will be amended to the results, to estimate the climate impact of afforestation.

The form of a tree: Strigolactone-deficient tree mutant reveals connection between higher order branching and decreased auxin gradient along main stem

The Scientific Committee - Potpourri session
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Abstract: Due to their long-life span, trees and bushes develop an increasing order of branches in a perennial manner. In contrast to a tall tree, with a clearly defined main stem and branching order, a bush is shorter with a less apparent main stem and branching pattern. To address the developmental basis of these two forms, we studied several naturally occurring architectural variants in birch (*Betula* sp.). Using a forward genetics approach, we identified a bushy *kanttarelli* variant with a loss-of-function mutation in the *BpMAX1* gene required for strigolactone (SL) biosynthesis. While *kanttarelli* is shorter than a wild-type (WT) birch, it still had the same number of primary branches, whereas the number of secondary branches is increased, contributing to the bush-like phenotype. To confirm that the identified mutation was behind the phenotype, we phenocopied the *kanttarelli* mutation in transgenic *BpMAX1::RNAi*birch lines. SL profiling confirmed that both *kanttarelli* and transgenic lines produced very limited SL amounts. Interestingly, the auxin (IAA) distribution along the main stem was different between the WT and a *BpMAX1::RNAi* line. In the WT, the auxin concentration was forming a gradient, being higher in the uppermost internodes and decreasing towards the base of the stem, whereas in the transgenic line this gradient was not observed. Through modelling, we showed that the different IAA distribution pattern may result from the difference in the number of higher order branches and the plant height. Future studies will define whether the IAA gradient itself affects any aspects of plant architecture.

The Integration of Remote Sensing and Field Surveys to Detect Ecologically Damaged Areas for Restoration

The Scientific Committee - Potpourri session

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Abstract: Ecological damage refers to the reduction in the value of the environment due to human activities and natural disasters such as climate change and biological disease. The area where ecological damage mainly occurs is the forest and restoration and management of damage is more important than other ecosystems. If a damaged forest is left unattended, secondary damage such as landslides is highly likely, so it should be restored prior to other ecosystems. The intensity of forest damage is worsening worldwide, and the importance of forest restoration projects at the national level is increasing. However, it is difficult to proceed forest restoration owing to lack of data on location and features of damaged forestry or vegetation species. In the absence of data on damaged forest, policy decision such as restoration prioritization and planning become difficult. In this study, ecologically damaged areas including forest for restoration in South Korea were detected using remote sensing and field surveys. For the analysis, national standardized vector datasets and Google Earth images were used; and field surveys were conducted from 2018 to early 2020. Our results showed that 62% of the ecological damage that occurred in South Korea existed in forest ecosystems; the damaged areas were mostly smaller than 50,000 m2 and most of the causes and types of damage due to human activities such as development were soil erosion related. In addition, the use and role of remote sensing to establish a database of the current status of the illegally damaged area distribution and legally appropriate ecological restoration plan at the national level could be suggested .

The Lauraceae evolution and the regulation of terpenoids biosynthesis

The Scientific Committee - Potpourri session
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Abstract: Plants are capable of synthesizing a vast array of natural small molecule compounds with different structures and functions, including alkaloids, steroids, tannins, flavonoids, and terpenoids, making them excellent 'chemists'. The Lauraceae family, in particular, is abundant in monoterpene compounds such as Linalool, camphor, eucalyptol, borneol, and citral. This family of plants is widely used for its high-value essence and spices, and is known as the 'king of spices'. China is the largest producer and exporter of Lauraceae essential oil raw materials, accounting for approximately 70% of the international market. We present here a chromosome-level assembly of the Litsea cubeba genome, along with low-coverage genomic and transcriptomic data for many other Lauraceae. Phylogenomic analyses show phylogenetic discordance at the position of Magnoliids, suggesting incomplete lineage sorting during the divergence of monocots, eudicots, and Magnoliids. An ancient whole-genome duplication (WGD) event occurred just before the divergence of Laurales and Magnoliales; subsequently, independent WGDs occurred almost simultaneously in the three Lauralean lineages. Comparative genomic analysis revealed that the monoterpene synthase gene family expanded significantly in the Lauraceae during WGD events, providing a genetic basis for the synthesis of its abundant monoterpene compounds. Furthermore, the functional verification of monoterpene synthases in Lauraceae are conducted, which are responsible for the production of specific volatile compounds. We identify TPS18, 22, 25, 42 could synthesis citral, linalool, α-pinene and other major monoterpenes form GPP. The functional differentiation of mono-TPSs, which are key genes for monoterpene skeleton synthesis, determines the diversity of monoterpene compounds. Additionally, this study identifies a Lauraceae-specific citral biosynthesis gene cluster, which includes MYB44 as a regulator and two ADHs as the modified enzyme. This cluster exhibits divergency in Lauraceae. The findings of this study provide insights into the evolution of the Lauraceae and the genetic basis for specific scent evolution.

The Role of Community-Based Resource Management Structures in Forest Landscape Restoration

The Scientific Committee - Potpourri session
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Abstract: Forest Landscape Restoration (FLR) plays a crucial role in averting deforestation, conserving biodiversity, mitigating climate change, and promoting sustainable development by reviving degraded forest ecosystems. As part of Ghana's emission reduction efforts, specific areas have been designated as Hotspot Intervention Areas (HIA) where local structures have been established to promote interventions including FLR. These structures were established to ensure community involvement in decision-making processes related to forest restoration. Such local community involvement in FLR have become important because they create a win-win situation for the environment and the local communities. The success of such FLR efforts however depend on the extent of community acceptance and engagement. The study therefore assessed the extent of representation and information flow within the Community-Based Resource Management (CBRM) structures, local people's perspectives on the CBRM structures and how such perspectives affect forest landscape restoration. These structures were established to ensure community involvement in decision-making processes related to forest restoration. Data were collected through semi-structured interviews and focus group discussions with sixty-two respondents. including members of the Hotspot Management Board, Sub-HIA Executive Committees, Community Resource Management Areas (CREMA), Community Resource Management Committees (CRMCs), and community members in the Juabeso-Bia landscape. Key informants from state institutions and Civil Society Organizations (CSOs) were also interviewed. The study established a multi-dimensional information flow within the CBRM structures, emphasizing the importance of communication across the different levels of governance. Additionally, the study shows the need for gender representation throughout the governance structure. Community members' perceptions of the CBRM structures had evolved from viewing them solely as information dissemination platforms to recognizing CBRM structures as participatory governance mechanisms where their voices are heard in forest landscape restoration. This shift in perception was attributed to the pivotal role of civil society organizations who alongside the forest landscape restoration, provided support to strengthen the community-based resource management structures through sensitization workshops and capacity building programs. The study exemplifies how community members who consider themselves marginalized due to socio-political differences, could sabotage forest landscape restoration activities.

The scale-dependent effect of forest characteristics on grouse occupancy varies the role of the green infrastructure for habitat maintenance

The Scientific Committee - Potpourri session

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Abstract: Maintaining forest habitats for several species requires an integrated planning of the green infrastructure (GI) comprising networks of protected areas with matrix-level management. However, the capacity of the GI to supply habitat may vary at different spatial scales, depending on how its management affects forest characteristics related to the ecological niche of the species. The purpose of our work was to evaluate the impact that the GI has on forest characteristics and how these affect forest grouse occupancy at multiple spatial scales.

To evaluate how grouse occupancy is affected by forest structure, we fitted Generalized Additive Mixed Models (GAMMs) linking the stand-level species presence/absence in the Finnish forests with forest variables related to composition and structure. To evaluate the impact of the GI, on top of the GAMMs we tested how conservation areas and matrix management affected grouse occupancy. The GAMMs were developed separately at each of three spatial scales (local=stand scale, home range=1 km, wildlife triangle =5 km). Occupancy for four forest grouse species (hazel grouse, black grouse, capercaillie, and willow grouse) was modeled using nationwide wildlife triangle census data and stand-level forest variables provided by the Finnish Forestry Centers.

We found that some forest characteristics were invariantly important in predicting occupancy at each scale for all the grouse species. For example, diversity in tree volumes increased grouse occupancy especially at stand and 1-km scales, while mean tree age decreased grouse occupancy mostly at 1-km and 5-km scales. On the other hand, other predictors affected occupancy at different scales in a species-specific way. Protected areas increased grouse occupancy at the regional scale, while matrix management at the stand scale.

In conclusion, our research proves that modeling occupancy with forest variables at different spatial scales can better inform forest managers about the species' potential use of the landscape. The evidence that different elements of the GI affect differently grouse occupancy at different spatial scales calls for a multiscale approach to conservation and management. This finding suggests that management should be applied at the relevant scale to affect forest characteristics improving species occupancy.

The wood anatomical structure between two dated marks reveals periodicity of secondary growth of rainforest species

The Scientific Committee - Potpourri session
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Abstract: In the tropics, specifically in equatorial dense rainforests, xylogenesis is influenced by minimal climatic seasonality, and many tropical trees do not exhibit clear growth rings. This makes it challenging to conduct retrospective analyses and predict future tree performance. This research examines the presence, distinctness, and periodicity of growth rings in dominant tree species in two semi-deciduous rainforests that differ in precipitation patterns. We investigated eighteen tree species common to both forests. Using the cambial marking technique, we verified the presence and periodicity of growth-ring boundaries in the wood produced between marking and collection through microscopic and macroscopic observation. The study found that all eighteen species can form visible growth rings at both sites. However, the periodicity of ring formation varied significantly within and between species, and within sites. Trees from the site with a well-defined dry season were more likely to form periodic growth rings compared to those from the site with less pronounced rainfall seasonality. The distinctness of the formed rings, however, did not depend on the site. Periodic growth-ring formation was more likely in fast-growing trees.

K E Y W O R D S

cambial marking, growth-ring distinctness, periodicity of growth-ring formation, secondary growth, tropical forests

Towards territorial forest-based bioeconomies through value webs from native palms in Colombia

The Scientific Committee - Potpourri session
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Abstract: Colombia is a highly bio- and ethno-diverse country. Its territory contains 314 types of ecosystems that provide habitat to about 76000 species of flora and fauna. Ethnic diversity is represented by 87 indigenous groups and afro-colombians (14% of Colombia's population), who have collective ownership rights of 34% of the national territory, mainly in forest areas. These forest ecosystems cover around 60 million hectares — 52% of total national area — and are highly threatened by deforestation. The dynamics between the on-going societal transition in the post-conflict phase, the imperative of biodiversity conservation and the need of providing fair livelihood options for inhabitants of rural areas indicate a complex social-ecological context. With this background, bioeconomy has emerged as a development pathway fostered by the Green Growth Strategy (2018) and the Bioeconomy Mission (2021), acknowledging the need of a territorial approach and seeing natural wealth as a key upgrading factor. From the about 26000 of identified plant species in Colombia, more than 6000 are used by humans. Most of them have been so far neglected and their sustainable use could be promoted by regulatory frameworks recently implemented, such as the Decree 690 of 2021, which enable the conditions for using Wild Flora and Non-Timber Forest Products (NTFPs). Among plant resources for NTFPs in Colombia, palms (Aracaceae) native to Colombia represent one of the largest plant families, with more than 250 species. Palms are used for multiple purposes mainly by forest-based communities and they are part of the cultural identity across the national territory. Taking palms as case study, we discuss the potential of NTFPs for Colombia's bioeconomy with the imperative of balancing forest conservation and socio-economic development. This requires considering the associated social-ecological relations and the key ecological role of palms in forests. Accordingly, we explore possible pathways for native palms as a source of NTFPs in 'territorial forest-based bioeconomies' in Colombia, integrating their biological, ecological, sociocultural and socioeconomic value in value web systems. We discuss the role of community-based approaches to NTFPs, possible governance strategies and the role of traditional and scientific knowledge towards developing forest-based value webs in Colombian territories.

Trade-off, synergies, and quantification of ecosystems services in Patagonia headstreams: The effect of land use changes.

The Scientific Committee - Potpourri session
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Abstract: Watersheds integrate vegetation, soils, geology, hydrology, and climate, and the watershed concept is fundamental in the management and conservation of the earth's critical zone. Small watersheds where streams of 0-2 order are formed might be assumed as ideally representative and sensitive to the two major drivers of terrestrial landscapes: changes in land use/soils and variability in climate forcing (including climate change). We evaluated small watersheds as potential ecosystem units based on a network of small headwater basins and their streams (2-5 km2; 0-1 order) in western Chilean Patagonia: 12 basins in four groups along a strong climatic gradient (precipitation 700-2000 mm/yr), each group consisting of three land use grades (intact, moderate and high level of intervention). We monitored over 7 years of flows, sediments, and chemistry on the streams and forestry plots on the watershed to quantify several ecosystem functions such as fiber products, water yield, carbon sequestration, soil conservation, and species richness as biodiversity proxy. Through the use of Bayesian networks, we were able to identify variations in ecosystem services, highlighting the effects of land use changes and climate gradients. Furthermore, we observed a range of trade-offs and synergies between these services.

Transcriptome and morpho-physiological analyses reveal factors regulating cone bud differentiation in Qinghai spruce (Picea crassifolia Kom.)

The Scientific Committee - Potpourri session
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Abstract: Coniferous species are mostly monoecious. Their usage in forest plantations is largely limited by the low and unstable yields of seed cones. Gibberellins (GAs) and ethylene are central gender regulators in flowering, although knowledge about their metabolism is limited in conifers. Here, we explore gender determination regulators, especially GA and ethylene metabolism genes, in Qinghai spruce (*Picea crassifolia* Kom.) by transcriptome analysis of female, male and vegetative buds during bud formation and development. Year-round observations were performed to determine the window of bud differentiation. Samples of buds before and after differentiation were collected for RNA sequencing, which showed that the bud gender determination process occurred before the morphological differentiation of female, male and vegetative buds. Sixteen homologs of GA metabolism genes were identified in the transcriptome. Concentrations of GA_1, GA_3, GA_9 and GA_{15} were identified and quantified using ultra-high-performance liquid chromatography high-resolution mass spectrometry (UPLC-HRMS). Furthermore, phylogenetic analysis was performed on 9 putative ACC synthesis (ACS) genes identified in the transcriptomes, and quantitative real-time PCR was conducted to examine gene expression. Our study provides information on GA and ethylene metabolism genes in female, male and vegetative buds during bud differentiation. Overall, fine-tuned regulation of GA metabolism contributes to both the reproductive transition and gender differentiation in this species, whereas ethylene might affect male cone bud formation. The current findings could further our knowledge about the regulatory mechanisms underlying the gender differentiation of cone buds.

Undoing colonial legacies and reversing the trajectory of indigenous tree and forest management in Kenya

The Scientific Committee - Potpourri session
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Abstract: This study points to the decline of indigenous forests and shortage of hardwood timber in Kenya as a systemic problem that has evolved over decades of colonial legacy and undervaluation of the potential of indigenous forests. In pre-colonial times, indigenous forests were managed by indigenous communities. They had their own rules and management systems that guaranteed sustainable use. During the colonial period—after very little research and scanty evidence—indigenous species were declared not suitable for industrial round wood supply. Forestry shifted focus to intensive management of exotic plantations and has remained so post-colonial era—as has the perception that indigenous species cannot be productive.

However, hardwood timber from natural forests was and still is prized for a multitude of commercial and subsistence uses. After rapid deforestation in the early 1980s, commercial use of indigenous species was banned in 1986. This slowed forest loss, but indigenous forests have continued to dwindle in area and quality. Furthermore, there are no policies that promote growth and utilization of indigenous trees; and without any chance for economic gains from planting and maintaining them, communities and farmers do not do so on their own. Though likely well-intentioned and necessary at the time, we believe that the ban on utilization of indigenous species in Kenya is now working against the conservation of natural forests and needs to be updated.

We present our study reviewing the history of Kenya forest policies and identify policy gaps. Through interviews with key government agencies, forest policy experts, private practitioners, wood merchants and agroforestry farming communities, we identify barriers, opportunities and interest in the restoration, management and utilization of indigenous tree species.

This is extremely timely, as large-scale tree-based restoration and climate projects are being funded and implemented in Kenya and around the world. Communities need to be able to benefit from their forests in order to maintain and scale such efforts and achieve the desired benefits for biodiversity, climate, ecosystems and sustainable development. Change in forest policies to promote indigenous species will help Kenya create the enabling conditions necessary to attract international funding for such multi-win initiatives.

Unlocking Opportunities: Bioeconomy-Based Tourism as an Emerging Trend

The Scientific Committee - Potpourri session

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Abstract: Forestry-related tourism is gaining increasing recognition not only in Western societies. People are becoming more aware of the multifaceted importance of forests, not just for ecological value but also for the recreational opportunities and their positive impact on physical and mental well-being. The tourism sector, in general, has witnessed significant growth and has emerged as one of the fastest-growing industries. However, the outbreak of the Covid-19 pandemic has brought about unprecedented disruptions and declines in tourism activities and trends. Paradoxically, the pandemic has also intensified the demand for travel and experiences connected to nature and forests.

In light of the prevailing trends that support the bioeconomy concept, the current period presents a remarkable opportunity to reshape the entire tourism sector in alignment with the principles of the bioeconomy. Nevertheless, it poses a challenge to determine the feasibility and suitable conditions for integrating tourism within the bioeconomy concept.

To explore this issue, research was conducted across selected European Union countries, aiming to represent various geographical regions. The analysis encompassed a total of 12 states and the European Union as a whole, with variations observed in terms of their approach to the bioeconomy and the adoption of their own bioeconomy strategies. Based on the extent of emphasis on tourism in the examined documents, the states were categorized into three groups. Despite the variations, it is evident that tourism is acknowledged within the bioeconomy strategies of the countries.

Bioeconomy-based tourism has emerged as a novel concept that aligns with the principles of the bioeconomy approach. The primary focus lies in promoting sustainable tourism practices that effectively integrate economic and environmental considerations. This involves optimizing the utilization of natural resources, minimizing wastage, and fostering economic growth through responsible tourism management.

In conclusion, there is a growing recognition of the significance of forests and nature-related experiences in tourism. The current global circumstances present both challenges and opportunities for integrating tourism within the bioeconomy concept. By embracing sustainable practices, tourism can contribute to the effective utilization of natural resources while supporting economic growth, thereby creating a model that aligns with the principles of the bioeconomy.

Use and Management of Bauhinia thonningii by smallholder farmers in different agro-ecological zones of Northern Ethiopia

The Scientific Committee - Potpourri session

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Abstract: *Bauhinia thonningii* is one of the indigenous leguminous tree species that fix nitrogen and contributes to several medicinal and nutritional values in Africa. The aim of this study was to assess the effect of indigenous knowledge on the use, management, attitude and practices on the conservation of *B. thonningii*. Totally six sub-districts were selected purposely based on the abundance of B. thonningii availability and farmers' utilization practices in the M2 and SM3 of Tselemti district, north western Tigray, Ethiopia. Structured interviews using Open Data Kit, semi-structured interviews with key informants, FGD, field observation, and secondary data sources were used to collect data for the study. Descriptive statistics and compare means by using one-sample t-test were employed to present the quantitative and qualitative variables obtained from the survey. The consumption of fruits (89% and 89%) and seeds (89% and 86%) by livestock were significantly higher than leaves (75% and 78%) in M2 and SM3. The abundance of *B. thonningii* has decreased according to 78% and 67% of respondents in the Warm moist lowlands (M2) and Tepid sub-moist mid highlands (SM3) agroecologies, respectively. The species is used for fodder by most farmers (97.8%) mainly to fill the fodder deficits during times of fodder shortage. Leaves, twigs and pods of *B. thonningii* were reported as edible parts of the plant by cattle, sheep and goats. Fresh leaves and seeds were common forms of feeding by 41% of the respondents in M2 and 47% in SM3 agroecology. The main threats are animal forage, followed by harvesting for fuel wood and charcoal production. The fodder from the species was more preferred by cattle, goats, sheep and camel in both agroecologies. Agricultural crops were cultivated by 67% in M2 and 31% in SM3 of respondents near the plant because of high soil fertility. The plant has a high use value in the study areas evidenced by multiple uses. Therefore, value addition to maximize benefits and enhance conservation, public awareness and community based management activities need to be encouraged. Attention should also be geared towards research and development on various aspects of the plant.

Using the 3PG model to project forest dynamics under different scenarios. An application to the Portuguese production forest using NFI data as input

The Scientific Committee - Potpourri session
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Abstract: The use of process-based models to produce growth and yield predictions is gaining relevance over traditional empirical models. Such models, integrating the main physical, biogeochemical and physiological processes involved in forest growth and development, give a mechanistic description of the interactions between the living plants and their environment and are able to assess the energy balance and the cycling of water, carbon and nutrients within a given ecosystem. This presentation analyses the use of the 3PG model, a simple process-based stand model requiring few parameter values and readily available data as input, to project NFI data. The 3PG model has been parameterized for growth simulation of eucalyptus, maritime pine and cork oak, the 3 most important forest species in Portugal that together occupy 71% of the total forest area. The 3PG model has been implemented in the standsSIM regional simulator and used using a GIS data base with a pixel size compatible with the NFI grids (500x500 m for the phot plots and 2x2 km for the field plots), including a large set of environmental information, including environmental variables and climate scenarios. The simulations based on the present climate were compared with similar simulations based on the existing empirical odels (GLOBULUS, PINASTER and SUBER, respectively for eucalyptus, maritime pine and cork oak) as a bench mark. Different scenarios of forest policy, forest management and climate were prepared and the 3PG model under the standsSIM simulator used to compare a series of sustainability indicators among the different scenarios.

Utilization of small softwood logs harvested in Western United States forest restoration programs in structural mass timber panels

The Scientific Committee - Potpourri session
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Abstract: Every year, restoration programs in Western United States generate large amounts of low-value small logs of underutilized softwood species. USDA is seeking value-added markets for the material in order to offset high costs of the restoration programs. It is expected that one of such markets may be the engineered wood sector, particularly structural mass timber products such as CLT and glulam. However, visual grades of lumber produced from small logs do not meet benchmark design properties published in US National Design Specifications (NDS) for respective species due to high content of juvenile practically barring them from structural applications. Similarly, it has been uncertain how the fire resistance and char rates of the lumber with substantial juvenile wood content compared to NDS fire performance guidelines. The long-term goal of research conducted at the Oregon State University is to address the barriers. The specific objective of current research is to determine standard NDS design characteristics for lumber processed from small diameter logs harvested in forest restoration programs and develop technologies that would allow utilization of thin and narrow lumber in mass timber products. The presentation will include the conceptual framework of the project, its history, progress and updated outcomes.

Value Chain on Industrial Agroforestry: A Smart Agroforestry Model to Achieve Circular Bioeconomy – Learnings from Tamil Nadu, India

The Scientific Committee - Potpourri session
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Abstract: India in general and the state of Tamil Nadu in particular has witnessed accelerated wood demand which has been estimated to over 70 million MT to meet the raw material requirement of wood-based industries. Forests played a vital role in meeting the industrial raw material requirement; however, with an enactment of Forest Conservation Act (1980), coupled with policy directions through National Forest (2008) and Agroforestry (2014) Policies have stopped the availability of wood from the forest and guided the industries to source the raw material through agro and farm forestry. However, the agroforestry promotion has witnessed wide range of challenges and constraints from the entire Production to Consumption System (PCS). Hence, a value chain on Industrial Agroforestry was conceived and implemented from 2008 till now which resolved the barriers through technological, organizational and marketing interventions. The development and deployment of High Yielding Short Rotation (HYSR) clones, Smart Silviculture and Multifunctional Agroforestry have augmented the productivity levels from 10 m^3 /ha/ annum to the levels of over 30 m^3 /ha/ annum. The introduction of value addition technology has translated agroforestry residues into value-added products thereby addresses the issues of reuse and recycling process and facilitate in augmenting circular bioeconomy. The establishment of Consortium of Industrial Agroforestry has linked all stakeholders involved in the entire PCS system. The introduction of contract farming models ensured buyback and price support system. Above all, the conceptualization and implementation of Agroforestry Incubator extended bioeconomic development through new business enterprises. In a holistic development, the current value chain system act as a smart agroforestry model and created self-reliance in raw material security (80,000 ha in a span of over 10 years), social development (300 man days of employment/ ha), economic development (BCR over 3:1) and environmental amelioration (3.5 mil. ton of Carbon) thereby extent a greater scope of replication across the world.

Vegetation Management Effects on Soil Nutrient Bioavalilability in Contrasting Site Conditions in the Pacific Northwest

The Scientific Committee - Potpourri session
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Abstract: Forest vegetation management (VM) is an integral part of reforestation planning by temporarily reducing the abundance of competing vegetation and allowing seedlings greater access to resources, particularly water, which is critical for seedling growth and survival during the annual summer drought in the Pacific Northwest of the United States (PNW). However, this reduction in abundance of early-seral vegetation may be affecting plant root turnover, soil microorganism abundance and dynamics, and soil nutrient bioavailability, which may impact the capacity of soils to support the projected increase in forest production. Plant Root Simulator (PRS) probes are an effective surrogate for bio-mimicking nutrient absorption by plant roots; they are ion exchange resin membranes held in plastic supports that can be inserted into the soil to measure ion supply *in situ*. To understand the effects of VM on soil nutrient bioavailability, PRS probes were installed in two sites with contrasting environmental conditions in coastal and inland Oregon state. Each site was planted with Douglas-fir seedlings and contains treatment plots with three replicates of eight combinations of VM regimes. Four PRS probe pairs were installed in all no-action control plots and all of the most intensive treatment plots, which includes a pre-planting herbicide application and a post-planting spring release herbicide application during the first and second growing seasons. The PRS probes remained in the soil from April to July of 2022, one year after the last herbicide application at the coastal site and three years after the last herbicide application at the inland site. At the two study sites tested, VM had no effect in reducing soil nutrient availability. However, there was a marginal trend of reducing potassium at both sites. At the coastal site, VM increased the availability of copper and zinc, and had a marginal trend of increasing calcium, sulfur, and most micronutrients. Our results therefore suggest that VM tends to either have little to effect on soil nutrient bioavailability, or may temporarily increase the availability of some macro and micronutrients.

Visualizing forest management and climate scenarios as basis for communication of forest adaptation needs to practitioners and the society

The Scientific Committee - Potpourri session
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Abstract: In the last decade, the direct consequences of climate change for Austria's and Europe's forests have become visible to a frightening extent. Large-scale forest damage caused by bark beetles, more frequent wet snow events, storms and forest fires resulted into new challenges for the forestry sector and dependent wood value chains that were previously unthinkable. With the risks of climate change and the uncertain economic outlook, the motivation of forest owners to participate in forest management is decreasing. This is particularly true for the high number of forest owners that manage small areas of less than 200 ha. In addition, the group of absent forest owners living in urban areas is increasing. Yet, active forest management is urgently needed in order to initiate forest conversion and to adapt forests to future climate conditions.

Forest change and the urgently required management activities including for example the establishment of mixed forests, intensified thinning regimes or assisted migration are difficult to communicate to forest owners and the society as long as no immediate climate change effects are being experienced. Moreover, also the possible economic consequences of forest conversion are difficult to explain. Therefore, forest owners, especially thus with small forest areas, often hesitate to initiate the highly needed adaptation measures.

Here, we introduce a present study, where interactive 3D visualizations were created to communicate the effects of different forest management alternatives and climate scenarios for forest development and the resulting landscape structure. The 3D visualizations are based upon simulations of forest growth and management with the climate sensitive forest growth simulator CALDIS. The simulations provide outputs for a wide range of forest ecosystem services and functions. The project area is the province of Styria in Austria and the data basis for the simulations is the Austrian Forest Inventory and the dynamic site classification of Styria. These visualizations should help to communicate the changes in the forest and which adaptions are necessary. The communication of the model outputs and 3D visualizations are accompanied by various regional events and a wide range of stakeholders from forest management and owner associations.

Vulnerability of the Dry Tropical Forests in Nicaragua's Central American Dry Corridor: Insights from El Tigre-Asososca over a 1200-Year Period

The Scientific Committee - Potpourri session
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Abstract: The Central American Dry Corridor is a region characterized by hydro-climatic variability and dominated by Dry Tropical Forests (DTF). These forests have been highly sensitive to climate variations, such as the Medieval Climate Anomaly and Little Ice Age, as well as pre-Columbian and post-Columbian anthropogenic development. This study examines the vulnerability of DTF ecosystems surrounding El Tigre-Asososca, Nicaragua, over a ~1200-year period. By utilizing proxy analyses of fossil pollen, macroscopic charcoal, and *Sporormiella*, the study reconstructs past vegetation dynamics, burning activities, and herbivorous animal abundance.

Through the integration of multiple proxies, this research provides insights into the historical responses of DTF to climatic fluctuations and anthropogenic disturbances in the El Tigre-Asososca region of Pacific Nicaragua. The findings have important implications for future land management and conservation strategies by identifying the key drivers of change in DTF ecosystems. Considering the impacts of climate variations and anthropogenic activities, the study offers a valuable understanding into the resilience and potential adaptation strategies that can be employed to protect DTF in the face of ongoing climate change and human development in this region.

Wood modification with nano-silica fortified polyvinyl acetate: Enhancing dimensional stability and hardness

The Scientific Committee - Potpourri session
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Abstract: Wood modification with polymeric resins fortified with nanoparticles is a promising technique to enhance the performance of wood. In this study, nano-wood composites (NWC) were prepared from Poplar wood (*Populus deltoides*) using polyvinyl acetate (PVAc) fortified with different concentrations of nano-silica (1, 3 and 5%) following vacuum and pressure method in a closed chamber. The real time tangential swelling and surface hardness (indentation) of the impregnated wood samples were measured using linear voltage displacement transducers (LVDTs) based customized swell-o-meter and Universal timber testing machine (UTM) respectively. The dispersion stability of nano-silica fortified PVAc, microstructures and distribution of nanoparticles and PVAc in the impregnated wood were observed using dynamic light scattering (DLS) technique, scanning electron microscopy and energy dispersive X-ray spectroscopy (SEM-EDX) respectively. Stable dispersions of nano-silica were achieved with polyvinyl acetate having zeta potential of -35 mV. The results showed that addition of nano-silica significantly improved the dimensional stability and surface hardness of the impregnated wood samples. The total tangential swelling was found to be reduced by 35% for the Poplar wood impregnated with PVAc fortified with 5% nano-silica compared to untreated samples. The end and side hardness values were increased by 27% and 33% with PVAc fortified with 5% nano-silica compared to untreated samples. The microstructural analysis revealed that nano-silica particles were uniformly distributed inside the wood microstructures, filled the voids and deposited on the cell wall, resulting in reduced water absorption thereby leading to the improved dimensional stability and enhanced surface hardness of the nano-wood composites. The findings also confirmed that nano-silica can be used to improve the performance of low-quality woods for their possible utilisation in certain value-added applications.

Woody debris volume and nutrient retention following conventional pulpwood and wood pellet feedstock harvests in the southeastern US

The Scientific Committee - Potpourri session
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Abstract: Wood pellets have emerged as an important feedstock for bioenergy fuel production and demand is expected to increase as renewable energy production expands globally. Planted pine (Pinus spp.) stands in the southeastern United States (US) are the major producer of raw material for manufacturing wood pellets, which are predominately being exported to Europe to meet renewable energy goals. Increased utilization of wood pellet feedstock is often sourced from in-woods chips or roundwood, using either pulpwood-sized roundwood or logging residues from harvesting chip-n-saw or sawtimber products, and may be sourced from first thinnings or clearcuts. Harvesting to produce wood for pellet plants may result in more intensive harvesting and less residual debris retained post-harvest. Concerns associated with increased debris removal include changes in post-harvest site characteristics that may affect future growth and the depletion of available organic matter and nutrients over time. This study evaluated 90 recent (<1-yr) operational harvests in the southeastern US to determine residue and nutrient retention and spatial distribution of debris across the sites. Sites were separated by harvest type (e.g., clearcuts, thinnings), and harvest method (e.g., roundwood for pulpwood markets, roundwood for pellet markets, and in-woods chipping for pellet markets). Residual woody material was measured using the planar intersect method and characterized by operation harvest feature (landings, harvest areas, skid trails). Heat maps were used to display the distribution of material and areas of significant reduction. Samples collected for nutrient analysis were categorized by size and decay class. This study is one of the first field-based experiments designed to evaluate the distribution and retention of residual material across wood pellet operations. It is important to delineate the differences in post-harvest site characteristics between conventional and wood pellet operations to develop more efficient resource utilization and to help guide sustainable growth of the bioenergy sector.

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

Ancient forest plant species as indicators of post-agricultural forest regeneration in the Carpathians

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: In the Polish Eastern Carpathians thousands of hectares of agricultural land were abandoned following the displacement of Ukrainian-speaking population in the 1940s, which resulted in widespread reforestation. Therefore, today, large areas of 60-70 years old post-agricultural forests span across the region, interspersed with well-preserved ancient beech forests. In light of the global goal of increasing forest cover**,** investigating forests that developed recently and are mature enough to compare their understory species composition with ancient forests is crucial for the research on regeneration and biodiversity of both existing and future secondary forests.

Our objective was first to map forests developed after 1940s as a result of afforestation or natural succession on abandoned agricultural land in the Polish Eastern Carpathians, and then to assess their regeneration rate based on understory species composition and its comparison with ancient forests. We also aimed to identify environmental variables that affect forest regeneration in mountainous areas. To map post-agricultural forests in the study area we used archival remote sensing data: German Flown Aerial Photography from 1944, Corona satellite images from 1969 and Sentinel-2 satellite images from 2020. Then, on randomly selected 294 forest plots we took phytosociological relevés, hemispherical photographs, and collected soil samples. Based on the analysis of relevés, we compiled a list of ancient forest plant species which was later used to quantify the Forest Maturity Index and the regeneration rate of post-agricultural forests. We also parametrized multiple regression models to find environmental factors that best explain forest regeneration.

We showed that there are 53,800 ha of 60-70 years old post-agricultural forests in the study area, constituting 27.6% of all forests. The results of field investigation revealed 15 understory species (out of 215) meeting the criteria of ancient forest species and 9 species with significantly higher cover and frequency in post-agricultural forests. Our preliminary modeling results demonstrated that regeneration rate decreases with elevation and increases with slope steepness. We currently test our hypothesis that the rate of regeneration decreases with distance from ancient forest.

Close-to-nature forest management in sub-humid Mediterranean mixed forests: description and evaluation of the silvicultural treatments

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: There is a growing need for adaptive forest management strategies that promote forest diversity and complexity and forest resistance and resilience to climate change impacts, while maintaining the system's ecological and economical sustainability. In this sense, silvicultural treatments based on close-to-nature principles were applied in ca. 200 ha of sub-humid Mediterranean mixed forests in Catalonia (N-E Spain). The main goal was to promote trees with the highest economic or ecological value by applying low-intensity selective thinning, while maintaining a mixed and multi-stratified stand structure. In this study, we describe and evaluate the short-term effects of the silvicultural prescriptions conducted in 39 mixed stands of conifers and broad-leaved tree species (e.g., holm and common oak, chestnut, pine, cherry, ash and maple trees). We relied on: (i) 70 permanent sample plots for the evaluation of different indicators (dasometric, understory, biodiversity, vulnerability to fire, etc.); (ii) 9 paired-plots (i.e., 9 managed plots, 9 control plots) for the quantification of the inter-annual tree growth at individual tree level; and (iii) 4 paired-plots for monitoring the intra-annual tree growth with dendrometers and hourly soil water content with FDR sensors. The effect of the treatments on tree growth and soil moisture was investigated by Spearman correlation analyses and mixed-effects models. We observed how a reduction in competition generally showed positive effects on the radial growth of different future crop trees and species and soil water content, despite the treatments were of low intensity. This single-tree selection system, that protects the forest microclimate, had also succeeded in maintaining the stand heterogeneity and diversity by reducing the competition and vulnerability to fires, laying the foundations for the future forest capitalization.

Close-to-nature silviculture worn out? From preserving the status quo to suiting climate change

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: The widely accepted assumption that untouched natural forests are inherently stable and resilient is being challenged by the rapid environmental changes of the 21st century. Close-to-nature silviculture (CNS) seeks to mimic natural forest dynamics by promoting native species suited to specific sites and facilitating natural regeneration. However, the suitability of tree species in the face of shifting environmental conditions raises concerns about maintaining future forest resilience. Empirical observations and model predictions reveal increasing stress on forests, particularly on water-limited soils, leading to recurring episodes of mortality. The slow response of forests to climate change can be attributed to the long lifespan and generation times of trees, as well as asymmetric competition within dense forest stands. Our research underscores the profound influence of disturbance severity and frequency on forest dynamics and highlights the potential for adapting tree species composition accordingly. Large-scale disturbances such as forest fires or windstorms reset the succession process, initiating the development of a novel forest starting from pioneer species. This process can unfold over several decades or centuries, with outcomes heavily dependent on concurrent environmental conditions. Conversely, small-scale disturbances, such as the death of individual trees, prompt the direct ingrowth of surrounding tree species, regardless of prevailing climatic conditions. Forest regeneration in small gaps, driven solely by seed availability or advance regeneration, tends to be subject to the long-term dominance of shade-tolerant climax species such as European Beech. Light-demanding and drought-tolerant "future" species such as oaks, lime, and maples struggle to establish themselves in shaded environments. In Switzerland, CNS practices promote traditional species composition, allowing for limited inclusion of either foreign provenances of native tree species or non-native tree species. While close-to-nature silviculture aims to facilitate natural processes and incremental adaptation, this management approach impedes rapid changes in tree species and hinders forest adaptation to the escalating pace of summer droughts, particularly in Central Europe. In light of increasing hot-droughts during the summer season, we propose an evaluation of a more adaptive CNS approach, which combines natural regeneration of native species with opportunistic tree species, ranging from pioneers to drought-resistant species, with the support of assisted plantations.

Close-to-nature silviculture: a long-standing approach in Romanian forests

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Close-to-nature silviculture, a multifunctional forest management with the target to obtain healthy and stable forests that produce wood (as well as non-wood forest products) with a minimum human intervention, has been traditionally applied in Romanian forests, dominated (68 percent by volume) by broadleaved tree species such as European beech *Fagus sylvatica* (37 percent) and oaks (especially sessile oak *Quercus petraea*, pedunculate oak *Q. robur*, Turkey oak *Q. cerris*, Hungarian oak *Q. frainetto*) (12 per cent). It has included some milestones such as:
- establishment of forests by using silvicultural systems (e.g., single-tree and group selection system, irregular shelterwood system, group shelterwood system) providing the natural regeneration under shelter of main forest species (broadleaves such as European beech, sessile oak, pedunculate oak, Turkey oak, Hungarian oak, as well as conifers like Norway spruce *Picea abies* and silver fir *Abies alba*), mostly in multi-species stands. The structure of such stands is multi-aged/irregular and provides a permanent soil cover;
- small-scale use of clearcutting (only in even-aged and pure Norway spruce, Scots pine (*Pinus sylvestris*) and European larch (*Larix decidua*) stands), the size of cutting area being reduced gradually from maximum 30 hectares in 1953 to maximum 3 hectares nowadays;
- application of low intensity thinning (up to 16 percent by volume), directed to favour the trees showing a good prospect for the future;
- predominant use of native tree species, mostly in mixed stands, and very limited use of non-native tree species (e.g., Douglas-fir *Pseudotsuga menziesii*, northern red oak *Quercus rubra*, black walnut *Juglans nigra*), especially for the enrichment/as supplement of natural stands to add economic revenue.

Obviously, close-to-nature silviculture, even providing many advantages for forest stability, biodiversity, recreation, aesthetics, soil protection, water management, has quite important disadvantages:
- difficult application of uneven-aged forest systems such as single-tree selection system, based on a 10-year cycle of forest inventory and requiring a high density of skidding trails and forest roads as well as skilled staff;
- high level of logging damages to residual stand, soil and young natural regeneration;
- last but not least, a quite strong resistance of field foresters towards a more complicated-to-apply forest management system.

Development of species-specific biomass equations for saltbush (Atriplex nummularia) in the Mediterranean region

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Accurate estimation of the aboveground biomass of shrubs is crucial for the effective conservation and management of Mediterranean ecosystems, particularly under the pressures of climate change and resource scarcity. Generalized biomass equations may not provide an accurate representation of biomass for specific plant species. This pioneering study introduces the first species-specific biomass equations for saltbush (*Atriplex nummularia*) in arid and semi-arid regions where shrubs play a key role in the ecosystem's biomass structure. In this study, we employed a destructive sampling technique on 243 saltbush individuals, focusing on shrubs aged 3, 5, and 7 years. Linear mixed-effects modeling was used for statistical analysis, with shrub height (H, m), basal diameter (D, cm), crown area (Ca, m^2), and age (years) as predictor variables. We found that the most accurate prediction models differed based on the biomass type. For aboveground biomass, D^2H and age were the most effective predictors. Similarly, D^2H and age were the best variables for predicting wood biomass. In contrast, D^2 alone provided the most accurate prediction of leaf biomass. The results suggest that accurately estimating aboveground and wood biomass requires plant size and age metrics, whereas leaf biomass is significantly influenced by basal diameter, demonstrating that distinct factors influence different biomass components. This study emphasizes the need for a management plan that ensures the sustainable and efficient use of natural resources, such as saltbush, over time. While progress has been made in developing biomass equations for saltbush, further research is required to refine and validate these models, considering site-specific conditions and potential climate change effects to improve biomass quantification accuracy.

Effect of aspect and altitudinal gradient on vegetation pattern and carbon storage potential in the western Himalaya

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: The Himalayan Forests are one of the fragile ecosystems that has experienced anthropogenic disruptions, leading to a decline in biodiversity and diminished biomass and carbon stock. Therefore, the study was carried out in the western Himalaya forest of Kandaghat, Solan Forest Division of Himachal Pradesh, India, The study area was divided into three altitudinal ranges, Viz., lower altitude (<1800 m), middle altitude (1800-2100m), and higher altitude (>2100 m), and four aspects (northern, southern, western, and eastern). The objective of the research was to provide a description and analysis of the impact of changes in the arrangement and composition of vegetation across different elevations and aspects. A comprehensive inventory of the flora revealed the presence of 45 distinct plant species, categorised into 13 tree species, 22 shrub species, and 13 herbaceous species, all of which were classified into 33 distinct families. The study further revealed that the tree density was highest (280.49 N ha^{-1}) at the middle altitudinal range on the northern aspect, while the lowest density (119.09 N ha^{-1}) was observed at a higher altitudinal range (>2100m) on the southern aspect. The highest density of shrubs (16,202 N ha^{-1}) and herbs (1,23,574 N ha^{-1}) was observed at a lower altitude on the southern aspect. Furthermore, it was observed that the herbaceous layer exhibited a higher degree of vegetation diversity compared to the shrub layer. This can be attributed to the relatively lower development of the canopy, which allows for ample sunlight to penetrate the ground and facilitate lush growth. The study observed a positive correlation between altitude and solar radiation across all aspects. The study found that the highest tree biomass (161.42 t ha^{-1}), carbon stock (80.71 t C ha^{-1}), and vegetation carbon density (83.47 t C ha^{-1}) were observed on the northern aspect at the middle altitudinal range while shrub biomass (2.56 t ha^{-1}) was highest at lower altitudinal range and herb biomass (3.21 t ha^{-1}) was at middle altitudinal range. Hence, it is imperative to accord significant consideration to altitude and aspect in order to effectively manage biodiversity and alleviate the impact of climate change.

Effect of water and potassium supply on the development and growth of teak plantations in the context of climate change

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: In Togo, teak (*Tectona grandis* L. f.) is the most important plantation species exploited by the government and local communities to meet the demand for timber and other wood products. Due to the lack of genetic enrichment, current plantations exhibit low productivity. Actions have been initiated to improve the genetic material and adapt it to the current production systems in Togo. In this context, the Forest Research Laboratory of the University of Lomé has established a forest station in Zogbépimé since 2015, where new imported teak genotypes such as Taliwas, Luasong, Perlis, and Indian teak are being tested. This study aims to analyze the effect of irrigation and water exclusion in situ on the growth of teak genotypes (Taliwas, Luasong, Perlis) and the effect of potassium supply on the growth of Indian teak trees.

To achieve this, experimental plots were subjected to water supply through irrigation and potassium application during the dry season. Dendrometric characteristics were measured before the treatments in 2020 and subsequently recorded after 12 and 24 months. The results indicate that irrigation and potassium application have a positive effect on the height and diameter growth of teak trees. Between 2021 and 2022, the height increment rates for the control plots ranged from 12.23% ± 6.56 to 19.44% ± 6.42, while for the irrigated plots, it ranged from 14.37% ± 7.43 to 24.20% ± 13.39. The diameter at breast height (DBH) increment rates after 24 months varied from 6.79% ± 5.04 to 22.10% ± 5.97 for the control plots and from 9.24% ± 6.07 to 24.80% ± 10.95 for the irrigated plots. In terms of the plots subjected to potassium application, the height increment rates between 2021 and 2022 were 15.07% ± 8.09 and 10.50% ± 7.36 for the treated and control plots, respectively, and the diameter increment rates were 10% ± 6.94 for the control plots and 12.99% ± 6 for the treated plots.

The results of the three teak provenances introduced in Togo and subjected to irrigation suggest that these provenances could adapt to climate variability. Potassium application significantly improved stand productivity.

Establishment of Colombian Pine (Retrophyllum rospigliosii) Plantations for Ecological Restoration and Carbon Sequestration

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: The Colombian pine (*Retrophyllum rospigliosii*) is a native and endangered coniferous species of the Podocarpaceae family that is of great ecological and economic importance in the Andean region of Colombia as source of timber or non-timber forest products. However, due to a lack of knowledge about its silviculture and management, large-scale propagation of the species in degraded areas has not been possible. This study evaluates various aspects of propagation, silviculture, biomass, and carbon sequestration based on the largest and monitored *R. rospigliosii* plantations established for restoration purposes in Colombia. *R. rospigliosii*restoration plantations were established between 1998 and 1999 in the departments of Antioquia and Cauca and were monitored by Smurfit Kappa-Carton de Colombia and the National Federation of Coffee Growers of Colombia. The evaluation of seed germination was carried out at the University of Cauca (Popayán). The study found that pre-germination treatments, including mechanical scarification plus the application of cytokinin, gibberellic acid, and indole-butyric acid, increased germination percent up to 85% compared to 33% in the control treatment. Early forest fertilization with medium to high levels of nitrogen and phosphorus, without potassium, significantly increased species growth, reaching a volume increase of almost 25% in the long-term compared to control plots. Established *R. rospigliosii* plantations reached relatively low dimensions after 20 years, with an average diameter of 22 cm, height of 18.1 m, and volume of 159.4 m^3 ha^{-1}. The low growth values found were strongly related to the topography of the area (86%, $p<0.05$), since the species is very site-selective, preferring convex and west-facing sites. The allometric equations adjusted to determine biomass and carbon in the plantation showed coefficients of determination greater than 90%, indicating a biomass accumulation of 125 tons ha^{-1} after 20 years, corresponding to a carbon sequestration of 54 ton C ha^{-1} or 194 ton CO2e ha^{-1}. These results summarize the main findings of one of the few long-term monitored experiments using native species for restoration and highlight the potential of *R. rospigliosii* plantations for carbon sequestration and climate change mitigation.

Evaluating tree biomass in continuous-cover Norway spruce stands

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: In Nordic countries even-aged forest management has been the dominant silvicultural practice. Reassessment of the forest management practices is needed because of biodiversity loss and climate change. Ecosystem-based forest management systems have been proposed as alternatives, or complementary practices to the intensive, even-aged forestry. Continuous-cover forestry is suggested to be one of the most promising practices of the ecosystem-based forest management toolbox. The research of continuous-cover forests has been lacking especially from the point-of-view of tree characteristics and wood properties.

Tree biomass models are an efficient way to examine carbon pools and to understand growth and yield of the forest. In our study we evaluate and compare stem biomass of continuous-cover and even-aged forest Norway spruce (*Picea Abies* (L.) H. Karst.) stands. We approach the stem biomass modelling with terrestrial laser scanning (TLS) data and x-ray diffraction measurements to estimate stem density profile of the tree stems. We assess one of the most used biomass models in Finland (Repola 2007). As the model is based on even-aged forests, here we examine the need to re-parametrize the model for continuous-cover forests. Our data from both continuous-cover and even-aged forests allows us to compare tree biomass at tree level and scale it up to stand level.

Our preliminary results show that stem taper between continuous-cover and even-aged forests is not statistically different. We hypothesise that although the stem form was similar the biomass might differ between the two management practices as biomass calculations adds stem density to the model. Previous studies have shown that slow juvenile growth of Norway spruces in understories affects wood density by reducing the lower-density juvenile wood in continuous-cover treatment trees. These results call importance of studies examining how the wood density affect the tree stem biomass and what is the effect of the forest practices to tree biomass.

Evaluating 'close to nature silviculture' for mitigating carbon emissions in the Balsam Fir-White Birch forests in Quebec under climate change

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: The oversimplification of forest structure because of the use of clear-cut harvesting practices over the past decades in Quebec has raised concerns for future forest resilience and carbon dynamics under climate change. Continuous cover silviculture is being explored to improve carbon dynamics (i) by increasing forest resilience under climate change and future disturbances and (ii) by favouring conifer seedling regeneration over thermophilous broadleaf seedlings. This study aims to compare stand carbon and regeneration dynamics between conventional regular structure and irregular continuous-cover practices for both short-and-long terms in the balsam fir-white birch bioclimatic domain of Quebec. We will use the spatially explicit process-based model 'HETEOFOR' to do this. We will then use CBM-CFS3 and its Forest Harvested Wood Products module to track the carbon dynamics from the ecosystem to the harvested wood products. In the short term, we expect that the regeneration of thermophilous broadleaf species will be proportional to the intensity of the partial cuts used in irregular continuous-cover practices. However, with multiple successional rotations and assuming the overstory gap occupancy from remaining trees, it will ultimately favor balsam fir seedlings in the long term. Carbon sequestration (in terms of CO_2-equivalent) is expected to increase in the long term in irregular continuous cover practices over regular clear-cut practices. The carbon storage in wood products is also expected to be higher in continuous cover silviculture because of the advantage of tree selection and considering the wood substitution effect. We further hypothesize that the forest will remain a net carbon sink under continuous cover practices. In contrast, under clear-cut practices, the forest is expected to act as a carbon source for a period starting after each harvest rotation because the microbial decomposition rate of carbon should be much higher compared to the subsequent carbon sequestration rate from trees.

Future of European forests under climate change and close to nature forestry assessed with high resolution resource model

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: European forest are rapidly changing: pressures from climate change and disturbances are increasing, as well as demands for goods and services. Analysing these future trends and where they possibly clash is very important. We gathered detailed NFI plot data and its individual tree measurements, now comprising >300,000 NFI plots and >4 million remeasured trees, thanks to 17 NFIs. For the demand side, we compiled the European Forest Industry Database (EUFID), which encompasses the location and capacity of 6,000 forest industry facilities, categorized into three value-chains: sawmills, pulp and paper, and bioenergy.

We developed the EFISCEN-space model, which now has spatially explicit distribution of timber resources at national forest inventory plot level, including details about the species and diameter composition. We fitted climate dependent tree growth functions, mortality functions and ingrowth functions, as well as litterfall rates and soil carbon models. High resolution (1x1 km) projections of the future carbon balance European forests, soils and harvested wood products under adaptive forest management will be presented, addressing new Regulations from the EU (nature restoration law). Forward looking regimes in which tree species dynamically shift and where forest management takes into account restoration needs and a closer to nature forest management are incorporated. In this way we can analyse and show from regional to EU level, results concerning biodiversity (indicators like dead wood and structure) to a full system carbon balance and level of fulfilling wood demand by assortment. Also the role of industry and how it can adapt to sudden disturbances and availability of wood is analysed.

Growing Grass, Cattle, and Pine Trees All at the Same Space in East Texas, USA

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: East Texas of the United States of America is known for its pine plantations for timber production. Meanwhile, raising cattle or growing grass for livestock is also an important component on the landscape and for the economy. While timberland is beneficial to the environment in terms of soil and water conservation as well as wildlife habitat, it requires substantially initial investment and generates revenue infrequently. On the other hand, pastureland for livestock or forage production yields annual income, but at the cost of soil erosion and water quality degradation. To balance to two, which seem to be conflicting with each other, a practice known as silvopasture is a win-win alternative. It is an agroforestry practice that combines the production of timber and livestock forage on the same land. By diversifying the products and income, the use of land becomes more sustainable while generating revenue and protecting the environment at the same time. Starting 2019, part of the Walter C. Todd Agricultural Research Center of Stephen F. Austin State University near Nacogdoches, Texas was established for silvopasture. Different silvopasture treatments were applied that included converting pasture to silvopasture by planting native grass and pine seedling, converting forest to silvopasture by removing pine trees to create corridors for cattle, and keeping existing pine plantation unthinned as control. This project was partially funded by Natural Resources Conservation Service of US Department of Agriculture the through its Conservation Innovation Grant managed by the Arthur Temple College of Forestry and Agriculture. The site has served as a Silvopasture and Native Grass demonstration area that welcomed more than 120 potential silvopasture producers with on-site tours. A virtual tour of the silvopasture practice was also launched in November 2021. The landscape change over time of this silvopasture site has been monitored through drone surveys. Landowners who may not have farms large enough to dedicate separate areas for timber production and forage production are likely to be most benefited by silvopasture practices.

Implementation of climate-smart practices with bamboo for adaptation and generation of resilience to face climate change in the Amazon Region

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: The Amazon Region, the world's largest humid tropical forest, is renowned for its cultural and biological diversity. With an area of 6.7 million km² shared by eight countries, it supports over 10% of Earth's known species and provides vital ecosystem services to local communities. However, uncontrolled expansion of agriculture, livestock production, mining, and unsustainable practices threaten the region's unique biology and cultures.
Bamboo, utilized in the Americas for thousands of years, presents a sustainable solution for climate change adaptation. The Amazon regions of Colombia, Ecuador, and Peru boast a rich diversity of native bamboos, with 28 reported species. Bamboo can be found in natural forests, plantations, and intermixed with local vegetation. Its cultivation empowers rural populations to develop smart strategies in the face of changing climate patterns.

This study focuses on implementing climate-smart practices with bamboo in the Amazon. In collaboration with 41 communities and associations across Colombia, Ecuador, and Peru, covering 283 hectares, climate-smart practices have been identified and implemented since 2021. These practices include using bamboo for riverbank protection, restoring degraded areas from livestock activities, employing live barriers for slope stabilization, creating wildlife corridors, integrating bamboo into agroforestry and silvopastoral systems, and utilizing bamboo for low-carbon infrastructure.

The adoption of these practices contributes significantly to adaptation and mitigation efforts in the Amazonia region. By harnessing the potential of bamboo, local populations and landowners enhance their resilience to climate change impacts. Moreover, the use of native bamboo species emphasizes the importance of conserving local biodiversity and promoting sustainable practices.

This study demonstrates the viability and effectiveness of bamboo-based climate-smart agriculture in the Amazon Region. The outcomes of this study provide valuable insights for policymakers, land managers, and stakeholders involved in climate change adaptation and sustainable development. By embracing bamboo as a versatile and resilient resource, the Amazon Region can safeguard its unique ecosystems, cultures, and livelihoods in the face of climate challenges.

Keywords: Amazon Region, climate change adaptation, climate-smart practices, bamboo, resilience, sustainable development.

IMPORTANCE OF NATIVE SPECIES FOR ENRICHMENT PLANTING TOWARD CLOSE TO NATURE SILVICULTURE IN TROPICAL RAINFOREST IN INDONESIA

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Tropical rainforest is one of the most species-rich in the terrestrial ecosystem in terms of species richness and endemics that support 18.7% of the world's plant biodiversity. One of the dominant native species in tropical rainforests in Indonesia is the dipterocarps species However, forest degradation has a direct effect to be loss of plant biodiversity, especially increasing the status of dipterocarps become the risk of extinction. One of the methods to rehabilitate secondary tropical rainforest is enrichment strip planting using native species. The native species could be used for enrich and productivity of tropical rain forest what were *Shorea leprosula*, S.platyclados, S.johorensis, S.parvifolia and S.macrophyllal The mean annual diameter increment of those species was 1.7 cm/year (more than 300% of natural regeneration of dipterocarps in tropical rain forest). Enrichment planting with native species offers several advantages, including the conservation of both the species themselves and their genetic diversity, while also adapting to the local environment for mitigation climate change. Furthermore, the practice of enrichment planting holds the potential to increase the standing stock of secondary tropical rainforests and contribute to the conservation of dipterocarp species.

Influence of Tree Attributes on silver fir (Abies alba Mill.) transitioning to higher defoliation classes determined by logistic regression

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Crown defoliation is one of several non-specific indicators of tree vitality and depends on numerous abiotic and biotic factors. In Croatia, the selective management of silver fir (*Abies alba Mill.*) forests may involve pure or mixed stands, which can be affected by various disturbances resulting in unbalanced tree attributes. The aim of this study was to estimate the probability of trees transitioning from one defoliation class to the next, examine the influence of stand structure on that process by comparing two sites with contrasting stand structure, and to analyse the changes in tree defoliation and survival over a 17-year period. In order to estimate the probability that trees are in higher than lower defoliation class, we used logistic regression with binary response, using defoliation classes: healthy 1(<25%), damaged 2(25-60%), severely damaged 3(>60%) as the dependent variable, and DBH (used as a measure of physiological maturity), crown length and crown canopy class as independent variables. Since crown position is categorical (dominant, codominant, intermediate, suppressed) we used dummy variables where the dominant category was taken as the baseline.

We evaluated models for each phase comparison of the dependent variable: level of defoliation class 2 vs. 1 and 3 vs. 2 for trees in 1990. After that, we used the Stuart-Maxwell test to determine whether the distribution of defoliation in 1990 and 2007 differed significantly for the same trees. In order to estimate the probability that trees that were defoliation level 1 or 2 in the year 1990 changed to a higher defoliation level over time, we used logistic regression.

The results showed that Site A had the highest tree mortality due to a disturbed selection structure with a higher ratio of old trees with large DBH. Additionally, DBH was found to be a significant predictor of the probability of trees being higher defoliation class, with a linear trend of increasing probability with increasing DBH. Crown position and height were also found to be significant predictors of defoliation class. When implementing silvicultural treatments, DBH, crown position, and crown properties should be considered, and appropriate forestry measures should be implemented in a timely manner

Landscape forestry in the tropics: moderating between close-to-nature and close-to-people-paradigms?

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Demographic trends, global economic development and climate change are putting tropical ecosystems and societies under extreme pressure with open questions about consequences for biodiversity conservation and human welfare. For a long time, identifying best management practices from close-to-nature silviculture was frequently considered as guideline for forest management. However, even the tried-and-tested principles of stand-based management or species-site match, are being shaken to its foundations by the rapid changes in the natural environment and society. New challenges require new principles. In this talk I will identify and critically discuss existing paradigms of management and tropical silviculture from first a close-to-nature and secondly a close-to-people perspective. Can landscape approaches moderate between these antagonistic poles under the light of global change? This includes questions of how to address spatial and temporal scales at the human-environment interface and how to reconcile forest user needs and practices with societal goals in a changing world. As part of the LaForeT-project (www.la-foret.org) a total of 500 forest inventories and 4000 interviews with households and focus groups of rural communities were carried out in 36 landscapes in Ecuador, Zambia and the Philippines. Based on different case studies from this project potentials and limitations of the landscape forestry concept will be discussed with respective implications for silviculture and forest landscape restoration. In addition, it is discussed whether the panarchy theory can provide an accompanying theoretical framework for both adaptive management and landscape approaches that combine human and natural dimensions.

Large-scale mistletoe inventory on Scots pine in Central Poland

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Mistletoe (*Viscum album* L.) is a semi-parasitic plant and in moderate abundance, it does not pose a lethal threat to a tree. However, recent droughts have made a heavy impact on forests and mistletoe in recent years began to appear on a larger scale in places where it has never been a threat before. The main purpose of this research was to perform a large-scale inventory of the mistletoe in the Kozienice Forest District (Central Poland) for assessing the number of mistletoe on individual trees and in the stands as well as to test a new inventory method adapted to Polish conditions. It is based on random sample plots, each consisting of 15 trees, on which the impact of mistletoe is assessed. On every sample plot the mistletoe occurrence, location in the crown, estimate of the percentage within the crown and the number of mistletoe on a tree are assessed. In addition, for further analysis, information on the stand (forest habitat type, site index) as well as measured trees (age, diameter, Kraft class, crown length, loss of assimilation apparatus, crown type) levels is recorded. For the current analyses, we used 400 sample plots, on which 6000 trees were assessed. Results show that 31% of trees are infected by mistletoe. Over 35% of the infected trees were damaged heavily by more than 6 specimens per single tree.

Lorenze Curve and Gini Index to evaluate the Diametric Distribution in Permanent Plots

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: As part of the process of installing permanent plots carried out by the National Network of Permanent Sampling Plots, plots were installed in Mozambique in Gorongosa National Park and Chimanimani National Park. Therefore, the present work aimed to evaluate the dimetric distribution of tree species in 3 permanent plots using the Lorenz curve and the Gini index. The study was carried out in permanent square plots of 1 ha installed in the Chimanimani National Park (AS01) and Gorongosa National Park (SZ02 and SZ03). To facilitate measurement, the plot was divided into 50 sub-plots of size 20 m x 10 m, where trees with DBH ≥ 10 cm were measured. In the North-South direction, 5 of these sub-plots were systematically selected for the measurement of trees/shrubs with diameters between 5 cm ≥ DBH < 10 cm. For the construction of the Lorenz Curve, the observable values in the data set were ordered in ascending order, and based on the accumulated relative frequency of individuals and diameter. The Gini Index was estimated using the Gini Index Equation. The results showed that in the survey of the tree population, with DBH ≥ 10 cm, there was a higher concentration of individuals in the smallest diameter class. When the diametric interval is increased, the number of trees becomes reduced. Thus, the diametric distribution of the population is continuous and decreasing, concentrating the largest number of trees.ha-¹ in the smallest diameter classes and, therefore, the smallest number of trees.ha-¹ in the largest diametric intervals. Thus, the ecological stability of the population with DBH ≥ 10 is verified. In the three permanent plots, a degree of inequality in the distribution of individuals in certain diametric classes was observed. The Gini Index values were 0.13 for the ASO1 plot, 0.23 for the SZ02 plot and 0.18 for the SZ03 plot. These values represent a smaller diametric inequality of the individuals observed within the three plots.

Keywords: Native Forest, Sampling Plots, Measure of Inequality

Modelling future forest dynamics in Switzerland to support the bioeconomy transition in the construction sector

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Switzerland has an ambitious goal to drastically reduce CO_2 emissions by 2050. In particular, the construction sector has immense potential by substituting carbon-intense material (e.g. concrete and steel) with biomaterials such as wood. However, to investigate the availability of domestic wood to sustain this transition, an assessment of future forest biomass availability as well as tree species composition is needed.

As part of the multidisciplinary project, MainWood, which is aimed at leveraging the transition to a construction bioeconomy across the wood supply chain in Switzerland, we simulate future forest development under anticipated climate scenarios (moderate and strong change) and for various stakeholders' informed management strategies. In addition, we evaluate forest exposure to risks such as fire, windthrow and pest outbreaks.

We select case study regions representing the most important production regions of Switzerland. To assess tree species' climate suitability and growth dynamics, we employ a dynamic process-based model at stand scale (ForClim), which we generalized at the landscape level. The model is initialized using a representative stand type approach, where forest stands are populated with locally adapted individual tree datasets using a novel statistical method based on the fourth Swiss National Forest Inventory.

Our simulations are based on state-of-the-art climate scenarios and different types of forest management scenarios: a "Business-As-Usual" scenario (Swiss close-to-nature and multi-purpose forestry) and alternative stakeholder-informed scenarios, including segregated management approaches (e.g., short-rotation and plantation systems) to meet expected future demand in wood production. We also evaluate how alternative forest management scenarios affect biodiversity, which will require a balance between wood extraction and dead wood remaining in the forest.

We found an increase in forest productivity expected at higher elevations, which however might not benefit the bioeconomy transition due to the difficult and costly harvesting operations in mountainous regions. At lower elevations, forest productivity will decrease, however, in a scenario of assisted migration the strong shift towards a higher proportion of deciduous tree species might counter-balance this loss. This will require the development of new technologies capable of implementing cost-effective construction processes that use new timber engineering products based on a mix of softwood and hardwood species.

Next Generation Forestry - Case Studies from Ghana & the Philippines

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Over the past decade EcoPlanet Bamboo pioneered “close to nature silviculture” in Nicaragua, through an innovative framework restoring some of the most marginal and degraded ex forested lands utilizing a long term strategy with native timber bamboo. The term plantation raises an image of neat rows of monoculture trees, yet the 3,500 hectare successful restoration farms in Nicaragua could not look more different.

EcoPlanet is now expanding this framework through PPP’s with the Government of Ghana and the Philippines on close-to-nature forestry spanning 20,000 hectares of degraded lands. These marginal lands are undergoing restoration into productive ecosystems, proving that next generation forestry is possible, and providing a platform for such integrated restoration forests to become the norm rather than the exception.

Carbon finance allows for a move away from a pure focus on IRR – what has traditionally driven the monoculture plantation forestry industry into its current practices. Select species of sympodial clumping bamboo, with a priority given to native species, are manually interplanted with the aim of protecting and enhancing whatever biodiversity remains. This is complemented by the additional planting of key native tree species at different stages of the restoration pathway.

The result is that just 47% of these 20,000 hectares represnts bamboo while 53% represents biodiversity – a significant increase from the typical 20-30% conservation areas of certified timber plantations. Furthermore, this bamboo is fully integrated amongst remnant forest patches and standing trees, creating a biodiverse forested ecosystem at a landscape scale vs the traditional split between productive and conservation forests.

As a grass ,bamboo benefits from selective annual thinning of individual poles from each bamboo clump, while not affecting either carbon gains, or the permanent canopy cover it provides. This allows a unique scenario of a forest providing vast volumes of deforestation-free biomass without any impact on its long term ecosystem functions and promoting, vs removing biodiversity.

This framework results in a functioning forested ecosystem that moves the paradigm away from monoculture timber plantations and towards one where productive forest species, biodiversity and people can exist in harmony.

Regenerative forestry actions aiming to make Finnish forests increasingly vibrant and diverse

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Metsä Group launched in March 2023 regenerative forestry principles aiming to enhance the state of nature by 2030. Metsä Group is a Finnish forest industry group focusing its operations in Finland providing wood supply and forest services to owner-members of its parent company Metsäliitto Cooperative. Regenerative forestry disconnects the economic growth and biodiversity loss including numerous measures that enhance biodiversity and the resilience of forests as the climate changes.

Regenerative forestry is based on the industrial use of native tree species. The goal is to diversify tree species composition and thus halt biodiversity loss. In forests with a diverse range of species and age classes, competition between species prevents the success of species cause forest damages. As the lack of decaying wood continues to be the most common single cause for the endangerment of forest species, regenerative forestry accelerates the creation of decaying wood. To secure the living conditions of species that inhabit ecologically valuable habitats, special attention is paid for biodiversity hot spots such as herb-rich forests, esker forest habitats and fire habitats. Also, water protection is being developed on peatlands.

Metsä Group Plus, a new forest management model, is one of the key practical measures for achieving targets of regenerative forestry. Under Metsä Group Plus model, more retention trees and high biodiversity stumps are left per hectare of forest during felling than certification systems require. Also the burning of retention trees will be increased and the highest level requirements of buffer zones around waterbodies is implemented. Other actions include sparing sparsely occurring broadleaved trees in wood supply in Finland. Metsä Group also helps to target FSC protection to the most valuable sites for nature through the Habitat Site Service.

The goal is to enhance make Finnish forests increasingly vibrant and diverse by 2030 as part of the strategy of regenerative forestry. The effects of regenerative forestry are measured using the best available information based on science-based data. Metsä Group's forest services are being developed in versatile manner. We are seeking new wide ranging cooperation to enhance biodiversity and to develop measurement of our actions.

Results of forest management for fire prevention on trees' vitality under extreme drought events

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: The mitigation of wildfire impacts in mountain dry conifer forests relies on variable retention harvesting along fuel breaks and understory fuel management, including prescribed burning. However, the current increase in drought events can negatively impact the vitality and survival of the retained trees suddenly exposed to an open forest structure. Indeed, in the last two years extreme drought is affecting Scots pine forests in the southwestern European Alps with an increase of yellowing needles in the top branches already before the start of the growing season. Here we quantify the effects of drought on trees' vitality (tree growth rate, yellow needles percentage, and wood hydraulics) in areas managed for fire prevention with controlled areas using an interdisciplinary approach based on dendrochronology, remote sensing, and wood anatomical analysis. Our preliminary results show that tree vitality is lower in treated areas when compared to controls. Therefore, we must adjust the intensity of thinning to maintain trade-offs between fire hazard mitigation and preserving tree vitality under drought conditions. This study is performed under the project Agritech.

Silvicultural Management for Enhancing Natural Regeneration of climate-vulnerable Abies nephrolepis in Mt. Hwa-ack, Korea

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: This study aims to identify appropriate silvicultural management practices considering the impact of climate change on subalpine evergreen conifer forests to enhance natural regeneration. The practical research site was established in Mt. Hwa-ack in Korea where *Abies nephrolepis* is distributed. *A. nephrolepis* is one of the representative climate-vulnerable species in Korea and is suffering problems with massive dead caused by heat waves and limited natural regeneration (lack of seedlings and ingrowth limitation). Considering species composition, stand structure, and micro-climate conditions (solar radiation, temperature, and relative humidity in the air and temperature and water contents in the soil) in eighteen plots (10m x 10m/plot), the experimental design was conducted. Thinning operations were implemented in November 2022 to control solar radiation conditions on the forest floor. In March 2023, the average seedling mortality in thinned plots (4.6 %) was lower compared to the control plots (7.4 %) with statistical significance ($p<0.05$). While solar radiation is essential for seedling growth, it can also be a limiting factor affecting soil moisture content and contributing to heat waves. Therefore, mid-term monitoring is necessary to assess the effectiveness of the treatment. To evaluate the efficacy of the silvicultural management approach, we're planning to monitor changes in seedling emergence, mortality, growth, and microclimate conditions. The practical outcomes of this research are expected to contribute to the in-situ conservation of vulnerable subalpine conifer forests in Korea.

Silvopastures for ensuring fodder and environmental security in semi arid regions

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Approximately 80% people living in the semi arid zones are dependent on livestock for their livelihood security. However, livestock sector in these regions are facing severe scarcity of quality fodder impacting the livestock productivity negatively in the zone. Thus, ensuring quality fodder supply in the region is very crucial to support local livelihood. Erratic rain fall, continuous drought spells coupled with the poor soil productivity make it difficult to spare agricultural lands in the region for fodder cultivation. Further, there is need to enhance vegetation cover in the region to create carbon dioxide sinks for environmental security as these regions are very sensitive to climate change. Under such scenario, silvopasture systems are sustainable land use option that can be easily established under degraded lands/alternate lands to ensure round the year fodder security and sequester huge amount of carbon dioxide in its biomass. Thus, silvopasture systems established at ICAR-IGFRI, Jhansi, India, consisting of three tree species viz. *Acacia nilotica*, *Ficus infectoria* and *Morus alba* and shrub *Leuceana leucocephala* in combination with two grass species (*Megathyrsus maximus* & *Chrysopogon fulvus*) and a fodder legume *Stylosanthes seabrana* were studied to unravel fodder production and carbon sequestration potential of silvopastures under semi arid conditions. *Megathyrsus maximus* produced higher green fodder biomass (33.07 Mg/ha) followed by *Chrysopogon fulvus* (22.54 Mg/ha) and *Stylosanthes seabrana* (4.62 Mg/ha) with different tree/shrub combinations of silvopastoral systems. Crown lopping (30%) of tree species and pollarding of shrub species produced maximum edible green biomass in *F. infectoria* (5.72 Mg/ha) followed by *L. leucocephala* (5.01 Mg/ha), *A. nilotica* (3.93 t/ha) and *M. alba* (2.87 Mg/ha). At the age of 12 years, total biomass carbon stock (above & below ground) of silvopasture system ranged from 8.56 to 27.74 Mg C/ha with maximum under *A. nilotica* + *C. fulvus* (27.74 Mg C/ha) combination. Thus, establishment of silvopasture systems with suitable tree grass/legume combination in semiarid zone are viable option to ensure fodder as well as environmental security.

Keywords: Silvopasture, fodder security, environmental security, livestock, carbon stock, semi arid region

Technical and financial evaluation of enrichment planting in logging gaps with two high-value timber species in the eastern Amazon

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Enrichment planting in logging gaps is an important silvicultural treatment to promote long-term timber production in tropical forests. Technical and financial information on enrichment planting with wood species of high commercial value in logging gaps is still poor in the literature, which creates uncertainty for decision makers about the method's effectiveness. To contribute to the discussion, this work aimed to technically and financially evaluate enrichment planting with *Swietenia macrophylla* and *Handroanthus serratifolius* in logging gaps of a managed forest in order to serve as a model to recover and increase production of these species in future cutting cycles. An experiment on enrichment planting was established in 46 logging gaps in 2009 with measurements of planted individuals in 2011, 2014, and 2017. A cost-benefit analysis using net present value (NPV) and a sensitivity analysis was carried out on different interest rates (10%, 11% and 12%) from 2023 for the production of roundwood and sawnwood. Eight years after planting, individuals of *Swietenia* and *Handroanthus* presented a diameter at breast height of 7.88 ± 1.41 cm and 5.20 ± 1.00 cm, and a Periodic Annual Increment (PAI) of 0.98 ± 0.38 cm year^{-1} and 0.65 ± 0.22 cm year^{-1}, respectively. At the last measurement, *Swietenia* and *Handroanthus* individuals presented survival percentage of 51% and 24% and mortality rate of 8% and 16% year^{-1}, respectively. NPV was negative for *Swietenia* and *Handroanthus* for both roundwood and sawnwood harvestedat 60 and 90 years. By increasing the PAI by 10% and 20%, the same result is obtained. Despite these results, we believe that the development of credit lines to encourage the planting of high-value species, combined with the generation of carbon credits, can promote the production and conservation of *Swietenia* and *Handronthus* in managed areas and ensure the maintenance of these species extremely threatened in their natural environments.

Keywords: Forestry of gaps, *Swietenia macrophylla*, *Handroanthus serratifolius*, Forest management, Cost-benefit analysis

The Carbon sink potential of arbor forests in China from 2020 to 2100: comparison of different forest management scenarios

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Forests store a large part of carbon and have high carbon sequestration potential, contributing to mitigating climate change. Here, we used three growth models which fit biological characteristics of trees and four National Forest Resources Survey to assess the carbon sink potential of Chinese existing and afforestation forests from 2020 to 2100 under the assumption of afforestation and different forest management scenarios. The results showed that Richard, Hossfeld and Korf provided a good fit for 26 kinds of vegetation biomass with forest age in natural and planted forests. The carbon stock model parameters have been verified with plot survey data. We compare observed data and predicted and find that carbon stocks of Chinese existing arbor forests would be 18.17 Pg in 2100 which has 7.61 Pg in 2020. The carbon sink potential of natural forest (0.129 Pg C/year–0.045 Pg C/year) is much greater than that of planted forests (0.105 Pg C/year–0.018 Pg C/year). Plantation management measures such as tree species replacement can increase carbon sinks in about 20 years. Tree species management for afforestation using tree species with strong carbon sink capacity in existing plantations can significantly increase carbon stocks. Natural forests such as broad-leaved forests, oak, and coniferous and broad-leaved mixed forests in Northeast and Southwest China are contributors to carbon stocks. Artificial forests such as Chinese fir forest, poplar forest and coniferous and broad-leaved mixed forest in central and southern China provide a strong guarantee for forest carbon sequestration due to their rapid growth rate. Overall, our findings will provide valuable guidelines to policymakers for designing strategies of the carbon neutrality target of 2060 with the implementation of effective management strategies for existing forests and expansion of afforestation.

The challenge to regenerate oaks in close-to-nature forestry in Central Europe

S1.1 Close-to-nature silviculture for global change adaptation and mitigation
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Abstract: The establishment of tree regeneration without creating large canopy openings is challenging in close-to-nature forest management (CTNFM) for light-demanding species, for example of the genus *Quercus*. In central Europe, seedlings of *Q. petraea* or *Q. robur* can be quickly overgrown by other, more shade-tolerant tree species if light availability is low. To assess how *Q. petraea* can be successfully regenerated in accordance with CTNFM principles, several studies were conducted.

In an initial literature review, we identified light availability, presence of competing vegetation, oak seedling density, deer browsing, and tending practices as most important factors for success or failure of regeneration. In subsequent studies, we analysed the light environment in 57 shelterwood systems and 51 canopy gaps across Germany, and assessed growth of oak seedlings in relation to light availability and competing vegetation in selected gaps. At all levels of light availability, height growth of oak seedlings was inferior to that of competing tree species such as *Fagus sylvatica* or *Carpinus betulus*. At the same time, early establishment of blackberry had negative effects on oak density and thus regeneration success. The spatial heterogeneity of radiation increased significantly in gaps up to 0.6 ha in size, while it was comparatively low in shelterwoods regardless of stand density. Based on our results, oak regeneration should be initially established at light conditions of 20-30% of radiation in the open, which provides for sufficient height growth in oak seedlings while reducing establishment of blackberry. Once saplings can no longer be overgrown by ground vegetation, radiation should be increased to above 50% to increase the capacity of oak to compete in height growth with companion tree species. This phased establishment can be achieved with shelterwoods in which canopy cover is gradually reduced to regenerate oak dominated stands. For mixed-species stands with groups of oaks, gaps of about 20-30 m diameter are recommended to initiate regeneration. With increasing light requirements of seedlings, gaps need to be expanded to achieve > 50% light in the open. Even with optimal light conditions in the different establishment phases, intensive tending is necessary to promote oak seedlings and saplings.

Thinning in a resprouting forest for climate change adaptation

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: A warming and drying climate in many regions has, and increasingly will, put forest ecosystems under stress and are a challenge for forest management. Concurrently, past management, such as timber harvesting in resprouting forests, have altered stand structure to create dense regrowth, with implications for forest resilience, streamflow, and riparian habitat under projected climatic conditions. One of the main intervention techniques to adjust stand structure is via thinning, which removes stems, and may increase soil moisture, and protect riparian zones and other habitats. Understanding how thinning can help mitigate vulnerability to warming and drying is challenging because it requires consideration of processes that occur on temporal scales from seconds to decades and spatial scales from cells to continents. To overcome this challenge, we integrated multi-scale and multidisciplinary data, including remote sensing, UAV-based LiDAR and multispectral data, ecological stand level data, molecular tools, and social research and outreach. These will help us examine a range of metrics including forest cover, stress, structure, flora, fauna, fungi, fire severity, hydrology, geophysics, fuel loads, compaction, herbicide residues, soil microbiome, carbon, and community perspectives. Results thus far suggest thinned catchments and their riparian zones lose less cover during drought/heatwave events, thinning leads to higher soil compaction on snig tracks and elevated 1hr fuels and coarse woody debris in the short term, depending on the type of thinning operation. An open and transparent quantification of responses to forest thinning is critical for understanding ecological benefits and tradeoffs for each type of thinning method, and for community acceptance of this form of proactive forest management intervention.

Transition from clear-cut based to closer-to-nature forestry clashes with short-term climate goals in Nordic countries

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Boreal forests comprise approximately 45% of the global stock of growing timber. The currently dominant forest management model in northern Europe focuses on growing even-aged, homogeneous stands of a few hectares with a clear-cutting cycle of 80-120 years. This clear-cut based forestry (business as usual, BAU), with its main focus on production, has led to degradation of other important ecosystem services, such as climate regulation, non-timber forest products, recreation, water regulation and purification, maintenance of soil productivity, biodiversity, and air-quality regulation.

Being one of the largest biomes on the planet, boreal forests have enormous potential to mitigate climate change by taking up and holding back carbon from the atmosphere. In order to assess their potential to mitigate climate change, it is mandatory not to look exclusively at the amount of carbon but also for how long this carbon is retained from the atmosphere. This retention time is crucial to compare the avoided radiative damage to the atmosphere of different management strategies.

We developed a novel mass-balanced and process-based compartmental boreal forest management model potentially comprising trees of different ages and species that follows the carbon path from its photosynthetical fixation until its return to the atmosphere by autotrophic or heterotrophic respiration or by wood-product burning. This model allows to assess potential climate change mitigation in terms of avoided radiative damage.

Continuous-cover forestry (as one way of closer-to-nature forestry, CNF) is superior to BAU for most parts of a rotation time of 80 years in terms of climate change mitigation potential. However, during a phase of transitioning from BAU to an established continuous-cover forestry, the climate change mitigation potential decreases. Moreover, this decrease fortifies if starting the transition phase is delayed.

Consequently, a transition from BAU to CNF as envisioned by the EU Forest Strategy 2030 clashes with short-term climate goals of carbon neutrality in Nordic countries (Finland: by 2035, Sweden: by 2045). However, the earlier the transition process starts, the smaller will be its long-term radiative damage to the atmosphere relative to the current business as usual.

Transitioning towards continuous cover forestry: How to sample for precise estimates of sustainability indicators.

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: The even-aged forests stand in Central Europe are threatened by climate change and increasing forest disturbances. To address this issue, forest stands are being transformed into more resistant and resilient mixed continuous cover forests, through changes in forest management. This creates a new challenge that is often ignored: The transition towards more structurally diverse stands implies a reevaluation of the size of forest management units and forest sampling designs. With data from established continuous cover forests, even-aged forests, and forests in transition from even-aged to continuous cover management, that use Fixed Area Plots Sampling and/or Angle Count Sampling with different radii and basal area factors, we cover the majority of European forest management systems and their respective sampling designs. We analysed different forest enterprises and evaluated their forest management systems and forest inventory systems. By doing so, we derived the sampling precision of sustainability indicators in the respective management system, such as increment and changes in stem number per DBH class for continuous cover management. Additionally, using the single-tree growth simulator MOSES, we simulated the transition of even-aged forests to continuous cover forests and analysed the needed changes in the sampling design. Our research yielded hands-on guides for forest managers. These guidelines highlight the essential changes in the size of management units and sampling designs, necessary to reach a certain precision of sustainability indicators in transitioning and continuous cover stands.

WHAT ARE THE IMPACTS OF PARTIAL CUTS ON BOREAL ABOVEGROUND CARBON STOCKS?

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: The boreal biome holds one-third of the world's carbon stock, with two-thirds of its forest being managed. Awareness of the environmental impacts of clear cuts has grown along with interest in exploring more sustainable management practices. As a result, partial cuts have emerged as a promising alternative to clear cuts. Yet, the sustainability of partial cuts from the carbon sequestration point of view is not completely understood. Moreover, the sustainability of partial cuts is questioned due to high post-harvest mortality rates caused by windthrow, and the impact of this natural disturbance on aboveground carbon stock remains unclear. This research aims to evaluate the effect of partial cuts and post-harvest windthrow mortality on mid-term aboveground carbon stocking. We selected 24 jack pine stands in Eastern Canada creating a harvest intensity gradient with control (0%), commercial thinning (30-35%), and shelterwood cut (40-50%) stands. Eight stands were selected for each harvest intensity and one 600 m² plot was installed in each stand. A total of 1056 tree cores (36 cores per plot) were extracted and analyzed using a dendrochronological approach. Harvest was performed 8 to 14 years before the study. Tree carbon stock was calculated using allometric equations. Our analyses revealed that carbon stock was reduced by 26% in commercial thinning and 41% in shelterwood cut treatments compared to control stands. Control stands showed a 0.6% reduction in carbon stocking due to windthrow whereas this proportion reached 2% for commercial thinning and 5% in the case of shelterwood cut. These results suggest that partial cuts reduce the aboveground carbon stocks, and that this reduction increases with increasing harvest intensity. These findings offer crucial insights to better understand the impacts of partial cuts and post-harvest windthrow mortality on boreal carbon balance to guarantee the sustainability of these treatments when implemented in the boreal forest.

Keywords: allometric equations, boreal forest, carbon sequestration, dendrochronology, silviculture, windthrow.

Where is our forest management heading towards? Analysis of the long-term effects of a forest management practices in the Community Forestry of Nepal

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: In Nepal, forest management is protection oriented with the main priority in increasing and maintaining the growing stock volume of the forests. This approach has increased the forest cover successfully, but the timber quantity and quality remain unexplored. Based on longitudinal forest inventory data of permanent sample plots over five time periods, this contribution analysis the change of the forest condition over the last two decades (2005, 2010, 2013, 2016 and 2022) for a Community Forest in the Terai region, focusing on basal increment, in-growth and regeneration. The Community Forest has been largely used for subsistence purpose, where trees basal 13.4 in 2005 to 23.1 m^2 per ha in 2022, however the increment has mostly in large size trees. The number of small size tree (less than 10 cm DBH) per ha decreased in all inventory period whereas elderly tree increased marginally. Furthermore, the condition of the regeneration is poor and even declining. This is primarily due to the practice of grass collection and haphazard harvesting of small the size trees during grass cutting. As establishment new tree is very limited, and diameter classes are dominated by large tree, stand structure does not of reassemble with inverse J shape curve, Hence, forest sustainability remain in questions. This is due to adoption of selective felling where priority is removing trees without considering their species characteristics. There is a need to shift the current forest management approach of the forests, in order to maintain an inverse J shape curve, support a continuous regeneration in the long run and increase the forest structure of the forests.

Keywords
Sustainability, *Shorea robusta*, Kankali, Criteria and Indicator, Transitioning forests, Stand equilibrium

Why do the portfolios of forest management systems vary so much across Europe?

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: Background: To cope with desires for "more of everything" from forest landscapes, and with built-in conflicts among different benefits, actors and stakeholders, one option is to apply different portfolios of forest management systems in different social-ecological contexts. Within the European continent, there is large variation in both the range of desired benefits, and application of different forest management systems.

Aim: The aim of this study is to test the hypothesis that the relative proportions of continuous cover and even-aged forest management systems applied among European regions can be explained by the complex net effect of physical, ecological and social system drivers.

Methods: We apply a comparative approach involving 24 countries. For each country, we collected data about physical variables (e.g., terrain and climate), ecological variables (e.g., life history traits of tree species), and social system variables (e.g., land ownership and types of value chains). We then carried out multivariate analyses to explore patterns in the application of different forest management systems across Europe.

Results: The variables exhibiting most variation were continuous cover forestry, terrain steepness and jobs per forest area. The multivariate analysis explained 74% of the variation in the dataset, with PCA1 (52%) positively related to deciduous tree species and negatively to conifers, and PCA2 (22%) positively related to shade-intolerant, and negatively to shade-tolerant and forest jobs. There were three main clusters of countries, which we summarise as Nordic-Baltic, Central European, and Mediterranean.

Conclusions: Using physical, ecological and social system indicators, the current variation in forest management systems on the European continent could be explained. However, because neither continuous cover nor even-aged forest management systems aiming at maximum sustained yield wood production have capacity to maintain biodiversity and strengthen resilience in the context of climate change, additional forest management systems need to be applied. This includes the emulation of natural forest and cultural woodland dynamics by applying new "closer-to-nature" forest management systems, which need to be complemented with spatial planning that segregates the delivery of different forest ecosystem service benefits.

“Planting conifers and reserving broadleaved tree species” --the “close-to-nature” silviculture in Northeast China

S1.1 Close-to-nature silviculture for global change adaptation and mitigation

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Abstract: The dynamic management approach of “planting conifers and reserving broadleaved tree species” (PCRB) in Northeast China’s temperate forest region was developed for restoring and/or reestablishing near zonal climax, the mixed forest of Korean pine and broadleaved tree species in humid temperate areas in East Asia, from the secondary forest which was derived from the primary forest of it. It is a typical “close-to-nature” silviculture that is combined the two contrasting trends in contemporary silviculture of ecologically-based practices and natural regeneration and technologically-based practices and plantation forestry, because of many of the secondary forest has become the mixed forest by artificially planted Korean pine and naturally regenerated broadleaved leaved tree species. Through or promoting the growth of Korean pine trees and broadleaved trees harmoniously, microspace of individual trees of Korean pine was quantitatively regulated according to Opening Degrees and the morphological development of Korean pine trees was elucidated by long time positioning investigation, and the following results give a sound support for our opinion: (1) the ratio of lower 2 wheel lateral branch base diameter to diameter at breast height (BBD/DBH) could be the indicator of under canopy Korean pine tree light environment, the smaller the better; (2) the response patterns of height, diameter, crown width and individual tree volume of different age-class Korean pine trees to each OP were different, OP=2.0 was significantly better than other two OPs for 30-year-old and 15-year-old Korean pine populations but no certain pattern for that of 9-year-old Korean pine population, especially, the individual volume of Korean pine trees in OP=2.0 were 197% and 113% higher than that of OP=1.0 and 1.5 respectively for 30-year-old population and 212% and 343% for 15-year-old population but no evident changes for 9-year-old population; ten year data of height, diameter and individual volume showed the same patterns; (3) 28.2% Korean trees in OP=2.0 for 30-year-old population has reached to the upper tree canopy height but only 4.1% and 1.1% for other two OPs. Conclusion: The practice of PCRB support that it is true of our recognition of “close-to nature” silviculture.

S1.2 Forest health under climate change and air pollution

Allocation of nutrients and leaf turnover rate in poplar under ambient ozone exposure

S1.2 Forest health under climate change and air pollution

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Abstract: An increase in ozone (O_3) is currently placing plant ecosystems under stress and may adversely affect the nutrient use of plants. Plants may modify leaf turnover rates and nutrient distribution at the organ level to respond to O_3 damage. We explored leaf turnover rate and allocation of primary (C, N, P, K) and secondary macronutrients (Ca, S, Mg) under several O_3 treatments (ambient concentration, AA, with a daily hourly average of 35 ppb; 1.5 x AA; 2.0 x AA) and fertilization levels (N: 0 and 80 kg N ha^{-1} y^{-1}; P: 0 and 80 kg N ha^{-1} y^{-1}) in an O_3 sensitive poplar clone (Oxford: *P. maximowiczii Henry* × *P. berolinensis Dippel*) in a Free-Air Controlled Exposure (FACE) experiment. The results indicate that both fertilization and O_3 had a significant influence on the nutrient content. Specifically, fertilization and O_3 increased foliar C and N contents (+5.8% and +34.2%, respectively) and root Ca and Mg contents (+46.3% and +70.2%, respectively). The leaf turnover rate was faster due to increased O_3 exposure. However, the PCA analysis showed that O_3 fumigation overall affected the allocation of primary and secondary elements. Plants usually try to increase the concentration of certain elements in their cell walls and other components to mitigate the damage caused by high levels of ozone. Consequently, the different displays of element allocation, such as nitrogen (N), in plant leaves in reaction to elevated O_3 levels can have significant ecological implications.

Anthropogenic disturbances and the emergence of native diseases

S1.2 Forest health under climate change and air pollution

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Abstract: Human-induced global changes are significantly altering natural forest ecosystems. Specifically, stressed tree species near the limits of their native ranges and those growing on marginal sites display various signs of poor health. This talk will focus on complex tree diseases (declines) caused by native pathogens and the key environmental drivers contributing to this phenomenon. These systems are frequently complex, with multiple drivers at work. Through four case studies conducted on different continents, we explored the underlying environmental drivers, both direct and indirect, responsible for these decline syndromes. While climate and weather events are commonly associated with forest decline, we discovered that disturbances caused by forest management or changes in land use also play a significant role globally. Changes in land use have directly benefited pathogens such as root rots in the Pyrenees (Spain) or indirectly by making the environment more conducive for canker and foliar diseases in Australia and USA. Shifting our focus towards understanding land-use changes could enhance our comprehension of ongoing decline issues. The coming century will likely witness an unprecedented increase in forest pathogen epidemics, necessitating a proactive rather than reactive approach. Diseases caused by native pathogens with complex aetiologies will become more prevalent, and effectively recognizing, characterizing, and managing these epidemics is challenging because the pathogens are often already widespread, making eradication unfeasible. We must adopt a comprehensive "whole ecosystem" perspective to address these challenges, highlighting the various factors and interconnections involved in forest declines. This approach enables us to tailor management strategies to each unique scenario. The proposed framework outlines six vital questions that need answering to untangle the direct and indirect environmental drivers behind tree declines.

Birch is a model system for acclimation and adaptation of northern forest ecosystems to rapidly changing environment

S1.2 Forest health under climate change and air pollution

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Abstract: Northern forest ecosystems are exposed to rapid environmental change, i.e., climate warming, extended growing seasons, increasing greenhouse gases, and changes in precipitation and water availability, accompanied by increasing pressure of herbivores and pathogens. *Betula* species are important deciduous trees species in the boreal zone, with extensive distribution across Eurasia. Silver birch (*Betula pendula* Roth) is an excellent model system for the adaptation and acclimation of northern trees to climate change due to recent advances in genomics, high genetic variation, and intensive studies with different abiotic and biotic stress factors. The aim of this presentation is to show the current understanding about the responses and acclimation mechanisms of birch species to changing environment in Scandinavia, based on our long-term common garden experiments across Finland and Europe and numerous open-field studies e.g. with elevated temperature, humidity, ozone and CO_2, complemented with novel spectral imaging research approaches. Our studies have shown that warming climate and increasing CO_2 is expected to increase the growth and biomass of birch, but the risk of herbivore damage will increase with negative impact on carbon sink strength. Deleterious impacts of high humidity, soil drought and increasing ozone conditions have been clearly demonstrated. In most studies, major shifts in metabolism as well as in carbon and nutrient balance have been documents, which may have further ecological impacts. However, high plasticity and genotypic variation predict excellent acclimation capacity of birches in a rapidly changing environment and a rich genetic pool for sustainable forestry. We have been able to demonstrate, for example, successful growth and performance of Italian genotypes in Finland and a special adaptation of northern genotypes to continuous summer-time sunlight conditions, i.e. “polar day syndrome”. In addition, birch species have a positive impact on biodiversity especially in mixed tree stands and reforestation areas and therefore deserve more attention in Scandinavian and European tree breeding programmes and silvicultural strategies. More research needed for multiple-stress interactions (e.g. increasing CO_2 x water stress), belowground processes and *B. pubescens,* which is better adapted to northern/subarctic and wet conditions as compared to *B. pendula.*

Can epigenetics help us understand climate-adapted phenotypes?

S1.2 Forest health under climate change and air pollution

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Abstract: Forests and climate are inherently linked, with the earliest documented assertion as far back as the 15th century. Today, our rapidly warming climate threatens the health of forest ecosystems and all the benefits they provide. Plant development is well documented to change in response to a wide range of environmental conditions, including severe examples such as drought stress. These plastic responses can shape phenotypes through underlying genetic variation and/or epigenetic variation (where DNA is modified without changing its sequence). DNA methylation is one such epigenetic mechanism that may be able to 'switch off' gene expression or suppress transposable element insertions by binding to a specific DNA sequence. Resolving the connections of DNA methylation with gene expression, phenotypic plasticity, and fitness in trees will clarify the extent to which epigenetics shapes tree response. This talk investigates DNA methylation and gene expression associated with drought-response phenotypes in a California endemic oak, *Quercus lobata* Née, an emerging model tree system, to provide practical tools for tree conservation. We report an experiment that uses whole genomes, transcriptomes, and methylomes from six families of half-sib progeny to measure response to drought stress. Specifically, we test the hypothesis that DNA methylation affects gene expression and ecophysiological phenotypes differentially between control and water-stress treatments. Early data show that drought stress results in extensive remodelling of tree methylomes, and it is not just important whether DNA methylation has occurred, but *where* and *how much.* We find methylated regions at the start- and stop-sites around genes, and, for some loci, it appears to be strongly and inversely correlated with gene expression. However, we also find a genetic basis for gene expression and ecophysiological response. We discuss the extent to which DNA methylation relative to genetic factors shapes oak response to climate change. In closing, we point out that many forest habitats are currently being restored and replanted with little knowledge of how individual trees will respond to a rapidly warming climate. Thus, a better understanding of the genetic and epigenetic causes of climate-adapted phenotypic response will help develop management strategies to preserve the oak ecosystem health.

Can Norway spruce be vaccinated against fungal infection and insect attack?

S1.2 Forest health under climate change and air pollution

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Abstract: Norway Spruce, *Picea abies*, is a long-lived, coniferous tree that faces many types of biotic stress over its lifetime. Therefore, it has evolved multiple layers of defense to protect itself from pathogenic and insect attacks. This defense system can be enhanced by applying external stimuli such as the natural plant hormone, methyl Jasmonate (MeJA). MeJA can both directly induce and prime tree defenses for future attacks as a cost-effective defense strategy. Studies in 48-year-old and 2-year-old Norway spruce trees show that spraying bark with MeJA resulted in fewer successful bark beetle attacks and reduce the lesion length from blue-stain fungus. This enhance protection may last weeks to years. Investigation of the mechanisms of MeJA-induced resistance (MeJA-IR) showed that MeJA directly induces the formation of traumatic resin ducts. However, accumulation of metabolites, such as terpenes and catechin, and expression of pathogenesis-related (PR) genes show a primed response. Additionally, MeJA alters the expression of epigenetic regulators, especially those associated with RNA-directed DNA methylation, suggesting epigenetic mechanisms are involved in the priming of defense in Norway spruce. We are currently investigating where epigenetic changes occur, how long MeJA-IR persist and how MeJA-IR effects spruce symbioses in order to make MeJA usage more practical in forest management.

Cedrus deodara tree-ring PDSI reconstruction identified monsoon failure in northern Pakistan in the mid-17th century

S1.2 Forest health under climate change and air pollution

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Abstract: As climatic chnages continues, the frequency and intensity of drought are being excerbated by increased temperatures. In norther Pakistan, knowledge of drought variability that extend beyond the instrumental period (ca. befor 1965) is scarce. Here, use tree-ring data from *Cedrus deodara* to provide a 487-yr warm season (Mar-Apr) drought reconstruction back to 1530 AD. The results showed that pluvial conditions were observed during the period occures 1678-1684, 1919-1936, 1947-1951, 1986-1998 and 2003-2010, while the driest periods occured 1544-1560, 1611-1624, 1737-1746, 1661-1666, 1773-1816, 1870-1886 and 1910-1913. The 17th century contained the highest number of extreme drought events (n=17), while the 19th century contained the heighest number of pluvials (n=6); no single wet years was captured after the 1690-1790 AD events. The influence of the Pacific Decadal Oscillation(PDO) and Indian Ocean Heat Content (IOHC) were statistically weak (r=,P<). This might have been the reason for the complete failure of the monsoon, whereas the drought events were more pronounced in the region. The results suggest that the influence of the PDO and IOHC strengthed the monsoon over the Dir mountains and weakened the monsoon over the Chitral Mountains, ehich had drought the 17th century, however the realistic simulationof the monsoon weakening pattern at the regional scale is still a challenge for climate models. New paleoproxy records will allow us to understand future analyses of climate uncertainties, which are highly concerning subjects in regards to current climate change.

Chemical priming of defence in forest health: oak- powdery mildew interaction

S1.2 Forest health under climate change and air pollution

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Abstract: Plants are continually exposed to multiple stresses, currently more frequent in a climate change scenario. However, plants have developed highly sophisticated strategies to face these threats. One strategy is the priming, a sensitisation of plant defence mechanisms. Many chemicals can trigger priming but it is not well studied in oak. This work aims to determine whether oak seedlings can express chemical-induced priming and its potential trade-off in growth. Oak seedlings were treated with salicylic acid (SA), jasmonic acid (JA) and β-aminobutyric acid (BABA) 7 days before infection with *Erysiphe alphitoides*, causal agent of oak powdery mildew (PM), to which seedlings show extremely high vulnerability. Growth presented greater differences after PM infection, generally, BABA-treated plants were smaller. SA and BABA treatments result in enhanced resistance to PM and JA in enhanced susceptibility. Resistance by SA and BABA was exclusively based on priming of SA-dependent gene expression and callose deposition, respectively. To investigate the mechanisms behind specific SA and BABA priming, untargeted metabolome and transcriptome analyses were performed. Green leaves were collected at 0, 1 and 2 days post infection. Metabolites were subjected to LC-MS/MS. Spectra were filtered using XCMS R script and MarVis was employed to putatively identify metabolites and pathways. A total of 272 for SA and 313 for BABA differentially accumulated masses were observed. Pathway enrichment analysis determined that BABA priming is mostly dependent on alkaloids biosynthesis, whereas SA failed to identify any specific pathways. Transcriptome data was analysed using the *Quercus robur* genome as reference (www.oakgenome.fr) with Python (HTSeq) and R scripts (DESeq2). DEG profiling showed similar patterns with some of the metabolite enriched pathways observed. Summarising, we have identified molecular markers of priming in oak seedlings. Our results, in terms of enhanced resistance to PM and early/late responses depending on the chemical applied, provide valuable information to fight pathogens in oak seedlings. Currently, we are testing the effect of putative identified metabolites responsible for priming by BABA and SA. Our results will provide valuable information to fight PM disease in oak seedlings, as it is considered a bottleneck for woodland regeneration.

Climate change impacts on Norway spruce in Eastern Europe: Early warning signals of forest decline

S1.2 Forest health under climate change and air pollution

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Abstract: Climate change is affecting forest ecosystems globally, in particular through warming as well as increases in the frequency and intensity of extreme events. Norway spruce (*Picea abies* (L.) Karst.) is one of the most important coniferous tree species in Europe. In recent extremely dry years in Central Europe, spruce suffered and large dieback has been observed. In Eastern Europe, no decline in spruce has been reported so far, but the anticipated changes in climate pose the question how the future of these forests may look like.

To assess the current state of spruce forests in Eastern Europe, we established a tree-ring network consisting of 157 Norway spruce chronologies of different age distributed along elevational transects in the Eastern Carpathians, Romania. We evaluated early warning signals of climate-change induced stress, i.e. (1) growth decline, (2) increased sensitivity of tree growth (assessed over the statistics first-order autocorrelation and standard deviation), and (3) increased growth synchrony. Furthermore, we used resilience indices to quantify the resistance of trees to extreme climatic events as well as their capacity to recover.

A pronounced growth decline was observed over the last two decades, which was strongest in younger stands and at lower elevations. At high elevations, Norway spruce was found to recover slower after drought events. Overall, our findings highlight an increased vulnerability of spruce in Eastern Europe. With ongoing climate change, high mortality and forest dieback may be expected also in this part of Europe.

Does global warming affect the emergence of new and native forest pathogens?

S1.2 Forest health under climate change and air pollution

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Abstract: Climate change has widespread impacts on ecosystems, which are subject to severe disturbances and become more vulnerable to many biotic and abiotic stressors. Warmer temperatures have been associated with an increased risk of disease development in plants. In addition, increasing temperatures make available new areas to be colonized and make possible pathogens' survival.

In northern latitudes, an increase in temperature (and water from snow and ice melt) should improve plant growth, but may, at the same time, make them more prone to disease. Indeed, under conditions of optimal resource availability, plants tend to allocate energy to growth-related processes rather than differentiation-related processes, which include secondary metabolic events with a general role in defense against pests and pathogens. In addition, milder and wetter climates may be an advantage for some pathogens.

Stresses associated with perturbations induced by global change may predispose plants in natural systems to infection. Conversely, plant pathogens may take advantage of these extreme events. As with other organisms, different pathogens react differently to climate change, meaning that while secondary pathogens are theoretically advantaged by plant stressors, primary pathogens may be frustrated by them.

Here we considered several examples of both introduced and native forest pathogens, analyzed their reaction to changing climatic conditions, and formulated some hypotheses to explain differential results, basing on both host and pathogen ecophysiology.

Effects of timing of budburst on Norway spruce susceptibility to the bark beetle Ips typographus and its fungal symbiont Grosmannia europhioides

S1.2 Forest health under climate change and air pollution

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Abstract: We studied the relationships between defense reactions to a bark beetle-associated bluestain fungus and susceptibility of Norway spruce to bark beetle attacks, to generate understanding of the influence abiotic factors has on the defense capacity in trees in the Swedish Norway spruce breeding program. In Sweden, the drought in 2018 weakened spruce trees and caused a bark beetle outbreak, which is still ongoing. The ongoing climate change is likely to increase the risk for this type of large-scale outbreaks, motivating the need to gain a better understanding of the variation in host defense capacity.

To estimate the potential of spruce's defenses, we have inoculated spruces with bluestain fungus (*Grosmannia europhioides*) and measured the tree's defense reaction at defined intervals in a spruce clone trial in central Sweden during the summer of 2022. We have also studied attacks by the spruce bark beetle (*Ips typographus*) using attack boxes to assess: (1) the necrotic lesions in comparison to the inoculation of the bluestain fungus; (2) the relationship between the defense ability of spruce clones and the ability to produce traumatic resin ducts, and (3) the defense potential of late-budburst of spruce clones vs. earlier-budburst clones.

Early-budburst clones produced significantly smaller necrotic lesions in the phloem following fungal inoculation compared to late-budburst clones. Early-budburst clones also showed a lower proportion of bark beetle attacks in the attack boxes compared to late-budburst clones (31% vs 41%).

In southern and central Sweden, late-budburst spruce clones are recommended (by "plantval"; the web-based tool developed by Skogforsk) in areas with a high risk of late spring frost. As late-budburst clones are more susceptible to attacks by both bark beetles and bluestain fungus than earlier-budburst clones, the earlier budburst clones should be used on sites with a low risk of late spring frost.

Enhancing the assessment of ozone visible foliar injury (O3_VFI): A tool for identifying O3_VFI and its dynamic interaction with stomatal regulation

S1.2 Forest health under climate change and air pollution

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Abstract: Ozone (O_3) is a secondary tropospheric pollutant that exhibits high toxicity to various plant species. Exposure to ambient O_3, and the particular ability of species to absorb gases through the stomatal conductance process, promotes the entry of these pollutants into the leaves. Visible foliar injury (O_3_VFI) can occur in sensitive plant species depending on the duration and level of O_3 to which plants are exposed. In angiosperms, O_3_VFI is indicated by dot-like or confluent whitish to dark-brown stippling associated with interveinal discoloration in the form of bleaching, bronzing, or reddening patterns. These symptoms form gradients of increasing severity basipetal, and their development is prevented by shading. Although O_3_VFI follows a particular development pattern, these symptoms exhibit distinct characteristics among species. The identification of O_3_VFI in various diffuse forest sites throughout Europe must be performed by trained individuals who can identify and quantify such symptoms across a range of species. In this study, we propose a new field assessment tool for O_3_VFI recognition based on the systematic evaluation of color composition based on a large set of pictures taken during five years of field assessment in forest sites in Italy. The color composition related to O_3_VFI in different species was achieved with appropriate software (Photoshop) able to select colors perceptible to the human eye. A color palette was created, which can be highly useful for observers involved in the field identification of O_3_VFI. Furthermore, for the Oxford (*Populus maximowiczii* Henry × *Populus berolinensis* Dippel), a comprehensive evaluation was conducted, correlating the predominant colors distributed in symptomatic leaves with the gas exchange capacity of the species. This analysis confirmed that the degree of damage development is associated with a progressive loss of stomatal movement regulation capacity, known as stomatal sluggishness. This study contributes to the assessment and dissemination of high-quality O3_VFI images, which will be valuable to several observers responsible for monitoring O_3_VFI and for theunderstanding the effects of O_3 on plants' physiological parameters.

Evaluating post-fire recovery of six 2017 summer fires in Sicily with Sentinel-2 time series analysis

S1.2 Forest health under climate change and air pollution

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Abstract: Forest fires are a common disturbance in the Mediterranean Basin, and plant communities native to the area have developed adaptation mechanisms to it. However, the current climate change scenarios with increasing fire regime may pose a challenge for these species. In this study, six fires that occurred in the Region Sicily during summer of 2017 were considered. Sentinel-2 imagery was collected every two months on the areas up to December 2022. The differenced Normalized Burn Ratio (dNBR) index was calculated to define the burn severity in the areas into three levels; then, the Normalized Burn Ratio (NBR) was used to monitor the post-fire vegetation recovery at patch level of the main four forest categories in the burned area, which are *Eucalyptus* spp. reforestation, Mediterranean conifers reforestation, Mediterranean maquis and *Q. ilex* forest. The TIMESAT software has been used to extract seasonal vegetation growth cycle parameters from the time series. A Random Forest model was set up to understand which variables among spectral, climatic and topographic ones had the most impact on the post-fire recovery, or degradation, of the patches. Results showed that the Mediterranean maquis, regardless of severity level, is the forest type that showed the fastest and most evident recovery, followed by the *Q. ilex* forest, then the *Eucalyptus* spp. reforestation and Mediterranean conifers; these latter two categories are also the ones that reported the highest number of patches showing degradation signs up to December 2022. As for the Random Forest model results, pre-fire conditions and fire severity in the patch were the most significant explanatory variables regardless of forest type and recovery level, followed by climatic and eventually topographic ones, apart from the *Q. ilex* forest, for which aspect was the most relevant variable analyzed. The results confirmed that the Mediterranean maquis is the most resilient category among the four considered, but attention should be paid as an increasing fire regime, coupled with climate anomalies such as lack of precipitation and higher temperatures, can generate a homogeneous fire-prone shrubland which can cause landscape degradation.

Exploring non-linearity in Norway Spruce dendroclimatic models in Carpathians

S1.2 Forest health under climate change and air pollution

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Abstract: Decrypting and understanding tree growth response to climate is still a central challenge in tree ring science. Various statistical methods were applied, from linear correlation to machine learning techniques, from frequentist to bayesian approaches or process-based models. The study aimed to evaluate the relationship between tree ring index and seasonal climate parameters (temperature, precipitation and SPEI) using machine learning techniques (Random Forest Analysis - RFA). The dataset consists of a large tree-ring network of 157 Norway spruce chronologies (3012 trees), from managed stands, covering different age classes and distributed along an altitudinal gradient in Eastern Carpathians (Romania). Daily climate data from E-OBS grid data downscale to a high-resolution grid (1 km2) (Moreno and Hasenauer (2016) were aggregated on a seasonal time scale. Raw tree ring widths were detrended using a 30-year cubic spline with a 50% frequency cut-off. To explore the non-linearity of the relationship between tree ring index (TRWI) and seasonal climate, we perform the random forest analysis (RFA) as a multivariate non-parametric regression method. The Increased Mean Square Error (%IMSE) was used as a robust measure of the variable importance. Non-linearity in tree growth response to climate was evaluated using partial dependence plots of RFA. Based on Random Forest analysis, the most important climate variables on Norway spruce radial growth were the drought intensity from the previous autumn and summer. The winter temperature had high relative importance as well (RFA). The differences in growth-climate responses within the altitudinal classes were highlighted. Partial dependence plots from RFA indicate a non-linear relationship between spruce growth and previous autumn temperature as well as the SPEI and the previous summer SPEI. Our preliminary results show that the relationship between Norway Spruce radial growth and climate, in the Eastern Carpathians, is complex and requires future investigations.

Forest health under climate change and its mitigation in Africa

S1.2 Forest health under climate change and air pollution

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Abstract: Over the past decades forest coverage is reducing at annual rate of ca. 3.9 million ha in Africa due to population pressure for settlement and agricultural expansion. Moreover, the ongoing climate changes has impacted the forest sector through longer growing seasons, expansion of insect species ranges, and increased frequency of wildfires. The increase in temperature and rainfall provides a warm and humid environment necessary for rapid multiplication of pests. There is an increasing challenge in Sub-Saharan due to climate change impacts on the pest survival, development, reproduction and spread as well as altering host defenses and susceptibility. The desert locust infestation in Eastern Africa is the most recent example of how climate change can lead to unprecedented damage on crops, grass, shrubs, and trees. In 2019, desert locust has destroyed 70,000 hectares of farmland in Somalia and Ethiopia. This has substantially affected the livelihoods of stallholder farmers and agriculture ecosystem. To alleviate the problem, cross-border surveillance and research collaboration are needed as well as authorities need to produce risk map to guide interventions to effectively control pests' outbreak. The forest ecosystem also plays an important role in maintaining biodiversity, enhancing climate resilience, and providing ecosystem services. Research has shown that increasing tree species richness/diversity of the forest ecosystem can improve tree resistance to insect pest damage. In this review paper, the present knowledge on the impacts of climate change on forests and forest pests and action taken to mitigate the impact in Africa is reviewed and summarized.

Hyperspectral and conventional colour imaging approaches in high-throughput phenotyping of drought responses of Populus tremula

S1.2 Forest health under climate change and air pollution

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Abstract: The application of imaging techniques in forest tree phenotyping allows for non-invasive, high-throughput monitoring of stress-related phenotypic traits, early stress detection, and the selection of tolerant genotypes. This study presents a methodological approach for incorporating a portable, low-cost hyperspectral imaging (HSI) system to the pipeline of an automated high-throughput phenotyping facility for drought stress and recovery monitoring. We acquired hyperspectral and conventional colour (RGB) images of 33 *Populus tremula* genotypes exposed to a four-week drought and a two-week recovery period. Hyperspectral images were analysed with K-means clustering and RGB images with a 25-hue colour segmentation. Classifications based on these two non-invasive imaging techniques were used for early detection and detailed characterization of the drought responses and the progress of recovery. The advantages of HSI compared to RGB imaging were evaluated alongside the benefits of integrating data from two imaging modalities. We found differing responses to drought stress in the *Populus tremula* genotypes studied. The effects of drought stress on *Populus tremula* induced physiological and biochemical changes detected in the growth, photosynthesis and foliar spectral reflectance before it was visible to human eyes, indicating that early-stage markers for assessing plant condition could be developed. Complementary phenotyping approaches can improve the detailed characterisation of phenotypic traits associated with a drought stress response.

IMPACTS OF ENHANCED CO2 ON OAK DEFENCES AGAINST POWDERY MILDEW

S1.2 Forest health under climate change and air pollution

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Abstract: Rising levels of atmospheric Carbon Dioxide (CO_2), have been demonstrated as harmful for environment and human health. Different strategies are in place to mitigate it such as reducing deforestation and increasing forested areas. In the UK, planting strategies include oak species as autochthonous tree species in european forest. However, young oak are highly susceptible to *Erysiphe alphitoides*, the causal agent of oak powdery mildew (PM), which is considered a limiting factor in oak woodland regeneration. Previous work in our group has shown that elevated CO_2 (eCO_2) causes seedlings to become more susceptible to the PM infection, which could have devastating future impacts. However, mature oaks are able to tolerate annual PM infection. We aim to understand how eCO_2 impacts mature oaks and seedlings comparing both experimental systems. For this, monthly leaf samples from mature oak canopy levels were collected from May-September. In parallel, leaves from naturally regenerated seedlings were collected after summer. Leaf-metabolites were subjected to LC-ESI-QTOF-MS/MS. Spectra were filtered using the XCMS R script and MarVis was employed to putatively identify metabolites and pathways. Mature trees showed low differentially expressed metabolites amounts within the same month, however changes occurred gradually over the months also demonstrating highly different patterns of expression between the months where the PM is present from those without, being May and September the extreme profiles corresponding to disease pressure. Comparisons between mature oak trees and an earlier experiment on oak seedlings were performed. Seedling profiles showed unique expression patterns but many of these compound groups are shared between young and mature trees. Putative identified metabolites are majorly related to secondary metabolism, phenylpropanoids and terpenoids, indicating eCO_2 impacts in defence mechanisms.

Mapping Vegetative Stress in Mangroves under the Influence of Climate Change: PRISMA Data Analysis and Insights

S1.2 Forest health under climate change and air pollution

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Abstract: Mangroves are vital ecosystems found in coastal areas worldwide, providing ecological, economic, and social benefits such as coastal protection, biodiversity support, habitat provision, carbon sequestration, water quality maintenance, fisheries support, livelihoods, tourism, recreation, and climate resilience for coastal communities. In Goa, Western Ghats, mangroves play a significant role, inhabiting various coastal locations, including estuaries, creeks, and backwaters. However, like in other regions, mangroves in Goa face threats such as habitat degradation, pollution, urbanization, and unsustainable fishing practices. Conservation efforts are crucial to safeguard these valuable ecosystems, ensuring their ecological functions and benefits to the environment and local communities. This study focuses on identifying and mapping vegetative stress in the mangroves of Goa using time-series hyperspectral PRISMA data and field observations. Different narrow-banded vegetation indices (VIs) affected by vegetation stress will be tested and calculated based on Separability (S) and Coefficient of discrimination (R^2) statistical tests to determine effective vegetation stress indices. The analysis prioritizes stress indices with the highest S and R^2 values for weighted and combined pixels. The resulting weighted combination index will be used to detect and map vegetation stress in mangroves. The findings will be validated by analysing spectral data from healthy and stressed plants in real-world conditions, comparing them to the vegetation stress assessment generated by ENVI software's agriculture stress tool (AST). Furthermore, the study will investigate the factors and drivers contributing to vegetation stress in mangroves in recent years, shedding light on underlying causes such as habitat degradation, pollution, urbanization, or unsustainable fishing practices affecting mangrove health in the Goa region. The developed weighted combination index will be utilized to detect and map vegetation stress, providing spatial information on areas of high stress within the studied mangrove ecosystems. By evaluating the calculated VIs, the study aims to determine the most effective indices for assessing the health and condition of mangroves in the Goa region.

Modeling and Mapping Habitat Suitability of Highland Bamboo under Climate Change in Ethiopia

S1.2 Forest health under climate change and air pollution

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Abstract: Highland bamboo (*Oldeania alpina* formerly *Arundinaria alpina* or *Yushania alpina*) is a species of significant conservation value in Afromontane ecosystems across Africa. It also plays a significant role in the livelihoods of local communities. However, global climate change is anticipated to alter its ecological niche, leading to range shifts and possible habitat contractions. This study aimed to identify potentially suitable habitats for highland bamboo in Ethiopia, determine the resilience of the species under climate change, and establish the environmental factors affecting its habitat. Species distribution modeling (SDM) was implemented in the SDM R package using 231 georeferenced presence records together with climate, topographic, and soil data. To assess climate change risks to the species, predictive models were developed assuming climate scenarios for 2061–2080 under two shared socio-economic pathways (SSPs), namely, SSP2-45 and SSP5-85. The results indicated that highland bamboo mainly grows in high elevation areas with altitudes of 2100–3100 m asl with mean annual temperatures of 11.5–19.3 ºC, annual precipitation of 873–1962 mm, precipitation of the driest quarter of 36–147 mm, soil pH of 5.6, and soil CEC of 30.7 cmolc/kg. The current potentially suitable habitat for this species in Ethiopia was estimated at 61,831.58 km^2, with the majority of habitats being in the southern and southwestern parts of the country. Our models predicted that the suitable habitat will shrink by 13.4% under the SSP5-85 scenario, while potential new suitable areas for this species were identified under the SSP2-45 scenario. Future vulnerable areas were mostly found in central Ethiopia. Based on the predictions, we conclude that most of the suitable habitats for highland bamboo will remain suitable between the years 2061 and 2080.

Optimizing tree density for creating resilient forests with climate change

S1.2 Forest health under climate change and air pollution

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Abstract: International agreements aim at creating forests that are productive, resilient to climate change, and that store carbon to mitigate global warming. These aims are challenged by increased tree mortality rates and decreased tree growth rates in response to increased incidence of drought. The challenge remains to develop forest management systems that increases productivity, resilience and carbon storage of trees and soils under climate change, but the scientific base and management guidelines for this are not yet operational.

Our aim is to quantify the effects of drought and management-controlled tree density on forest productivity, forest resilience, and carbon storage in trees and soils. We hypothesize that such targets can be achieved via controlling stand density using low levels of tree harvest intensity.

We use a multi-site, forest experiment covering 15 plots of >1ha (5 for beech, Scots pine, and Douglas fir, respectively), with 4 stand density treatments (control, 20% trees removed, 80% trees removed and clear-cut) in each plot. We quantified nutrient-, water- and carbon stocks and fluxes by measurements on: nutrient deposition, weathering, leaching and tree removal; water and carbon dynamics in trees and soils using automized sensors systems; responses of the biological soil community (mycorrhizae composition and abundance) and their role in decomposition and carbon storage in soils.

We show how low harvest intensity levels 1) mitigate negative effects of reduced nutrient deposition and increased leaching on forest nutrient budget, 2) favour mycorrhizal communities and their role to soil carbon storage, 3) reduce tree dehydration during dry, hot periods, (4) and improve tree growth and regeneration. These trends are consistent across species, but quantitatively these responses differed across species. We also present a mechanistic 3D forest models that is tested and calibrated and forest experimental data, and aims to integrating, understanding and projecting long-term management implications for forest dynamics under climate change.

Our results imply that a selection forest system with regular low intensity harvest, but without end harvest, creates the most productive, resilient forests for different tree species on poor soils. Model validation for different tree species, soils and climates will be required for application across continental scale.

Ozone as a threat for Northemispheric forests

S1.2 Forest health under climate change and air pollution

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Abstract: Surface ozone (O3) is a threat to forests by decreasing photosynthesis and, consequently, influencing the strength of land carbon sink and the forest productivity. However, due to the lack of continuous surface O3 measurements, observational-based assessments of O3 impacts on forests are largely missing at hemispheric to global scales. Currently, some metrics are used for regulatory purposes by governments or national agencies to protect forests against the negative impacts of ozone: in particular**,** exposure-based metrics, i.e. AOT40, and a new standard POD1, based on ozone uptake by the forests. We analyse here the different air quality standards set or proposed to protect forests from O3 and to evaluate their spatial and temporal consistency while assessing their effectiveness in protecting northern-hemisphere forests. On the basis of the standards, we calculated the expected biomass losses, by the use of appropriated dose-response functions. Then, we compare the results with the information obtained from a complex land surface model (ORCHIDEE). We show how the proposed concentration-based air quality standards substantially overestimate the extension of potential vulnerable regions, predicting that 46% and 61% of the Northern Hemisphere (NH) forested area are at risk of O3 pollution. Conversely, the new proposed standard (POD1) identifies lower extension of vulnerability regions (39.6%). A comparison between expected biomass losses obtained with different standard and ORCHIDEE results were performed. We found in general very low levels of correlation between biomass losses and GPP or biomass losses calculated by ORCHIDEE, but the correlation is dependent by forest type.

OZONE RISK ASSESSMENT IN THE MEDITERRANEAN REGION: PARAMETIZING SOIL MOISTURE LIMITATIONS ON STOMATAL UPTAKE

S1.2 Forest health under climate change and air pollution

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Abstract: Ozone (O_3) can produce several harmful effects, including defoliation of tree crowns, growth decrease or leaf damage that are more related with the stomatal uptake by plants than with the concentration in ambient air. In the Mediterranean region of Europe, where high O_3 concentrations are frequently recorded, soil moisture act as one of the main limiting factors for O_3 stomatal uptake. In agreement with this, O_3 risk assessment methodologies developed in the framework of the UNECE Air Convention are currently based on the phytotoxic O_3 dose (POD_y). Our objective is to parameterize the stomatal response functions to soil moisture to improve the estimation of POD_y under water-limited conditions, particularly in the Mediterranean region. The EMEP MSC-W Chemical Transport Model is using a general soil moisture index (SMI) parameterization to simulate the impact of soil moisture on POD_y. Measured soil moisture at different sites in Italy and Spain and pre-dawn leaf water potential and gas exchange data from scientific literature and field datasets have been used to develop SMI and soil water potential functions for Mediterranean forest and semi-natural vegetation species.
Comparison of modeled and observed SMI shows that it is a suitable index to reflect seasonal and inter-annual variability in soil moisture, but tends to overestimate soil moisture in dry seasons and sites. In consequence, modelled SMI and the standard parameterization resulted in overestimation of POD_y up to 9% and 38% for Holm oak and annual pastures, respectively, compared with calculations using observed soil moisture and species-specific parametrizations at a field site in Spain. Greater variations in POD_y estimation are found when varying the soil moisture monitoring depth. The soil water potential seems to be more suitable for POD_y calculations at the local scale.

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Pest risk survey of Cupressus lusitanica in Rift Valley Ecoregion of Kenya

S1.2 Forest health under climate change and air pollution

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Abstract: Cupressaceae species are a major plantation species in Kenya that were introduced in the early 1900s by British foresters to address timber and wood products shortage in the British protectorate. Among the first species introduced were *Cupressus macrocarpa, Widdringtonia whytei* and *Cupressus torulosa*. The three species have since been abandoned due to pest and disease attack. *Cupressus lusitanica* replaced *C. macrocarpa* which was badly affected by *Monochaetia unicornis* canker which was first reported in the country in 1952. The present study was conducted to identify causes of die-back and death on *C. lusitanica* in the Rift Valley region of Kenya. Fifty six (56) stands of cypress ranging between 3 to 10 hectares (ha) in size were surveyed and disease incidence and severity scored in the dry and wet seasons. The plantations surveyed were also checked for symptoms of insect pest attack. Samples of twigs and seeds of affected trees were collected in sterile khaki packs and preserved in cooler boxes for analysis in the laboratory. No insect pests were recorded in all stands surveyed but disease severity ranged from category 1 (healthy) to 5 (dead). Fungal isolation was carried out using moist chambering and agar methods on 2% malt extract agar (MEA). *Botryosphaeria sp*. 45%, *Pestalotia sp*. 33%, and *Fusarium sp*. 10% were the most commonly isolated fungal species. The identified fungal species were then tested for pathogenicity and developed similar symptoms as those recorded in the field. The fungal species *Botryosphaeria sp.* and *Pestalotia sp*. were re-isolated from the inoculated tree branches. Molecular identification of the fungal species to species level is ongoing. The study identifies a major threat to large scale planting of cypress in the country necessitating selection of resistant varieties of *C. lusitanica* for futuure plantation establishment for timber. Changes in climate have created a major risk of susceptibility to pests and diseases from tree species that were previously thought to be resistant. Continuous monitoring for disease and insect pests attack will identify high risk areas in a timely manner for proactive management and control of tree damage and mortality in plantation forestry.

PESTS AND DISEASES AFFECTING MANGROVE FORESTS: A CASE STUDY OF LAMU AND KILIFI COUNTIES, KENYA

S1.2 Forest health under climate change and air pollution

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Abstract: Mangroves render numerous socio-economic ecosystem services including poles; timber, fruits, medicine, and breeding zones for aquatic creatures. The role of blue forests in climate change mitigation cannot be underrated as they sequester more carbon compared to terrestrial species and help control erosion and ocean winds. Globally, mangroves health is threatened by both biotic and abiotic factors reducing forest cover hence need for this study. From literature, several pathogens including *Ceriospora rhizophorae, Colletotrichum sp., Pestalotiopsis sp., Polystigma sonneratiae Botrosphaeria ribis* have been reported to attack mangroves with little to no data for Kenya. A pest and disease survey was carried out in Lamu and Kilifi mangrove ecosystems to identify pests and diseases affecting mangroves. The study focused on identification, species specificity, occurrences and severity of infestation and infection. Sediment from affected mangroves sites were also analyzed. The surveyed areas were dominated by *S. alba*, *C. tagal*, *R. mucronata*, *A. marina, B. gymnorhiza*, *L. racemosa*, and *X . moluccensis* in mixed or pure stands. From results; *S. alba* was highly infested by the metabellid larvae moth (*Salagena obsolescens*) and wood boring beetle (*Bottegia rubra)* resulting in massive dieback with severity reaching 90% of sampled population. Snail infestation was more prevalent in *A. marina* and *R. mucronata* and very severe (80%) in dry season. Barnacles, bagworms, and lichen infestation were pronounced in *R. mucronata* and *C. tagal* especially the young sapling and planted seedlings resulting. Incidences of *A. marina* infested by crabs was reported. Sediment quality tests showed high levels of nutrients like phosphorus, nitrogen and heavy metals resulting from soil erosion. In conclusion, most pests and diseases were reported in *R. mucronata*, *A. marina* and *S. alba* and therefore more research on epidemiology to avail critical information on their impacts and management as this is a major emerging problem threatening benefits from blue economy and conservation efforts.

Key words: Mangroves, Pests, Diseases, Management, Kenya

Poor host choice in Leptocyte species could be harnessed for protection of Susceptible Eucalyptus plantations

S1.2 Forest health under climate change and air pollution

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Abstract: The productivity of Eucalyptus species outside Australia is threatened by invasive insects such as the thelytokous parthenogenetic galling wasp *Leptocybe invasa* Fisher & LaSalle (Hymenoptera: Eulophidae). Different species and genotypes of eucalypt have shown variability in galling, apparently providing opportunities for selection and improvement of seedlings available to growers. We hypothesized that females will only select, for oviposition, hosts plants that will best support larval survival according to female preference-larval performance hypothesis. The objective of the study was to quantify variability in preference of the wasp and host plant resistance *E. camaldulensis* (29 genotypes representing 7 subspecies).

We investigated host acceptance for oviposition by female wasps in response to young leaves of 29 genotypes (grown under nursery and field conditions) representative of all seven subspecies of Eucalyptus camaldulensis Dehnh. We also carried out studies on wasp galling incidences and intensities in common garden arboreta comprising all the 29 genotypes and planted in different agro-ecological zones suitable for *E. camaldulensis*. These genotypes were planted in Western and Eastern Kenya and allowed to suffer natural infestation in field conditions.

Females of *Leptocybe invasa* showed no apparent discrimination to any of *E. camaldulensis* genotypes and laid eggs on all of them despite variability in their chemical and physical characteristics that were studied. Larval survival however occurred variably in different genotypes with subspecies *simulata* supporting no gall development while subspecies *minima* supported the highest. This indicates that not all genotype accepted for oviposition by female wasps were good host plants to support larval survival.

These results find application in management of the insect in its invaded regions as several *E. camaldulensis* species can be planted together to reduce damage on the susceptible genotypes. Studies should be carried out in other non- galled *Eucalyptus* species to investigate whether they are readily accepted for oviposition.

Key Words: *Leptocybe invasa*, *Eucalyptus camaldulensis*, genotypes, variability, host preference, host resistance.

Productivity of Chir pine (Pinus roxburghii Sargent.) based silvipasture forest ecosystems in relation to fire incidence in north-western Himalaya

S1.2 Forest health under climate change and air pollution

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Abstract: Forests play a crucial role in upholding the livelihoods of local people, environmental conservation and ecological stability. Forest fires have emerged as a prominent natural calamity and pose a significant danger to forest ecosystems worldwide, resulting in substantial biodiversity loss and environmental pollution. The primary factor responsible for the occurrence of forest fires in the western Himalayas is the substantial buildup of Chir pine (*Pinus roxburghii*) needles, which possess high combustibility and consequently contribute to the repeated incidents of fires. Consequently, it is imperative to establish appropriate management protocols to achieve optimal productivity and prevent damage to the pine forest ecosystem caused by wildfires. The present study aimed to evaluate the impact of forest fires on the floristic composition, biomass and carbon density, and soil physico-chemical characteristics across different altitudinal ranges (900-1200 m and 1200-1500 m above mean sea level) in four distinct forest fire zones (high, medium, low and non-fire zones. The findings of the study revealed that the non-fire zone had the highest recorded tree density at both altitudes, while the medium-fire zone had the highest density of shrubs. The tree and shrub species' regeneration pattern in fire zones exhibited the greatest success in the high-fire zone, whereas the medium-fire zone recorded the highest grass productivity (2.23 Mg ha^{-1}). The non-fire zone exhibited the highest tree carbon density (84.29 Mg C ha^{-1}) conversely the high-fire zone displayed the highest under-story carbon (2.35 Mg C ha^{-1}). The non-fire zone exhibited the highest recorded density of ecosystem carbon, reaching a maximum of 142.67 Mg C ha^{-1}. There is a notable variation in soil properties in relation to changes in altitude with medium and low-fire zone found to exhibit higher values of soil parameters. The non-fire zone exhibited the highest carbon management index value, reaching a maximum of 223.95. Overall, the study concludes that it is imperative to implement measures aimed at effectively managing fire in order to preserve biodiversity, reduce carbon dioxide emissions, and regulate the provisioning services of chir pine-dominated forest stands located in the north-western Himalayas.

Suitability of Vangueria infausta (Burch) subsp. rotundata (Robyns) and Berchemia discolor (Klotzsch) Hemsl for Dryland Agroforestry in Kenya

S1.2 Forest health under climate change and air pollution

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Abstract: Agroforestry systems in the drylands have been promoted as a means of increasing socio-economic and landscape productivity in Kenya. However, experiences show that frequent droughts, fungal and insect attacks continue to limit the productivity and development of these systems in East Africa. This is has been shown by the gradual deaths of many exotic tree species used. Therefore, attempts are being made to screen indigenous tree species for use in the drylands. The aim of this study was to assess the suitability of two tree indigenous tree species; *Vangueria rotundata* and *Berchemia discolor* as alternatives for dryland agroforestry in Kenya. The survey assessed the incidence and severity of canker and dieback disease and isolated fungi affecting *V. rotundata* and *B. discolor* in Tiva and Ikanga sites in Kitui County, and Mukange in Makueni County. Fungi were isolated from infected leaves, branches, and twigs of the two tree species using standard isolation techniques on malt extract agar and identified using both conventional and molecular methods. The CTAB method was used to extract the DNA from the fungal isolates followed by PCR amplification and sequencing of the ITS gene region. The resulting sequences were subjected to a nucleotide BLAST search, and the fungi identified by comparing the sequences with closely related sequences in the NCBI database. Fifteen fungal species belonging to seven fungal families *Botryosphaeriaceae, Sporocadaceae*, *Nectriaceae*, *Trichosphaeriaceae*, *Pleosporaceae*, *Diaporthaceae,* and *Glomerellaceae* were identified. Fungi from the *Botryosphaeriaceae* family were the most dominant. A pathogenicity test conducted using *Alanphillipsia aloeigena*, *Lasiodiplodia lignicola*, and *Dothiorella sp*., *f*ungal species from the *Botryosphaeriaceae* family on *V. rotundata, B. discolor,* and selected native agroforestry tree species viz. *Croton megalocarpus* Hutch and *Tamarindus indica* Lam. and *Olea europeae* L. showed that they were the cause of the canker and dieback symptoms. However, pathogenicity was lowest on *B. discolor f*ollowed by *V. rotundata.* The study concluded that these two species were tolerant to the canker and dieback pathogens and therefore are potential candidates for dryland agroforestry in Eastern Kenya drylands.

Thermal buffering of retention forestry in a changing climate: Status, drivers and future ecological applications

S1.2 Forest health under climate change and air pollution

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Abstract: Retention forestry is increasingly adopted as an alternative to clearcutting practices and involves retaining structural and compositional complexity (e.g., living and dead trees) from preharvest to postharvest. Past studies have examined the role of retention forestry in supporting various ecosystem functions and biodiversity, whilst its microclimate buffering capacity has been largely neglected. We investigated the microclimates and the underlying mechanisms of retention forests relative to clearcuts and old forests in a boreal forest landscape in central Sweden. We found that both air temperature and vapour pressure deficit (VPD) differed significantly between the forest types. Old forests consistently exhibited the highest macroclimate buffering capacity, followed by retention forests, while clearcuts displayed the lowest capacity. Basal area and canopy cover were identified as the key determinants influencing air temperature and VPD across the forest types. These microclimate differences were further attributed to differences in tree species diversity, standing and lying dead trees. Maintaining diverse tree species indirectly lowered the stand's maximum temperature via its positive effect on the canopy cover, while large volumes of lying dead trees tended to raise the maximum temperature by negatively impacting basal area and canopy cover. In addition, standing dead trees directly lowered the maximum temperature within forest stands. Finally, edge effects were observed in the retention forests, with south-facing edges experiencing significantly higher maximum temperature and VPD compared to north-facing edges and forest interiors, while reducing the lying dead stems in the south-facing edges can mitigate this edge effect. Our findings support the positive influence of retention practices on a stand's microclimate buffering, achieved through preserving diverse tree species, standing dead stems, and implementing measures to prevent wind-induced tree mortality, particularly in south-facing edges. Forest managers and policy makers can utilize these results to minimize the climate-change impacts on below-canopy biodiversity and ecosystem functioning.

Traits underlying differences in resistance between non-induced and induced Norway spruce emblings and seedlings

S1.2 Forest health under climate change and air pollution

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Abstract: There are various methods to enhance plant resistance and minimize pest damage. In conifers, treatment with methyl jasmonate (MeJA), a stress-signaling plant hormone associated with defence responses, has been found to increase resistance to the pine weevil *Hylobius abietis*, a major forest regeneration pest in Europe. Similarly, studies on Norway spruce (*Picea abies*) plants propagated through somatic embryogenesis (SE), a clonal multiplication process, have also shown increased resistance to the pine weevil when compared to conventional spruce seedlings. In a recent field and lab study examining the combined effects of SE and MeJA, we found that SE-propagated plants (emblings hereafter) treated with MeJA exhibited much greater resistance than plants in each of the separate treatments (SE or MeJA). Remarkably, MeJA-treated emblings experienced an 86% and 48% reduction in damage in the field and lab respectively, and a 98% decrease in mortality in the field, when compared to untreated seedlings. However, the specific mechanisms or traits underlying this response are not known.

Using induced (MeJA and/or mechanical damage) and non-induced 2-year-old Norway spruce, we investigated differences between emblings and seedlings in (1) resin duct number, size and density, and (2) bark terpene chemistry.

Preliminary results indicate that emblings and seedlings indeed exhibit differences, both in resin duct formation as well as terpene chemistry. However, emblings appear to have similar numbers of constitutive resin ducts and a lower number of traumatic resin ducts relative to seedlings. Moreover, emblings tend to have lower concentrations of some terpene compounds relative to seedlings. Further analyses are in progress to uncover other potential differences in resin duct morphology, and pinpoint specific compounds that differ between non-induced and induced emblings and seedlings.

Using satellite imagery to investigate regime shifts in a degraded Miombo woodland in Zambia

S1.2 Forest health under climate change and air pollution

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Abstract: The extensive Miombo woodlands in Zambia and neighbouring countries are threatened by exploitation and climate change, despite their importance for millions of people's livelihoods in southern Africa. Severe droughts make fire disturbances more intense and frequent, which aggravates the ongoing woodland degradation. This can lead to a transition towards an alternative stable state when a critical fire disturbance threshold is reached, i.e. a regime shift. Evidence shows that regime shifts can be anticipated by detecting early-warning signals such as critical slowing down (CSD) in the recovery rates of the vegetation to disturbances such as fires. This study provides empirical evidence for a regime shift that occurred in a highly degraded Miombo woodland site in Zambia, i.e. Katanino Forest Reserve. Based on a combination of field data characterizing the vegetation structure and remote sensing NDVI time series, we demonstrate that a major abrupt shift in vegetation greenness occurred in the study area around 2015 after a prolonged period of intense forest degradation. Further, we show that the regime shift was preceded by CSD in vegetation greenness, quantified here as autocorrelation at-lag-1 trends in NDVI time series. Finally, we identify fire frequency as an ecological driver of the detected regime shift across the study area. Our study is one of the first to combine field with remote sensing data to examine CSD over an entire study area. This type of analysis can provide an important method for restoration practitioners to monitor pending regime shifts and identify ecological drivers of such shifts. Practitioners could use this type of information to adapt their planned restoration interventions to the distance to a pending or a past regime shift, which can ultimately improve restoration program outcomes.

Water availability determines heat stress impacts in temperate broadleaved tree species

S1.2 Forest health under climate change and air pollution

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Abstract: Heat waves and co-occurring droughts are increasing in frequency and magnitude globally. Thus far, our understanding of how common temperate broadleaved trees respond to summer heat and particularly combined heat and drought is limited. Yet broadleaved tree species might become more important for future forest composition in a changing climate. This study explores how three temperate broadleaved tree species *Acer platanoides*, *Quercus robur* and *Fagus sylvatica* respond to increasing temperature under restricted or ample water availability. Using single-tree-chambers, we investigated how leaf temperature, tree carbon and water relations as well as leaf senescence were affected by a step-wise air temperature increase from 25°C to a maximum of 45°C in a well-watered control or drought treatment.

In all species, transpiration increased along air temperature resulting in leaf cooling under well-watered conditions, while leaf temperatures exceeded air temperatures in the drought treatment. With increasing temperatures net assimilation declined while overall root and shoot respiration were maintained. In the drought treatment, respiration already exceeded assimilation at 25°C for *A. platanoides* and *Q. robur*, whereas the control treatments of all species were able to keep a positive net carbon uptake even beyond 40°C air temperature. The negative impact of drought was also visible in higher leaf senescence compared to the control treatment, except for *Q. robur* which did not show signs of leaf damage.

In summary, our findings highlight the critical importance of water availability during heat stress to mitigate high tissue temperatures and sustain a positive net carbon uptake.

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

Adapting choice of species and seed origin to enhance and preserve European forest carbon sink

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The role of European forests as carbon sinks is increasingly endangered by climate change-induced droughts and disturbance events. On the policy level, European Union has an ambitious plan to increase the terrestrial carbon sink and achieve net zero emissions by 2050. Adaptive management strategies such as choice of species and planting materials are therefore crucial for maintaining forest carbon sinks and increasing forest resilience. Assisted migration (AM) of forest tree species and populations was suggested to avoid maladaptation and to maintain forest growth under future climate. We identified AM schemes for seven major European tree species based on 587 range-wide provenance trials, evaluating more than 3000 provenances. Using models that account for environmental and genetic factors of phenotypic trait variations, we estimated the annual aboveground carbon sink (CS) of 40-year-old trees under current and projected future climate by adapting species composition and seed sources.

To increase forest resilience under climate change, coniferous trees might need to be replaced by deciduous trees in large parts of their distribution, with significant consequences for ecosystem services and biodiversity. If local seed provenances are employed, this change will result in a decrease of the current CS of 44 $Tgyr^{-1}$ by 32-43% until 2061-80. However, if seed provenances adapted to the future climate are utilized, current CS can be maintained or even increased to 46-55 $Tgyr^{-1}$. Transnational AM can boost both resilience and the CS of European forests

Assessing soil carbon and nitrogen cycles three years after a large wildfire in Scots pine forest

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: In 2018, Sweden faced one of the most extreme wildfire seasons in modern history, highly impacting parts of the boreal forest ecosystem. Carbon (C) and nitrogen (N) plays a crucial role in the functioning and productivity of boreal forests. During a wildfire, the soil nutrients and organisms may be lost because of the reduction in the soil organic layer, impeding the fitness of the surviving or regenerating vegetation. With projected alterations in boreal forest fire regimes due to climate warming, there is a urgent need to identify sustainable post-fire management strategies.

We investigated the impact of wildfire and post-fire forest management in the C and N cycles in a Scots pine forest in central Sweden. In the summer of 2021, three years after the wildfire, we measured soil respiration and gross N mineralization, nitrification and NO_3^- and NH_4^+ consumption rates, using the ^{15}N-pool dilution technique by injecting ^{15}N labels in the soil *in situ*. We anticipated that the forest floor in high fire severity stands, where a significant portion of the soil organic layer is consumed, experience the most pronounced adverse impact compared to low fire severity and unburnt soil. In low fire severity soils, where the soil organic layer remains, fire may reduce the soil C to N ratio. This encourages gross N mineralization as N is in excess and therefore we expected enhanced gross N mineralization rate in low fire severity soil as compared to high and unburnt soil. Further, we expected that soil organisms stand a better chance of re-establishing soil processes in an unlogged forest compared to a salvage-logged forest, in low fire severity stands where the trees survived the fire. In this contribution we will present the outcomes of our measurements and discuss their implications for how post-wildfire severity following salvage logging impact the soil C and N cycles. The reduced production of plant available inorganic nitrogen, combined with the loss of the soil organic layer, could have significant long-term implications for the sustainability of boreal forests. Therefore, our objective is to provide informative insights that can facilitate the development of sustainable forest management practices.

Assessment and monitoring of carbon stocks at two degraded and semi-degraded wild pear stands in the Zagros forests, Iran

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Zagros forests are among the natural ecosystems of Iran, which, due to their vast extent, play an important role in the carbon cycle, therefore, determining the carbon stock and monitoring its changes can play an important role in management planning. This research was conducted in two sample plots (100 × 100 meters) located in Fars Province, Iran. In order to estimate the above-ground carbon stock, the quantitative characteristics of all the trees in the sample plots were counted. Also, in each sample plot, five soil samples were taken regularly from a depth of 0-30 cm and the content of carbon, nitrogen, phosphorus, moisture, microbial respiration, apparent specific gravity, and percentage of soil gravel were measured along 4 years. First of all, our data indicated that human and livestock grazing extensively have shifted tree community from Pyrus stand to Crataegus stand. The above-ground biomass of trees in the semi-degraded and degraded plots was calculated as 8.21 and 15.85 tons per hectare, respectively. Also, the amount of carbon stored on the ground in degraded and semi-dagraded plots was 8.26 and 4.22 tons per hectare, respectively. The comparison of soil carbon stock between the sample plots of semi-degraded and the degraded showed that the average soil organic carbon stock in the semi-degraded plot is 164.2 and in the degraded plot is 75.2 tons per hectare. Our finding exposed that forest degradation extensively impact on forest ecosystem services. In this regard, plant diversity and soil carbon stock profoundly has been declined by the forest degradation actions.

***Keywords*:** Above-ground carbon stock, Soil carbon, Monitoring, Wild pear.

Availability of soil nitrogen determines CO2 fertilization effect on urban forestry species-Physio-biochemical response of Neolamarckia cadamba

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Climate change is not a say of tomorrow but today's reality and to meet carbon neutrality targets of Sustainable development goals through forestry systems, the study of urban forestry species is important to mitigate climate change. Enhanced CO_2 and nutrient-deficient soils are major stress that hamper the biochemical traits of urban forestry species, including climate adaption and potential. This study suggests whether nutrient availability (nitrogen) improves CO_2 fertilization effects and biochemical response of urban forestry tree species (*Neolamarckia cadamba*). The plants were grown in nitrogen regimes (Low - N_{200} Kg N ha^{-1}, medium - N_{300} Kg N ha^{-1}, and high - N_{500} Kg N ha^{-1}) within enhanced CO_2 concentration (800±20 µmol mol^{-1}). Elevated CO_2 levels were found to increase plant biomass and alter plant nitrogen metabolism, leading to changes in the production of secondary metabolites, antioxidants, physiological and biochemical responses. The foliar transpiration, protein content, chlorophyll, gross primary productivity (GPP), night plant respiration (NPR), net primary productivity (NPP), net ecosystem exchange (NEE) were enhanced by 39%, 43%, 36%, 17%, 65%, 99%, 96% respectively under high nitrogen availability in CO_2 fertilization conditions whereas declined malondialdehyde content by 36% under high nitrogen availability and CO_2-enriched environment compared to counterparts. We reported that biochemical traits were significantly improved under enhanced CO_2 concentration and applied nitrogen compared to ambient CO_2 concentration and low soil nitrogen availability. It was reported in my study that how nitrogen interventions improve the gross primary productivity, net ecosystem exchange and water use efficiency of the *Neolamarckia cadamba* that is crucial and important for deciding the mitigation potential of the species We inferred that nutrient (nitrogen) management practices would improve the benefits of rising atmospheric CO_2 concentration, which enhances physio-biochemical response (CO_2 fertilization effect) of urban forestry species. To meet carbon neutrality targets of Sustainable development goals through forestry systems, Kadam can act as wonder agroforestry species as its carbon exchange mechanisms increase with nitrogen interventions.

Can fertilization of forest accelerate adaption to a warmer climate?

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Today's changing climate with rising temperatures and differences in precipitation is forcing the forest to adapt faster than a normal evolutionary process. A common suggestion to forest owners is changing the composition of species in the forest. This method is relative complicated and time consuming. Instead, we want to test an alternative method that would be easier to imply – this fertilization. We hypothesize that fertilization can improve the individual trees' capacity to acclimate their photosynthetic apparatus to changing temperatures.

In this project we compare two forest areas, one in southern parts of Sweden and the other in northern parts, giving us two populations with relative different climate and conditions. Within these areas we have both fertilized and unfertilized trees of several species. Fertilization is often thought of as a tool mainly for increasing forests' productivity. However, we believe nitrogen could also contribute to an acclimation to a warmer climate through physiological adaptations within the tree. If possible, we will also include habitats that vary in access for water, this would include a possible effect of abiotic stress and the efficiency of taking up fertilizers combined with access to water. In all we are hoping to get a greater understanding of nitrogen's role in the acclimation of the photosynthesis apparatus.

If our hypothesis is supported by the data, this would be an important mechanism through which fertilization can improve forests' ability to bind CO_2. This in turn could have wide-ranging consequences for society's ability to use forests as a carbon sink.

Carbon Budget Modelling to Predict Carbon Stocks in Temperate Forests: a case study over Canadian forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: In response to the global climate crisis, several provinces in Canada are testing the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) and associated methodologies to assess the carbon dynamics of their forestry sector. The CBM-CFS3 bases simulations on a range of studies and national forest inventory plots to predict carbon dynamics using merchantable volume yield curves. The provinces maintain permanent forest sample plots (PSPs), that allow the development of empirical province-specific carbon models with allometric equations. This study compares forest carbon stocks predicted with the empirical and CBM-CFS3 models in the case of various forest types in Nova Scotia. The empirical models were stratified into five forest types and predicted the carbon for seven carbon pools as a function of the plot age. Predictions with the empirical and CBM-CFS3 models were assessed against observed PSP data at the plot level and compared against each other at the stand and landscape levels. At the plot level, the empirical models predicted carbon closer to the observed data than the CBM-CFS3 model, with the extent of over- or under-estimation depending on the carbon pool and forest type. At the stand scale, the CBM-CFS3 model predicted forest carbon to be within 3.1%–17.6% of the empirical model on average. Differences in predictions between the CBM-CFS3 and empirical models decreased to within 2.4% of the empirical models at the landscape level. Thus, the implications of using one method over the other decrease as the prediction scale increases from stand to landscape level, and the implications fluctuate as a function of the forest type and age.

Carbon density, Nutrient storage and Microbial characteristics of forest ecosystems in mid hill conditions of north-western Himalayan

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Environmental degradation and climate change are significant problems of the 21st century to be addressed for the survival of the human race. Forests are one of the most important solutions to addressing the effects of climate change as approximately 2.6 billion tonnes of carbon dioxide, one-third of the CO_2 released from burning fossil fuels, is absorbed by forests every year. The present study evaluated the potential of 16 forest ecosystems for their carbon storage, nutrient status and soil microbial properties in the mid-hills of north-western Himalaya. The results revealed that maximum vegetation and ecosystem carbon density was recorded in Lower Western Himalayan Ban-Oak Forest with values of 228.26 Mg C ha^{-1} and 382.07 Mg C ha^{-1}, respectively. Shiwalik chir pine forest had the highest nitrogen concentration (13226.33 kg ha^{-1}). Lower Western Himalayan Ban-Oak had the highest phosphorus concentration (2989.19 kg ha^{-1}). The highest potassium concentration (5335.87 kg ha^{-1}) was found in the Leucaena leucocephala plantation. Lower Western Himalayan Ban-Oak had the highest calcium content (37499 kg ha^{-1}). Soil organic carbon (2.35%), available nitrogen (519.44 kg ha^{-1}), available potassium (575.01 kg ha^{-1}) and exchangeable calcium were highest in the northern dry mixed deciduous forest (1683.82 mg kg^{-1}). Whereas Lower Western Himalayan Ban-Oak had the most increased available phosphorus (23.31 kg ha^{-1}) and CEC (17.38 mg kg^{-1}) and Natural grasslands had the highest exchangeable magnesium (934.68 mg kg^{-1}). The highest bulk density (1.49 g cm^{-3}) and soil pH (7.17) was found in Natural grasslands. The maximum soil EC (0.22 dsm^{-1}) was recorded under Dry bamboo brakes. Lower Western Himalayan Ban-Oak showed a significantly faster rate of surface litter decomposition in comparison with other forest ecosystems. Northern dry mixed deciduous forest had the highest soil microbial activity (0.26 CO_2 evolution g^{-1} soil), microbial biomass (1094.49 µg g^{-1} soil) and bacterial count (195.21 x105 cfc g^{-1} soil). This study concluded that the Lower Western Himalayan Ban-Oak Forest has greater potential for carbon storage and nutrient replenishment rate and needs to be conserved and promoted for arresting environmental degradation and climate change.

Carbon fluxes of a natural Mediterranean Aleppo pine ecosystem using eddy covariance and soil respiration measurements

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The accurate estimation of ecosystem carbon and water fluxes is critical for the assessment of the biogeochemical cycles at the local, regional, and global scale and for understanding their response to the ongoing climate change. The eddy covariance technique is a useful tool for providing high-frequency and long-term measurements of ecosystem level carbon, water, and energy fluxes. However, while temperate and boreal forests are quite well-studied, less information is available for arid and semi-arid areas, such as those at eastern Mediterranean basin. Aleppo pine (*Pinus halepensis* L.) is widely spread in the Mediterranean region and Greece represents the eastern European limit of the species' natural distribution. Aleppo pine is well-adapted to the xerothermic conditions of the region, however, to date there is limited knowledge on the land – atmosphere interactions of natural Aleppo pine forests.

In this study, a monitoring site has been established in a natural, coastal Aleppo pine forest in Chalkidiki, Greece, which belongs to the national and European Long-Term Ecological Research network (LTER) and is protected by NATURA 2000. The site is equipped with an eddy flux tower and a full meteorological station that performs continuous eddy covariance and meteorological observations (air and soil temperature, precipitation, vapour pressure deficit, solar radiation, soil moisture and temperature). Moreover, soil respiration continuous measurements are performed with a close-path soil CO_2 analyzer. Finally, seasonal phenological dynamics are quantified with vegetation indices from satellite remote sensing.

The aims of this study, which is carried out within the ECOCARBON project, are to (1) present the annual pattern of ecosystem primary productivity and evapotranspiration at the study site, (2) assess the main environmental drivers and their contribution to carbon and water fluxes and (3) assess the most representative vegetation indices for the ecosystem's fluxes and phenological phases.

Carbon sequestration potential of eight economically important tree species in Northeast China under climate change

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The carbon sequestration potential of forest ecosystems is expected to play a crucial role in mitigating global warming, depending on how climate change will affect tree growth under various local environmental conditions. Here, we investigated the climatic limiting factors for forest tree growth and future carbon sequestration potential for eight economically important forest tree species in Zhongtiao Mountains of Shanxi Province in China. Specifically, we test if moisture limitations compromise annual radial increments (ARI) and a carbon sequestration index (IC), based on tree-rings and wood density. A bootstrapped response function analysis of historical detrended ARIs, reveals statistically significant moisture limitations in two or more summer months for half of the species investigated. Using a custom heat:moisture index based on these seasonal growth limitations, we predict IC under multi-model CMIP6 climate change projections for the region. Under moderate future climate scenarios for the period 2041-2070, the carbon sequestration potential for most species is likely to increase significantly. This is because under current climate only some species experience moisture limitations, and a projected increase in seasonal precipitation mitigates these growth limitations. We conclude that model projections are favorable for carbon sequestration and future commercial forestry potential in the Zhongtiao Mountain forestry region.

Carbon stock estimation in halophytic wooded savannas of Uruguay: an ecosystem approach.

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Savannas constitute a combination of tree and shrub patches with an herbaceous understory. This biome contributes significantly to the soil organic carbon (SOC) and above-ground biomass (AGB) carbon (C) stock globally. In Uruguay, subtropical wooded savannas cover 100,000 ha approximately, of which 28% is restricted to sodic soils. However, there are few studies about the contribution of each ecosystem component to the C stock and the development of site-specific allometric equations. In this sense, the objectives of this study were: *(i)* fit allometric equations for the AGB of the most frequent tree species and *(ii)* quantify the contribution of each component (soil, trees, shrubs, and herbaceous plants) to the ecosystem C stock. The study area corresponded to 5 ha of subtropical halophytic wooded savannas on typic natraqualfs from the protected area "Esteros y Algarrobales del Río Uruguay". Five plots (20 x 20 m) were randomly installed, measuring the basal diameter (BD), diameter at breast height (DBH), and total height (H) of each tree. At each plot, a soil sampling was performed to estimate the SOC stock up to the B_{tn} horizon (57 cm depth). Then, a semi-destructive biomass estimation was carried out, considering 30 individuals of *Neltuma affinis* and 23 of *Vachellia caven*, the most frequent tree species. For shrubs and herbaceous plants, a destructive sampling was applied, arranging 15 (2 x 2 m) and 30 (0.2 x 0.4 m) sub-plots randomly inside the main plots for each component, respectively. For *Neltuma affinis* the fitted equation was: AGB (kg tree^{-1}) = exp [− 1.282 + 0.402 × BD − 0.006 × BD^2]; R^2*-adj* = 0.97; *RMSE* = 9.92. For *Vachellia caven* the adjusted model was: AGB (kg tree^{-1}) = BD^2 × [0 .041 + 0.002 × BD × H]; R^2*-adj* = 0.98; *RMSE* = 5.31. The ecosystem C stock reached 116.71 ± 11.07 Mg ha^{-1}, of which 90.7% was contained in the soil, 8.3% in the trees, 0.8% in the herbaceous plants, and 0.2% in the shrubs. These results highlight the value of subtropical halophytic wooded savannas as C sinks and their importance in the mitigation of global warming under a climate change scenario.

Carbon stocks and fluxes of a natural Mediterranean Aleppo pine ecosystem

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Climate change challenges forest ecosystems worldwide with increasing cases of forest degradation and loss of biodiversity. While the atmospheric CO_2 increases, forests play a crucial role in mitigating climate change by acting as carbon sinks, absorbing and storing carbon dioxide as biomass. Mediterranean forests are particularly vulnerable to climate change, setting, thus, as high priority to understand and quantify the carbon stocks and fluxes in such ecosystems. This study is carried out within the project ECOCARBON, at a natural, near-coastal Aleppo pine ecosystem in Chalkidiki, Greece which is part of the national and European Long-Term Ecological Research network (LTER) as well as the NATURA 2000 network of protected areas. Our goal is to estimate the carbon stocks (above-, and below-ground biomass of both the tree overstorey and the shrub understorey, forest floor, deadwood, soil organic carbon) and fluxes (litterfall and fine root production and turnover) of the ecosystem during one year. Moreover, the carbon dioxide equivalents sequestered by the studied ecosystem will be calculated in order to determine its contribution to the carbon footprint of the region. In the study area, 15 sampling plots of 0.1 ha area each have been established, taking into account their spatial distribution, as well as tree and understorey density, for the estimation of all carbon stocks and fluxes. The mean diameter at breast height of the Aleppo pine stands in this region is 34.70 cm, and the tree age ranges from 30 to 110 years. Currently, information on the carbon sequestration of natural ecosystems, particularly taking into account the carbon storage in the understorey shrub layer, is scarce in Greece. Here we present the methodology and the estimates of carbon stocks and fluxes in all forest components and we discuss the effect of driving mechanisms, such as seasonal climatic variability, tree age and stand density on the ecosystem's carbon sequestration potential.

Changes in soil organic carbon following afforestation of former cropland: two repeated samplings of oak and Norway spruce chronosequences

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Afforestation of former cropland has the potential to sequester atmospheric CO_2, but the contribution of soils and the specific effects of tree species and time since afforestation on soil organic carbon (SOC) dynamics remains uncertain. Consequently, long-term experimental platforms and continuous monitoring of SOC dynamics are needed to explore the specific sink strength of soils after afforestation. The chronosequence approach has been widely used for the assessment of temporal changes in new forest ecosystems after land-use change by the space-for-time substitution, but a combination with repeated sampling provides the potential to make up for the shortcomings of the chronosequence approach, which may be restricted by confounding site-related factors.

During more than two decades, a unique combined chronosequence and resampling study of oak and Norway spruce stands have been conducted in former cropland in Denmark with the aim of estimating the effects of afforestation on soil C sequestration. The results from previous studies indicated that afforestation of former cropland within the temperate region may induce soil C loss during the first decades followed by a recovery phase of yet unknown duration.

The previous studies studied only bulk SOC but the sequestration mechanisms require studies of the specific pools of SOC, as characterized by e.g. physical fractionation, and the origin and chemistry of the soil organic matter (SOM). Hence, fractionation of the bulk soil to characterize particulate- and mineral-associated organic matter and tracing the plant- and microbial-derived SOM by biomarkers is now introduced to understand the plant–soil-microbial interaction behind SOC dynamics following afforestation. Based on the third sampling and comparison of three chronosequence trajectories, this presentation will address (1) the changes in SOC stocks and the rate of C sequestration after >50 years of afforestation, (2) the difference in SOC stocks and C sequestration rate between two tree species in forest floors and mineral soil, (3) the mechanisms and stability of SOC to discuss the long-term SOC dynamics affected by afforestation.

Changes in the forest carbon dynamics of the North American deciduous forest can be expected in the future with the arrival of Asian jumping worms

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The invasion of Asian jumping worms (Amynthas spp.) in the deciduous forests of Northeastern North America has raised concerns regarding the potential alterations in forest carbon dynamics. This study aims to assess the future impact of Asian jumping worms on forest carbon dynamics. Through a comprehensive review of existing literature, I synthesised available information concerning the effects of Asian jumping worms on litter decomposition, soil respiration, nutrient cycling, and vegetation dynamics, which collectively influence the forest carbon dynamics of the Northeastern North American forest. The review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to extract studies and data that directly and indirectly reported the effects of Asian jumping worms on forest carbon dynamics in the deciduous forests of Northeastern North America. The findings of our study indicate that Asian jumping worms can expedite litter decomposition, leading to increased nutrient mineralisation and alterations in physical soil properties. Consequently, this may result in elevated soil respiration rates and a reduction in the potential for carbon sequestration within the forest ecosystem. Furthermore, changes in vegetation composition and nutrient availability, attributable to the activity of Asian jumping worms, may impact aboveground carbon stocks. However, the precise level, consequence, and direction of these effects require further clarification, as they are likely to vary depending on worm density, infestation duration, and environmental conditions. To gain a comprehensive understanding of the specific impacts of Asian jumping worms on forest carbon dynamics, future studies should emphasise long-term monitoring to evaluate the spread of these worms and their adaptive mechanisms in response to the environment. It is crucial to comprehend the potential changes in forest carbon dynamics associated with the invasion of Asian jumping worms in order to develop effective management strategies. The integrity and functionality of Northeastern North American deciduous forests are of utmost importance in the face of this invasive species.

Changing quantity and sources of plant litter inputs for 5 years alters CO2 efflux and carbon stocks in the organic layer but not in the mineral soil

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics
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Abstract: Despite critical roles played by soil organic matter (SOM) including C sequestration, nutrient provision and moisture retention, SOM dynamics in forests are poorly understood. A litter manipulation experiment was established in 2016 in a white pine (*Pinus strobus*) plantation near Québec City, Canada, to monitor the long-term impact of changing quantity and sources of plant litter inputs on soil C. Treatments include double litter (DL), no litter (NL), no roots (NR), no input (NI) and control (CO), consistent with the standard treatments of the Detrital Input and Removal Treatments (DIRT) network, as well as specific treatments consisting in double wood (DW), wood ash (WA) and nitrogen fertilizer (NF) addition.

Continuous monitoring of soil CO2 efflux revealed higher C losses for the double input treatments (DL, DW) and WA, whereas lower ones were observed for all exclusion treatments (NL, NR and NI), relative to the control. While no significant changes were found in mineral soil C after 5 years of litter manipulation, important C stock changes were observed in the organic layer with lowest values for all litter exclusion treatments. Results on soil water, eDNA, soil physical fractions and stable isotopes are also presented and discussed.

These results show that despite dramatic changes in C fluxes, in and out of the soil system, changes in mineral soil C are difficult to observe and highlight that the processes responsible for accumulation and (de)stabilisation of C are slow, especially in these forests of the hemiboreal zone. Collectively, results from this study and from other sites of the DIRT network reveal that alteration of forest productivity and associated litter inputs due to climate change, forest management, or other disturbances will not likely result in soil carbon stabilization or destabilization in the short term.

Chemical composition and stability of soil organic matter density fractions under forest type change

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Changes in the temperate forest species composition are expected under global change. At the same time, forest soil carbon sequestration is studied as a potential tool of climate change mitigation. Thus, we need to know how the expected change in species composition will affect soil carbon storage. It has already been shown that coniferous litter is of lower quality and higher stability and is preferentially stored in more vulnerable organic horizons. However, we lack information on the effect of forest type on the stability of soil organic carbon in mineral horizons. Here, we focus on the chemical composition and stability of the density fractions of soil organic matter in the mineral horizon under deciduous and coniferous forests. We expect contrasting qualities in light fractions under the two types of forest, but not in mineral-associated organic matter that is highly microbially transformed.

Climate change, megafires and the fate of Australia's Eucalyptus forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Multiple fires of more than 1 M hectare have burned through the forests of south-eastern Australia over the last 4 decades, impacting over 12 M ha of *Eucalyptus* forest. Within these forests the obligate-seeder eucalypts usually regenerate from seed following high intensity fire that kills the seed-bearing trees, while resprouter eucalypts regenerate to varying degrees from the existing stems depending on the intensity of fire. In fire-killed forests seeds released from the canopy usually regenerate profusely with high seedling densities followed by competition-induced thinning and mortality. Over the last 160 years, large bushfires in obligate seeder type forests have usually started in January or February at the height of the summer. With warming climate fires are trending to start earlier in summer, prior to the full maturation of seeds, potentially impacting regeneration success. The more frequent weather extremes seem to be reducing fire intervals to less than 20 to 40 years – and this may limit the seed source for recovery of obligate seeder forests following future fires, and the structure of forests may be altered through fire-induced increases in mortality. This presentation discusses the potential for climate change to increase fire, stimulate forest mortality, alter forest structure and reduce the carbon carrying capacity of *Eucalyptus* forests. The results of field studies of the recovery trajectory of these forests over the last 4 decades are drawn on to explore active forest management actions, including thinning, planned burning and invasive weed control, to increase forest resilience to climate change and the risk of severe fires in the future, and to either build, maintain or limit declines in forest carbon stock.

Context matters: window of opportunity for forest managers to optimize soil carbon stability

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Despite the general agreement that maximizing carbon storage and its persistence in forest soils are top priorities in the context of climate change mitigation, our knowledge on how to steer soil organic carbon through forest management remains limited. For some soils, tree species selection based on litter quality has been shown a powerful measure to boost SOC stocks and stability, whereas on other locations similar efforts result in insignificant or even opposite effects. A better understanding of which mechanisms underpin such context-dependency is needed in order to focus and prioritize management efforts for carbon sequestration. In many temperate forests, soil pH is low and acid buffering mechanisms play a key role in belowground ecosystem functioning. These non-linear mechanisms result in threshold behavior in soil pH, which considerably mediates tree species effects on carbon cycling. The threshold between the exchange buffer and the aluminum buffer around a pH-H2O of 4.5 is of particular relevance for temperate forests. When a shift between these buffer domains occurs, it triggers changes in multiple compartments in the soil, ultimately altering the way carbon is incorporated and transformed. Moreover, the impact of such a shift can be amplified by feedback loops between tree species, soil biota and edaphic conditions. Hence, taking into account context-dependencies related to soil acidity will allow developing more efficient, context-explicit management strategies to optimize SOC stocks and their stability.

Correlation between soil variables in the Humid Forest of the Eastern Region, Paraguay.

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The physical and chemical properties of the soil are related to the water and nutrient quality and availability for plants, allowing for proper root development and ensuring optimal growth. The aim of this research was to determine if there is a correlation between the soil chemical parameter: organic material, and the physical parameters: sand, clay, silt, as well as organic carbon in the humid forest stratum of the Eastern region (BHRO) in Paraguay. The data were collected in 2015 as part of the national forest inventory. Twenty plots were sampled, and soil samples were collected using a 100 cc cylinder at the following depths: A (0-5 cm), B (25-30 cm), and C (45-50 cm). Soil sample analysis was conducted at the Laboratory of "Compañía Tecnológica de Comercio y Servicios Agropecuarios" TECSA S.A. Pearson correlation analysis was performed between the soil variables and principal component analysis (PCA) for all sampled plots at the three depths (A, B, C). The depth with the highest correlation in the analysis (>30%) was chosen (HENDERSON, 2003). Depth A showed the highest correlation, therefore the other depths were excluded. A weak positive correlation was observed between silt and clay and organic matter in the BHRO, indicating that the presence of these soil variables does not contribute to the increase or decrease of the sampled organic matter. The variables that showed a strong negative correlation were sand and clay, indicating their contrasting physical or chemical characteristics. Organic carbon showed a strong positive correlation with organic matter, indicating that the presence of one contributes to the presence of the other. Understanding the physical and chemical properties of the soil and their interrelationships could positively influence the selection and implementation of any forest activity that may affect its productivity.

Diminishing legacy effects from forest fertilization on stand structure, vegetation community, and soil function.

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Fertilization with N is a cost-effective way of increasing forest biomass yield and increasing timber harvest profitability, while the impacts on the ecosystem are usually assumed to disappear within 10 years of application. To clarify if legacy effects are longer-lasting, we analysed 21 Pinus *sylvesteris* and *Picea abies* stands. The stands, 25 years old at the time of this study, were fertilized with 150 kg N ha^{-1} once or twice during the previous stand rotation, or unfertilized. We preformed follow-up measurements on soil N mineralisation and N availability, forest growth, ground vegetation community composition, soil and vegetation C/N ratios and soil C stocks, many of which were shown to be responsive to legacy N fertilization earlier in stand development. Our results show that all the significant effects present in the previous measurement period (over a decade ago), were weaker or completely absent in the current study (i.e. 25 years after initiation of the new stand). These results indicate that legacy effects of fertilization during the previous stand rotation diminished through time, indicating an eventual convergence of stand properties between fertilized and unfertilized stands. Given that convergence does not appear to occur until c. 25 years into the subsequent stand rotation and c. 40 years following N fertilization, it suggests that care should be taken to mitigate unwanted, long-term effects when utilizing N addition to promote tree growth in boreal forest.

Disentangling the effects of tree species communities on litter decomposition in forests of the northern hemisphere, using standardized litter

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Litter decomposition is a key ecosystem function in forests. Through its impact on carbon, nutrient and water cycles it regulates nutrient availability and the carbon budget in forests. The major factors influencing decomposition are well documented on regional and global scales, but this is less so at the local scale. Under similar conditions of macroclimate, topography and soil, litter decomposition under forests is expected to depend mainly on tree species composition, this through the direct effects of litter quality and indirect effects of the tree canopy. The tree canopy shapes the local decomposition environment by the accumulation of organic matter and the regulation of the local microclimate.

The scope of this project is to disentangle these direct and indirect effect on litter decomposition at a local scale. Therefore, a unique experimental setup was conducted in the geographical arboretum of Tervuren, Belgium. Here, patches of tree species from temperate and boreal regions were planted in a common garden. By selecting similar (initial) site condition and stands that are at least 40 years old, we assume that the trees had sufficient time to "shape" their environment. This research can therefore focus specifically on tree species composition and their direct and indirect impacts.

We analyzed the decomposition rates for two types of standardized litter substitutes: green tea (high quality litter) and rooibos tea (low-quality litter). We incubated 1440 teabags at two depths for a 3-month period under all 120 selected stands. At the same time, we characterized the local stand composition, decomposition environment and corresponding litterfall. We hypothesized that the decomposition of low-quality rooibos would mainly be driven by tree identity (matrix quality) while high-quality green tea would mainly be influenced by stand structure (microclimate). First results suggest that different (interacting) mechanisms are controlling the decomposition rates of the corresponding litter quality (high/low) and placement (forest floor/upper soil).

Through highlighting these specific tree species effects on decomposition, we can increase our knowledge on mixing tree species with different traits and origins, and their potential carbon storage in forest soils.

Disentangling the impact of nitrogen availability on forest soil organic matter dynamics – Modelling the interplay of microbial and plant responses

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Nitrogen (N) enrichment (e.g., via N deposition) is a major global change factor that strongly influences forest soils. Recent meta-analyses have shown that N addition positively impacts total soil organic carbon (SOC) stock, scaling positively with increasing dose and duration. Past experiments also showed that excess N directly affects microbial activity and SOC decomposition more strongly than plant litter production. This contradicts the assumptions on the role of N in most soil biogeochemistry models.

Furthermore, the composition of SOC depends on N availability, as N does not act on bulk SOC uniformly. Rather, excess N tends to suppress the decomposition of recalcitrant SOC pools such as lignin-rich materials and protein-rich, low C:N organic matter, whereas it speeds up the decomposition of labile organic matter, owing to changing enzyme activities, microbial biomass, and community composition. However, a coherent mechanism to explain this divergent response of different C pools to N is still lacking and needs to be incorporated into soil models.

We investigated the complex effects of N availability on both SOC quantity and quality (e.g., particulate organic carbon and mineral-associated organic carbon) using a novel model derived from the CENTURY soil submodel combined with the ForClim forest gap model. We amended CENTURY with new process equations representing hypothesized enzymatic, microbial and plant responses under varying N availability (relative to C availability) based on the literature. Multiple model variants are set up to reflect different combinations of these processes and are validated by comparing to data collected across a wide environmental gradient in Switzerland and beyond. Our modelling reveals the relative importance and relevance of these processes across different forest sites, thereby allowing us to distil a coherent mechanistic account of N influences on forest SOC dynamics. Lastly, we also test the legacy effect of N in a scenario where N deposition rises first and then declines (similar to what happens in reality, e.g., in Europe), revealing hysteresis via positive feedback from N retention, i.e., higher N availability leads to more SOM stored that can in turn release more N via mineralization.

Drought reduces rhizosphere soil carbon inputs and shifts soil microbial communities in a pine forest

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Severe droughts impact soil organic carbon (SOC) cycling. Yet, there is limited understanding of drought effects on rhizosphere C, which contribute to new SOC formation while fueling soil microbial communities and thus SOC mineralization. Here, we quantified rhizosphere C inputs and losses in a long-term irrigation experiment in a dry Scots pine forest using ^{13}C-enriched soil ingrowth bags. Fungal and bacterial communities inside the ingrowth bags and in adjacent soils were analyzed by Illumina MiSeq sequencing.

After two years, new SOC formation was 5 times greater in root-accessible vs. root-exclusion bags. In the first year, the new SOC formation was stimulated by water addition as compared to natural drought, both in root-accessible (+25%) and root-exclusion bags (+50%). In contrast, old C losses increased in root-accessible bags under irrigation (+88%), resulting in an overall limited effect on the SOC balance within bags. After two years, the irrigation showed a limited effect on new SOC both in root-accessible and root-exclusion bags. The lacking irrigation effect on new SOC may be partly related to greater respiratory losses of new soil C (i.e. +55% old C losses under irrigation), suggesting increased rhizosphere C inputs under irrigation, which were rapidly mineralized. In support, root ingrowth in root-accessible bags increased by 70% under irrigation. The increased supply of belowground C and increased C turnover in the rhizosphere under irrigation was paralleled by shifts in fungal and bacterial communities in ingrowth bags as well as in adjacent soils. Accordingly, the presence of roots was a main driver of fungal and bacterial community structures in the ingrowth bags.

Overall, our results in this long-term irrigation experiment imply that naturally dry conditions slow SOC cycling, suppressing both rhizosphere C inputs and losses. The reduced supply of belowground C leads to cascading effects on soil microbial community composition under drought.

Dynamics of carbon storage in a tropical Eucalyptus plantation over multiple rotations

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Eucalyptus is the most widely planted forest genus worldwide. In Brazil, Eucalyptus plantations rank among the world's most productive forests and cover more than 7.5 Mha. Improving our understanding of the dynamics of carbon storage in these anthropized ecosystems and how management practices, especially clear-cutting, affect it is important for future land sink projections. Here, we present an unprecedented 14-years series of continuous CO_2 fluxes (net ecosystem productivity, NEP) from Eddy-covariance measurements conducted in a commercial Eucalyptus plantation in Southern Brazil (the EUCFLUX project). The measurement period encompasses 3 rotations (including a full rotation of 9 years). Clear-cutting were followed by planting after a delay of 1.5 month after the first harvest and 5 months after the second harvest. NEP data were compared to the stem biomass exported at harvest to estimate the long-term C storage of the plantation (i.e., the net ecosystem carbon balance, NECB).

We show that NEP reached a maximum value of ~2 MgC/ha/month, totaling ~86 MgC/ha in a 9-year rotation. Clear-cuttings turned the plantation into a net carbon source for 7 and 12 months after the first and second harvest, corresponding to the emission of ~8 and ~11 MgC/ha, respectively. The payback period (the amount of time before the plantation recaptures as much CO_2 as was emitted after harvest) was 19 and 30 months, respectively. When using the time of planting as reference, the data was remarkably similar between rotations: the plantation turned into a net C sink 5.5 months after planting and emitted ~5MgC/ha during this period. Ten months after planting, the plantation already sequestered as much C as was emitted in the first months of the rotation. However, we found that NECB was close to zero. This suggests that despite having very high NEP, below-ground and litter C storage is low in this plantation and that the trunk export at harvest is a C flux of comparable importance as the NEP integrated between two consecutive harvests. Therefore, our results suggest that C storage in the soil stabilizes after successive rotations in highly productive commercial Eucalyptus plantations.

Effect of coastal reforestation on soil chemical characteristics of grey mangrove forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The effect of reforestation on mangrove forests is poorly understood. The purpose of this study is to assess how some soil chemical properties of mangrove forests are affected by reforestation. For this purpose, a large unvegetated vacant gap (2000 m^2) was selected for reforestation. In January 2018, 10 soil samples were randomly collected for laboratory analysis using tubes with 0.5 m in diameter and 30 cm in length. After the initial soil sampling, 125 grey mangrove seedlings were planted in the gap. In January 2022, 10 soil samples were collected from the same positions for chemical analysis. Besides of soil microbial carbon (C_{mic}) and electrical conductivity (EC), the concentration of zinc (Zn), sodium (Na^+), magnesium (Mg^{2+}), Phosphors (P), and organic carbon (OC) were measured for all soil samples and then statistically analyzed using t-student (t-paired). The results indicated that the concentration of Mg^{2+} (16.62%), P (15.38%), OC (45%) and microbial biomass carbon (47.53%) were significantly increased in the 5-year reforested gap relative to the bare gap ($P<0.05$). The electrical conductivity (-19%) and Na^+ (-18.5%) were lower in planted gap than those of bare soil ($p<0.05$). The changes are likely the result of the grey mangroves influence on tidal induction and the input of litter. Hence, mangrove planting the coastal area, not only improve the soil nutrients of the habitats but also decline the soil salinity. Our study highlights the importance of rehabilitation of Mangrove forest stands by direct seedling plantations.

Effect of elevated air humidity and soil moisture on water flux and foliar nutrient content in silver birch: the Free Air Humidity Manipulation study

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Air humidity can influence ecosystem functioning and its components in several ways, inducing primarily changes in the intensity of evapotranspiration. Changes in evapotranspiration affect the balance of water and minerals in trees and, consequently, the growth rate. A Free Air Humidity Manipulation (FAHM) experimental facility (https://sisu.ut.ee/fahm1/main?lang=en) was established in South-East Estonia to investigate the impact of elevated air humidity and soil moisture on trees and forest ecosystem functioning. The measurements of the current study were conducted at the FAHM experimental site in the droughty summer of 2018. We aimed to elucidate the effect of elevated air humidity and soil moisture on water flux and nutrient uptake (NPK) in silver birch trees from the 22nd of May to the 22nd of September. The average long-term increase in air relative humidity is 5-6% in humidification (H) treatment compared to control (C) conditions during mist fumigation (applied from 9:00 to 19:00 h from May to September) in the FAHM experiment. The natural precipitation was 186 mm during the study period (36% below long-term average). In soil irrigation treatment (I), the experimental plots were additionally watered once a week, whereas the total amount of added water equalled to 140 mm of precipitation. Our results demonstrated significant differences among treatments in tree sap flux density (F) and foliar nutrient concentrations. The timing of autumnal leaf abscission varied between treatments depending on F and foliar [N]. The delayed leaf abscission was positively related to tree diameter increment of the following year (2019). Our findings suggest that trees of H treatment behaved differently from those of I and C treatments and confirm the distinct effects of elevated air humidity and soil moisture on trees' functioning.

Effect of land use change on soil phosphorus: how does deforestation, time since crop establishment, and agricultural management affect P lability?

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Soil phosphorus is an essential nutrient for plant growth and ecosystem functioning. Various factors can influence the availability and distribution of the different P forms. This study aimed to investigate the effects of land use, time since deforestation, and agricultural management on soil P forms using a sequential Tiessen and Moir fractionation approach. We compared cultivated soils that have experienced deforestation for three periods (25, 34, and 72 years) and the neighboring undisturbed forest soils, located in Central Macedonia Region, northern Greece. Two different agricultural management practices were examined: conventional tillage with irrigation for cotton-wheat rotation with alternating crops every two years, and reduced tillage without irrigation for wheat cultivation. The Tiessen and Moir sequential phosphorus fractionation method was used to differentiate soil phosphorus fractions based on their lability. Results revealed a significant 90% increase in total P content following deforestation and cultivation, as determined by the sequential procedure. Labile P forms exhibited a substantial 140% increase, moderately labile forms increased by 110%, and residual forms increased by 60%. Differences in soil P forms were observed between wheat fields and cotton-wheat rotation fields, highlighting the influence of land management practices on P dynamics. Furthermore, the time since deforestation played a pivotal role in shaping soil P distribution with previously deforested sites showing lower moderately labile organic P content and a higher proportion of labile organic P and moderately labile inorganic forms. This underscores the importance of considering the legacy effects of land-use change on soil P availability. In conclusion, this study demonstrates that land use, time since deforestation, and agricultural management practices significantly impact soil P forms. A comprehensive understanding of soil P fraction dynamics is essential for effective land management and sustainable agricultural practices. The findings contribute to existing knowledge on soil P cycling and offer valuable insights for land managers and policymakers to develop strategies for enhancing soil health and nutrient management in diverse land use scenarios.

EFFECT OF LAND USE CHANGE ON SOIL QUALITY AT SELECTED DEGRADED LAND AND FOREST PLANTATION IN MALAYSIA

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forest land conversion is a significant issue driven by population growth and economic development in any developing and developed countries. Converting forests into other uses like agriculture or urbanization can have adverse effects on soil properties. Forests are complex ecosystems that have evolved over thousands of years, and their removal can cause changes in soil physical, chemical, and biological characteristics. Deforestation often involves removing the forest canopy, leading to increased soil erosion and loss of organic matter. This loss affects soil fertility and its ability to support plant growth. Tree removal also alters soil moisture levels, impacting soil structure and nutrient availability. The study aims to assess the impact of land use change on soil quality in Kuala Kubu Bharu, Selangor, Malaysia. The study was conducted on an open forest area, a natural forest owned by a private company, and an active agricultural area with a forest plantation. Soil samples were collected at three different locations, using a soil auger at depths of 20-30 cm. The samples were air-dried for 24 hours and sieved to remove small pebbles. We used the pipette method to determine soil texture (sand, silt, and clay) and CHNS analysis and Atomic Absorption Spectrophotometer (AAS) to analyze soil chemical properties (pH, cation exchange capacity, total carbon, total nitrogen, and exchangeable bases such as Ca, Mg, K, and Na). We are expected to develop sustainable land-use practices and mitigating the negative impacts of land-use change on soil health. The results of the study will provide insights into the effects of different land uses on soil health and guide efforts to mitigate these changes.

Effects of biochar and microbial soil amendments on post-mined soil: implications for shortleaf pine (Pinus echinata) restoration

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Coal strip mining has left degraded soils throughout the southeastern United States. These soils tend to have low pH, high bulk density, impacted hydrologic processes, and an accumulation of heavy metals that limit revegetation and reforestation efforts. Shortleaf pine (*Pinus echinata*) has a natural ability to grow on post-mined sites and has the largest native range in the southeastern United States, making it an ideal species for restoration efforts. However, limited empirical field trials have been conducted on the success of soil amendments on both soil health and tree productivity. A field trial was established on a reclaimed mining site in 2021. The shortleaf pine was planted in a completely randomized block design with 10x10-foot spacing with two treatments: biochar and microbial inoculation in four replicates. Soil bulk density, pH, heavy metal content, electrical conductivity, carbon content, and nitrogen content were measured every three months. Shortleaf pine survival and growth through height and ground line diameter measurements were also taken at planting and at the end of each growing season.

After two years, overall survival is 71.07 ± 6.59 % with the lowest survival in the microbial treatment at 59.26 ± 10.92% and the highest survival in the biochar treatment at 77.08 ± 3.08%. Soil amendments were found to have significantly (p<0.05) impacted height change. Tree height growth was the largest in the biochar treatment at 35.51 ± 2.89 cm and lowest in the microbial treatment at 10.41 ± 3.02 cm. Although not significantly impacted by soil treatment, mean carbon content increased in the mixture treatment of both biochar and microbial soil amendments by 2% while all other treatments decreased.

Year 3 analysis is pending. Future results are expected to show a more productive environment than the original reclaimed mining site for shortleaf pine. This study will create evidence for the use of biochar and microbial soil amendments in restoration on post-mined sites.

Effects of clearcut forestry on soil respiration and aboveground litterfall in mature boreal spruce forests of south-eastern Norway

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forests constitute the largest terrestrial carbon (C) stock in Norway, and forest ecosystems at these latitudes are important for global C dynamics particularly due to their large belowground C stocks. Clearcut harvesting is generally thought to reduce soil C stocks; however, knowledge on long-term effects is limited since most of the data come from studies done within 15 years of harvest. Furthermore, we lack understanding of the underlying C-flux components, especially in clearcut forests that have reached maturity.

In a paired plot design at 12 locations in south-eastern Norway, we compare mature clearcut Norway spruce forests with nearby forests that have never been subject to clearcutting. We have collected two full years of aboveground tree litterfall, with monthly collections during the snow free period of 2022. In addition, we have measured in situ soil respiration using LI-COR Smart Chamber (8200-01S) and carbon dioxide (CO_2) analyser (LI-870). Soil respiration measurements were performed monthly during the snow free period from September 2021 to November 2022. Following the last respiration measurements, we collected soil samples from inside the chamber collars to perform chemical analysis (C and nitrogen). We report both soil CO_2-efflux per area and per gram C. In addition, we use microclimatic variables and stand parameters to help explain variability in soil respiration.

Investigating the major soil C input and output in the two types of forests, we aim to disclose potential long-term differences in C cycling caused by forest management. Utilizing a unique study design with mature Norway spruce stands we contribute new data about soil C processes from the late stage of a typical rotation period in stands subjected to clearcut harvesting and in near natural stands in south-eastern Norway.

Effects of intensive Acacia mearnsii cultivation on soil acidity and soil fertility indicators

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The Fagita Lekoma district in northwest Ethiopia has undergone a significant land-use change over the last two decades. Around 50% of the cropland has been converted from annual crop agriculture to short rotation agroforestry using *Acacia mearnsii*, a tree speciecs native to Australia, over a period of 20 years. The land use change is primarily driven by the market demand for charcoal. The *Acacia* cultivation leads to significant biomass removal from the field when it is harvested every 4 to 6 years. This study aims to analyze the effects of intensive *Acacia mearnsii* cultivation on soil acidity and available nutrient status, considering different rotation frequencies of the cultivation. A total of 144 soil samples were collected between April and May 2022 from plantation stands of different stand age and rotation cycles. The data was analyzed using a two-way Analysis of Variance (ANOVA), followed by a post hoc test to identify significant differences between the *Acacia* plantation rotation cycles. Soil acidity (both pH and exchangeable acidity) was higher with increasing number of rotation cycles; however, the results were not statistically significant. No statistically signficant difference was observed among the different cycles of plantation rotation for available soil N (1M KCl extractable NH_4^+ and NO_3^-). Active carbon got higher with stand age across all rotation cycles but was lower with an increased frequency of plantation. There was a statistically significant difference between the first and second rotation cycles, while no statistically significant difference was observed for plantations under the third rotation cycle. No notable difference in phosphatase enzyme activity was observed among the different rotation cycles. The percentages of total organic carbon and nitrogen decreased as the rotation cycle increased. A statistically significant difference was observed between the first and third rotation cycles for both soil properties. Despite the fact that the tree benefits the soil through it's nitrogen-fixing abilities, the export of other soil nutrients raises concern, as acidity seems to increase with cultivation frequency. Our results contradicts earlier observations that claim that the *Acacia* plantations are neutralizing soil acidity.

Effects of structural complexity in temperate forests on decomposition processes

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Temperate production forests have experienced a homogenization of forest structure under established management regimes, leading to a reduction of possible different ecological niches and a change in local microclimatic conditions, and subsequently a loss of ecosystem functions and biodiversity. Management approaches such as the Enhancement of Structural Beta Complexity (ESBC) aim at reintroducing heterogeneity in production forests by emulating natural disturbances and succession through silvicultural manipulations.
By breaking down organic matter and making it available for other organisms, decomposition processes are an integral part of nutrient and carbon cycling, but are often not in the focus of scientific studies, especially the decomposition of animal derived necromass such as carcasses. Controlled by factors such as microclimate, decomposer abundance and substrate quality, all of which are directly influenced by forest stand structure, decomposition processes are likely strongly affected by homogenisation. As part of the BETA-FOR research unit this study aims at disentangling the relationship between homogenization and decomposition in temperate production forests with a focus on decomposition rates and decomposer diversity.
BETA-FOR has introduced nine different ESBC treatments at eleven forests sites in production forests in Germany, each site comprised of nine ESBC-patches and nine control-patches. On each patch, decomposition rates of different necromass such as animal dung, rat carcasses and leaf litter were determined by exposing the materials to patch conditions for specific lengths of time. Pitfall traps baited with animal necromass (dung and carcasses) were installed directly afterwards to investigate decomposer diversity. Field experiments were started in summer 2022 and are still on going.
Preliminary results show a greater variance of decomposition rates of rat carcasses and animal dung, as well as an overall faster decomposition of rat carcasses on ESBC-sites. Analysis of seasonal variation and decomposer diversity are still in progress. However, first results indicate stronger differences in decomposition efficiency and thus nutrient turnover in addition to higher beta-diversity of decomposers, when forest sites are more structurally heterogeneous. ESCB-management could therefore be a useful strategy to improve nutrient cycling in production forests and increase decomposer diversity across spatial scales.

Elevated nitrate leaching risks under pure Douglas fir stands can be lowered by mixing with European beech

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forest management aims for productive and stable forests that continuously provide ecosystem goods and services, including balancing nutrient fluxes (nitrogen). Increasing heat and frequent droughts in temperate European forests make the introduction of non-native Douglas fir (*Pseudotsuga menziesii*) an increasingly relevant climate change adaptation strategy, particularly as an admixture to native tree species, such as European beech (*Fagus sylvatica*).

Douglas fir can alter biogeochemical processes in forest soils, potentially leading to an excess of nitrogen in the ecosystem, but the biotic and abiotic controls of this effect need further examination (species interactions, soil type). Here we studied nitrate leaching on plots of two contrasting regions (southern loamy and northern sandy site) planted with either pure Douglas fir, pure Norway spruce (*Picea abies*), pure European beech or a mixture of beech with either of the conifers. We used P80 suction lysimeters at 5 and 60 cm soil depth and collected soil solution over two continuous years to estimate nitrate leaching risks.

We found highest concentrations of nitrate in soil solution in lower soil layers under Douglas fir, which corroborates the findings of some studies conducted in pure stands. In Douglas fir-beech mixed stands, however, we found significantly reduced and sustained nitrate concentrations in soil solution, implying a mixture effect. Furthermore, soil texture played a key role in controlling nitrate leaching under Douglas fir as indicated by increased leaching on sites with finer soil texture. We discuss the results considering throughfall, litter, soil and microbial characteristics.

We conclude that Douglas fir stands pose a relatively higher leaching risk than Norway Spruce and a considerably higher risks compared to beech stands. However, the low susceptibility to leaching of beech stands seems to be a strong effect trait in mixtures, diminishing the high leaching potential Douglas fir induces on some sites. Low leaching potential is key to sustain adequate nutrition in temperate forests and reduces pollution of groundwater. Our findings strongly urge forestry experts to carefully assess site conditions and foster mixtures with European beech when planting Douglas fir.

Evaluation of carbon sequestration capacity of Forest Ecosystem based on the InVEST model

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: InVEST model has been widely used in all aspects of forest ecosystem service assessment for its advances in driving data collection, quantitative and spatial description of results simulations *et al*. However, during the application of this model, how to calibrate the model locally and how to eliminate the problem of low applicability to areas presenting weak land cover change caused by the simplification of the model is the key points to estimate the ecosystem services accurately. In this study, Kaihua county, the headwaters of Qian Tang river in Zhejiang, East China, was chosen as an example to analyze the changes of carbon stocks from 2000 to 2020. Results showed that forest is the dominant land cover in Kaihua accounting for 77.16%~81.64% at the year 2000, 2010 and 2020, variations of forest carbon stocks showed an insignificant trends only 4.16% and 3.95 from 2000 to 2010, and 2010 to 2020, individually. There are two reasons for this, one is that the changes of land covers were weak during the 20-year study period. The other one is that the carbon sequestrations caused by annual growth of different forest types including woodlands, shrubs, and sparse woodlands etc, were ignored during the process of carbon storage calculation in the InVEST model. Therefore, annual carbon sequestration increments were introduced to revise the results of the InVEST model, and the modified carbon storage increments reached 13.80% and 10.57%, respectively. Additionally, not all the age groups of forest have the same carbon sequestrate rates, the young and middle-aged forests have the largest increments while capacity of carbon sequestration among the near-mature and matured age groups declined significantly. Therefore, further research should quantify the impacts of changes in the proportions of young forests, middle-aged forests, near-mature forests, and matured forests ranged from 27.89, 39.62, 17.40, 15.09 in the year 2004 to 40.82, 36.66, 2.87, 9.65 in the year 2017, to improve the scientificity and accuracy of carbon sequestration modeling of forest ecosystems.

Evaluation of the impact of establishing electrical transmission lines on carbon stocks in upland forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Quebec could become a major player in greenhouse gas reduction through its capacity to export hydroelectricity to neighboring jurisdictions to contribute to their decarbonization efforts. In 2020, Quebec's energetic potential was estimated at 32 TWh based on Hydro-Quebec's surplus. This will undoubtedly lead to an expansion of the hydroelectric transmission network within Quebec's territory. It should be noted that the transmission line network for hydroelectricity in Quebec covers approximately 170,000 hectares, with the majority located in forested areas. However, although we currently know the impacts of the construction and maintenance of transmission lines on biodiversity, we are unaware of the actual carbon footprint of these lines on forested areas. Calculations in Canada's official greenhouse gas inventory are currently imprecise regarding land-use change, which are used for that type of linear disturbance.

The goal of this research project was to quantify the carbon stocks alongside the transmission lines across different forest ecosystems of Quebec and to evaluate their distribution and variability through various bioclimatic zones. The different carbon stocks that were measured include living biomass (aboveground and belowground), dead organic matter (deadwood and litter), and soils (soil organic matter) at different depths. The analysis of stocks were mainly conducted along two gradients of variability: i) the local ecological gradient created by the corridors of the transmission lines themselves and ii) the bioclimatic gradient of the hydroelectric network. In each of the study zones, sampling was conducted in the corridor, in the forests on the periphery of the corridor for a possible edge effect, and in the deeper undisturbed forests as control.

We observed that total carbon stocks were influenced by position in the transect, but not by bioclimatic zones. Corridor plots had significantly lower total carbon stocks than the other plots by the absence of grown forests. Furthermore, no significant difference was found in aboveground carbon stocks between edge plots and control plots, suggesting no significant edge effect by implementing corridors. Altogether, the accuracy of hydroelectricity's life cycle will be improved by these results and could potentially influence future policies concerning its exportation.

Explicit inclusion of forest canopy microclimate temperature buffering in a process-based model

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forest canopy buffering of macroclimate temperatures is well documented, but how local effects of microclimatic buffering scale up to long-term, broad-scale forest and disturbance dynamics remains unresolved. Forest management and processes such as carbon and nutrient cycling occur at landscape scales, making forest landscape simulation models important tools for projecting change. Yet, to date microclimate has not been explicitly considered in these models. We address these research gaps by explicitly modeling microclimatic temperature buffering as a function of topography, forest structure and composition, and seasonal phenology in the individual-based forest landscape and disturbance model iLand. We specifically ask, *How does simulated temperature buffering capacity vary in a topographically complex mountain landscape?* We compiled previously published data from over 300 plots widely distributed throughout temperate European forests and fit multiple linear regressions predicting monthly minimum and maximum buffering capacity (microclimate [at 1 m height] minus macroclimate, or free-air, temperature). In a forested mountain landscape (Berchtesgaden National Park, Germany), we simulated forest change, dynamic bark beetle disturbances, and microclimatic buffering at 10 m spatial resolution for 20 years under recent historical climate (2000-2020). Average annual daily maximum temperature buffer (TMaxBuffer) was -0.6°C and varied between summer (-1.1°C) and winter (-0.1°C). Forest types differed in temperature buffering capacity. Some forests (beech, spruce, mixed conifer-broadleaved) tended to cool maximum and warm minimum spring and summer temperatures, whereas others (larch-pine, dwarf mountain pine) showed the opposite trend. Bark beetle outbreaks reduced summer microclimatic buffering capacity by 70% (-1.6°C pre-outbreak to -0.5°C post-outbreak summer TMaxBuffer). With explicit inclusion of microclimate temperature, iLand can be used to explore how forest canopy buffering affects key processes such as decomposition, bark beetle dynamics, and tree regeneration over space and time. Understanding if and how microclimate temperature affects forest processes and scales up to landscape change is critical as climate warms and disturbances increase.

Factors driving changes in plant and microbial communities between coniferous and broadleaf deciduous boreal forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Changes in tree-canopy dominance can alter ecosystem functioning and habitat conditions for plant and microbial understory communities. Natural and anthropogenic disturbances have produced changes in tree-canopy dominance from coniferous to broadleaf deciduous forests, generating shifts in litter inputs and understory community composition. With a 5-year *in situ* experiment in eastern Canada, we analyzed the factors driving changes in understory plant and microbial communities and the resistance to shifts between forest types, using adjacent stands with similar topoedaphic conditions dominated by black spruce (*Picea mariana* (Miller) Britton, Sterns & Poggenburgh) and trembling aspen (*Populus tremuloides Michx.*) forests. We first analyzed how shifts in litter deposition affected plant understory community composition. Then, understory communities were physically exchanged between forest types, to determine their resistance under a new tree-canopy dominance through time, as well as the resilience of the forest understory after the transplantation. Finally, after 5 years of cumulative treatments of litter addition and understory transplantations, we used high throughput sequencing to identify changes in soil bacterial and fungal communities among treatments and forest types and to compare their community composition to the phyllosphere communities from leaves of both tree types. Results indicate that the diverse understory vegetation of aspen forests were resistant through time both after changes in litter deposition and in the new habitat of black spruce-dominated forest. In contrast, spruce understory (*e.g.* mosses and ericaceous plants) was negatively affected by broadleaf litter addition and transplants into aspen stands were invaded by aspen understory community species over time. Soil bacterial and fungal community composition was driven by a legacy effect of each forest as they were not affected by aboveground changes in plant understory composition or litter inputs, being different from the tree phyllosphere. Our study highlights the resistance and resilience of aspen forests and its role in plant and microbial diversity, in contrast to black spruce forests. Understory vegetation plays a crucial role in the resilience and preservation of ecosystem services in boreal ecosystems, particularly in the face of increasing changes in tree-canopy dominance in the boreal biome.

Foliar nutrient status of main European forest tree species and its association with forest growth

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Nutrients in forest ecosystems have a significant impact on tree growth and vitality. As the capacity of forests to sequester carbon increases with nutrient availability, it is essential to consider tree nutrient status when simulating future forest carbon uptake.

In this analysis, we make use of more than three decades of foliage data as part of the ICP Forests European monitoring network to analyze the nutritional foliar status of main European forest tree species. Temporal trends of foliar phosphorous (P) concentrations exhibited significant decline in main forest tree species. Over the investigated spatial domain of around 300 European monitoring plots, the percent change of foliar P concentration was in the range of – 6.1% to – 2.9% for beech, oak, pine, and spruce over 10 years relative to the year 2012, which could result in a weakening of carbon sequestration capacity in Europe if trees become increasingly P deficient. Trends of foliar nitrogen to phosphorous (N/P) ratios were significantly positive by tendency on multiple forest monitoring plots for oak and pine. This change in N/P balance suggests an increasing degeneration of P nutrition relative to N nutrition with potential adverse progression of tree canopy defoliation and discoloration.

In a follow-up analysis, we investigate the impact of meteorological parameters such as vapor pressure deficit and precipitation on ICP Forests growth data in intensive European monitoring plots of high and low nutritional status in order to examine the nutritional effect on climate-dependent tree growth rates and advance the link of carbon and nutrient cycles.

Forest Degradation in the Anthropocene: What and how much are we losing?

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forest degradation is a global human-induced phenomenon posing a major threat to ecosystem services, biodiversity and human well-being, being also a precursor to further forest loss. Although there is a large and growing source of literature documenting the environmental impacts of forest degradation, there are no comprehensive analyses of the impacts of degradation on forests. To address this knowledge gap, we conducted a systematic review of scholarly databases related to forest degradation and related terms for the period 1990-2022. This presentation outlines the concepts, causes, methods, and impacts of forest degradation at global and regional scales, under a conceptual model, contributing to understand their final effects on attributes, functioning or resilience. To this end we approach two main questions: What is being affected? At what level or intensity? Our results contribute to determine the scope of human influence on forests and allow better and more informed decisions in local and regional contexts for conservation and management efforts, also orientating future research in the area.

Forest soil carbon cycle in a drier climate – linking experiments, monitoring and natural gradient studies

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Dry extremes are increasing in frequency. Impacts of drought on soils and their biota range from immediate reductions of metabolic activities, acclimation of physiological processes to species shifts. Longer-term responses encompassing changes in soil organic matter (SOM) depend on carbon allocation from plants into soils and on the resilience of forest ecosystems to drought, which include the recovery from drought and the adaptation of plant and soil communities. Here, we present results from experimental manipulations of water regimes in forests at daily to multi-annual time scales as well as from natural precipitation gradients reflecting longer-term trajectories.

At daily to monthly time scales, we show in whole tree ^{13}C-pulse labelling experiments in a young beech forest and a mature pine forest, that drought suppresses the coupling of above- and belowground communities. Less new tree assimilates are allocated to the soil and their microbial communities (here measured as ^{13}C-PLFA). However, upon rewetting trees allocate greater amounts of assimilates belowground, probably to regain rhizosphere functions.

In a 20-year long irrigation experiment in a drought prone pine forest, water addition strongly increased soil C inputs by litterfall but also C outputs by soil respiration by a factor of two to three. Irrigation promoted bacteria and fungi with more copiotrophic life-style strategies being typical for a high C availability. We relate these shifts in microbial communities not only directly to the altered water regime but rather to a belowground "system change". Long-term irrigation induced a vertical redistribution of SOM from the organic layer into the mineral soil, which in turn affects SOM composition and microbial communities. The likely mechanisms for the SOM changes include a greater rhizodeposition as well as an increased incorporation of litter into the mineral soil through soil fauna reflected by a many-fold increase in the abundance and activity of soil fauna (e.g. earthworms) in irrigated soils. These findings indicate that reoccurring summer droughts reduce C inputs and storage in the mineral soil in this pine forest. This pattern is congruent with larger scale patterns across Swiss forest soils, showing declining soil C stocks with decreasing annual precipitation.

Greenhouse gases flux from forest cover loss between 1984 and 2022 and livestock grazing in tropical dry forests: a simulated analysis

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The Agriculture, Forestry and Other Land Use (AFOLU) sector accounts for about 23% of global greenhouse gas (GHG) emissions mainly carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). At the same time, well managed ecosystems in the sector contribute to climate change mitigation with the potential of absorbing about one third of the global anthropogenic CO_2 emissions. This study simulated the net GHG fluxes in a business-as-usual (BAU) scenario from forest degradation through illegal logging and intensive livestock grazing; and potential GHG offset options targeting community-driven restoration and livestock population management. Remote sensing was applied to compute forest cover change between 1984 and 2022 to indicate degradation level in Chepalungu Forest (5,004 ha), a tropical dry forest in Kenya. Reference carbon stocks were estimated from a similar non-degraded forest through inventory, while livestock population was determined using direct count approach. Tier 2 data were used to estimate GHG flux using EX-Ante Carbon-balance Tool. In about four decades, the forest area declined circa 87%. The existing livestock population in the forest composed of cattle, goats and donkeys was estimated at 27,005 under low productivity management. Under BAU scenario, emissions from forest degradation and grazing were estimated at 43,026 TCO_2eyr^{-1} (17,125 and 25,901 TCO_2eyr^{-1}, respectively). Restoration and sustainable management of 2,110 ha of degraded forest land and proportional livestock reduction by 280% to achieve the required carrying capacity led to an emission reduction of 64%, thus creating a net sink of 27,548 TCO_2e annually. Forest restoration had the highest flux share (40%) as potential net sink of CO_2 through biomass build up, while livestock management reduced net enteric CH_4 and N_2O emissions from manure by 55 and 5% respectively. These findings suggest that avoiding forest degradation and maintaining appropriate stocking rates in natural systems has a high potential to mitigate against climate change. Further, countermeasures that balance community needs and emission reductions, such as agroforestry, silvo-pasture and a shift to low methane emitting livestock may also significantly reduce emission levels.

How does the exclosure affect the chemical and biological properties of soil in oak forests?

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Human activities and the entry of livestock make destroying the forest as well as soil destruction
the basis of the life of terrestrial ecosystems. In this study, the effect of exclosure on some chemical and biological properties of soil was investigated in two Iranian oak habitats, Chari (exclosure) and Mavraz (without exclosure) habitats in Chaharmahal va Bakhtiari province. Soil samples were collected from a depth of 0-10 cm and chemical characteristics (pH, electrical conductivity, percentage of moisture, carbon and organic matter, total nitrogen, available phosphorus) and biological characteristics (microbial biomass carbon, soil respiration, substrate induced respiration, nitrification potential) were measured during two years. The Results showed that the effect of the site (exclosure) on available phosphorus, total nitrogen, substrate-induced respiration, the effect of time on carbon and organic matter, soil respiration and nitrification potential, and the effect of their interaction on electrical conductivity, organic carbon, organic matter, soil respiration, and nitrification potential was significant. The result indicated that the amount of available phosphorus in Chari (exclosure) due to higher vegetation cover and species diversity. The increase in total nitrogen in Mavraz habitat can be explained by the entry of livestock waste. There is a positive relationship between biological activity and organic carbon. In conclusion, habitat exclosure affects the biological and chemical properties of soil and has positive effects on soil fertility in the long term and consequently oak trees health.
Keywords: Basal respiration, Monitoring, Nitrification Potential, Organic Carbon, Protection

How extreme weather events affect the dynamics of the coarse wood debris in a Secondary Atlantic Forest Fragment?

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Extreme events, such as strong winds and storms, have a great influence on forest dynamics. The occurrence of extreme weather events has been increasing in the world, due to the worsening of climate changes. Such events cause tree mortality, which leads to an increase in necromass and alteration in the forest carbon stock. However, there are a few studies in the Atlantic Forest, even with the relevance of understanding the effects of extreme events on this biome. Our goal was to quantify the volume, necromass and carbon stock of the coarse wood debris (CWD) before and after the occurrence of a strong storm and to evaluate the impacts of the event on the forest components. The study area is a secondary forest fragment, with an area of 17 hectares, located in Viçosa, Minas Gerais, Brazil. The storm occurred in October 2019 and lasted about 5 hours, with wind gusts reaching 82.4 km/h and accumulated precipitation of 112.4 mm, with 67 mm recorded in the first hour. Coarse wood debris, such as branches, stumps and fallen trees on the ground and with a diameter ≥ 5 cm, were inventoried in 10 plots of 1000 m² (20 x 50 m), a few days before and shortly after the occurrence from the storm. Carbon content values were obtained using a dry combustion elemental analyser. The volume, necromass and carbon stock of the CWD before the storm was 31.57 m^3 ha^{-1}, 16.05 Mg ha^{-1} and 7.93 MgC ha^{-1}, respectively. After the storm, volume, necromass and carbon stock reached a total of 38.72 m^3 ha^{-1}, 20.12 Mg ha^{-1} and 9.94 MgC ha^{-1}, respectively. The carbon stock after the storm increased by about 2.01 MgC ha^{-1}, with the greatest impact being in CWD with lesser degree of decomposition. It is concluded that storms can influence the carbon dynamics of a forest, being interesting to study its effects within the Atlantic Forest as well as for several forests in the world.

How fast does forest carbon recover after fires – a perspective from south-eastern Australian temperate forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The Black summer 2020 wildfires burnt through about 7 Mha of mainly temperate Eucalyptus forests in south-east Australia, releasing an equivalent of Australia's total net annual emissions.

Study sites in SE Australia that had been assessed for all aboveground C pools in 2016, were burnt in high intensity prescribed burns in 2018, and high to moderate severity wildfires 2020. Carbon recovery was assessed in 2023, three years following moderate to high severity wildfires and five years after high intensity prescribed burns.

Within 6 months after wildfire tree mortality accounted for about 20 MgC/ha (or 10%) of carbon transfer from live to dead trees with a further similar amount 3-5 years after fires. Carbon loss from live trees burnt in high severity wildfires was 40 Mg C/ha (or 20%) with further loss of 5 MgC/ha after 3 years. In contrast, carbon loss from moderate severity wildfires and high intensity prescribed burns was only a half of that with a sign of recovery 3-5 years after. Compared with 2016 only 50% pre-fire live trees remained alive in 2023, with almost no recruitment of new Eucalyptus trees but profuse regeneration of Acacias.

Fires consumed about 50% of carbon stored in dead standing trees with no significant changes observed in CWD because of the recruitment of new CWD following fires. While all litter on the forest floor was burnt in fires, rapid recovery of litter due to litterfall from scorched and killed trees resulted in full recovery of litter soon after fires, and a doubling of litter loads 3-5 years after fires. Findings of this study question the assumption of exponential fuel recovery currently used in carbon assessment and fire modelling in Australia.

Our findings also indicate that as fire severity increases, carbon loss increases and recovery time is longer, suggesting that increase in fire occurrences and severity associated with climate change will reduce carbon carrying capacity for these temperate forests. Implication for the regional carbon balance will be discussed in this talk.

Identifying mycorrhizal decomposer fungi and their relationship to forestry in Sweden

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Mycorrhizal fungi form essential symbiotic relationships with the roots of plants, where the fungal partner grows into the soil, accessing nutrients and transferring some to their plant host in exchange for photosynthates. Some ectomycorrhizal fungi – here termed as mycorrhizal decomposers – possess genes coding for potent oxidative enzymes, such as manganese dependent peroxidases. Previous research suggests that certain fungi with these enzymes may reduce carbon stocks and potentially contribute to forest productivity by cycling organic nitrogen. Yet, current rotation forestry decreases ectomycorrhizal fungal diversity and may interfere with the pivotal activities of mycorrhizal decomposers. We explored which mycorrhizal fungi belong to this unique group in Swedish forest soils, and how they are related to forest disturbances, such as tree harvesting. Potential Mn-peroxidase activity and fungal community data were collected with high spatial resolution from six pine and six spruce forests in central Sweden, encompassing both young (15-20 years) and old (> 80 years) stands. We evaluated potential drivers of Mn-peroxidase activity, including soil fertility (based on carbon to nitrogen ratio and soil pH) and fungal community composition. We found little spatial auto-correlation in potential Mn-peroxidase activity even within 10 cm, indicating that hot-spots of enzyme activity are highly localised. Within site variation in enzyme activity was better explained by variation in the fungal community than by soil fertility. Some ectomycorrhizal groups with genetic potential to produce Mn-peroxidases, such as *Cortinarius semisanguineus* s.l, *Hysterangium* spp., *Gautieria monticola, Russula* spp., and *Lactarius* spp. were were significantly co-localised with hot-spots of Mn-peroxidase activity. Based on the Swedish Forest Soil Inventory data these fungi, which were identified as potentially important mycorrhizal decomposers, vary in their sensitivity to tree harvest. Notably, *C. semisanguineus* is present even in relatively recently cut forests (< 60 years old), while *Cortinarius aurae* s.l*,* is predominantly present in forests that have never experienced cutting. The finding suggests that some mycorrhizal decomposers are better adapted to fast recolonization after clear-cutting.

Immediate and carry-over effects of late-spring frost and drought on forest gross primary productivity capacity in the Northern Hemisphere

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forests are increasingly exposed to extreme global warming-induced climatic events. However, the immediate and carry-over effects of extreme events on forests are still poorly understood. Gross primary productivity (GPP) capacity is regarded as a good proxy of the ecosystem's functional stability, reflecting its physiological response to its surroundings. Using eddy covariance data from 34 forest sites in the Northern Hemisphere, we analyzed the immediate and carry-over effects of late-spring frost (LSF) and growing season drought on needle-leaf and broadleaf forests. Path analysis was applied to reveal the plausible reasons behind the varied responses of forests to extreme events. The results show that LSF had clear immediate effects on the GPP capacity of both needle-leaf and broadleaf forests. However, GPP capacity in needle-leaf forests was more sensitive to drought than in broadleaf forests. There was no interaction between LSF and drought in either needle-leaf or broadleaf forests. Drought effects were still visible when LSF and drought coexisted in needle-leaf forests. Path analysis further showed that the response of GPP capacity to drought differed between needle-leaf and broadleaf forests, mainly due to the difference in the sensitivity of canopy conductance. Moreover, LSF had a more severe and long-lasting carry-over effect on forests than drought. These results enrich our understanding of the mechanisms of forest response to extreme events across forest types.

Impact of bamboo on nutrient cycling and soil carbon stocks in highlands of Kenya

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Bamboo is among the fastest growing woody plant in the world with proven potential for soil erosion control, climate change mitigation and adaptation. Kenya has a total bamboo growing area of 133,273 hectares, concentrated in mountain ranges and forests. In Kenya, bamboo is gazetted as the 16th cash crop with potential for contributing towards economic development. Recently, bamboo growing has received massive attention from the Government and private investors. As bamboo plantations increase, there is need to quantify other ecosystem services accrued to the species such as nutrient cycling and carbon storage. Nutrient cycling and soil carbon stocks (CS) are vital factors in soil health which significantly affects ecosystem functioning. However, there is inadequate information on impact of different bamboo species on soil nutrients dynamics and soil carbon stocks. As such, data was collected from cropland (control) and 12-year-old bamboo plantations of *Dendrocalamus brandisii, Bambusa tulda, Dendrocalamus membranaceous, Bambusa vulgaris* and *Dendrocalamus asper* at Muguga, Kenya*.* Soil samples were collected from depths of 0-20 cm. Leaf litter quantities and litter quality were determined for the different bamboo species. The results showed significant differences in CS across land-use systems ($p<0.04$) with *Dendrocalamus brandisii* having the highest CS of 70.46 t C/ha while the cropland had the lowest CS of 41.48 t C/ha; a difference of 69.9%. In terms of soil nutrients, significant differences were only observed for nitrogen and phosphorus ($p<0.04$ and $p<0.01$, respectively) with *Dendrocalamus asper* recording the highest phosphorus concentration (29.6 ppm) while the control had the lowest concentration (4.53 ppm). Nitrogen concentration was significantly higher in the farmland ($p<0.05$) due to constant application of nitrogen fertilizer while soils under *Bambusa tulda* had 106% higher extractable potassium than the farmland. *Dendrocalamus brandisii* recorded the highest leaf litter of 2.25 t/ha. In terms of litter quality, *Dendrocalamus brandisii* had the lowest C/N ratio of 28.7 while *Dendrocalamus membranaceous* had the highest C/N ratio of 49.8. This study shows that bamboo plantations have the potential of mitigating climate change through soil carbon storage and enhancing nutrient cycling which is crucial for optimal ecosystem functioning.

Impact of forest management on forest carbon accumulation.

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: In the age of climate change, increasing greenhouse gas emissions and EU regulations, Poland, as a member of the European Union, is obliged to take the necessary measures to become an environmentally friendly country. This results in pressure for new environmentally friendly solutions. We has taken steps to use forestry practises developed so far (between 2017 and now) to increase carbon accumulation. Data was collected from approximately 6,662 hectares where management practises such as natural regeneration, the introduction of understory stands or the introduction of fast-growing species such as Douglas fir were implemented. The Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) was used for modelling. The outcome of the work is to estimate the impact of different management measures on carbon sequestration and/or retention and to select the best management practises in terms of carbon sequestration. Previous work and experience indicate that the greatest impact on carbon sequestration comes from the introduction of understory stands, natural regeneration and reduced tillage interventions when establishing new forest areas. The scientific studies conducted (e.g., carbon content in the soil, growth rate of trees in the stand, or carbon content in individual components of the forest ecosystem), combined with their verification in forestry practice, enabled the development of forest management practices that maximize the amount of carbon sequestered or stored.

Impact of soil compaction by forestry machinery on tree radial increments

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forestry machinery is a necessity for active forest stand management. The increasing weight of machines used in forests substantially affects soil conditions as their passage causes soil compaction, and changes in physical, chemical, and biological properties of soils. The changes in soil characteristics subsequently influence tree growth and productivity. The aim of the work was to quantify the impact of soil compaction on the radial growth of trees. The empirical material was obtained from tree cores sampled from 57 trees growing at a permanent research plot located at the University Forestry Enterprise of the Technical University in Zvolen, Slovakia. We evaluated the intensity of soil compaction after the passage of a forestry skidder LKT 81 ITL in 2020 with a digital penetrometer (Eijkelkamp Penetrologger 0615SA) and the density of passages. The results showed that one year after the skidder passages, the radial increment was significantly reduced by 28%. A significant reduction in radial tree increment was also confirmed when comparing the mean radial increment derived from the three years before and three years after the soil compaction. Soil compaction with the skidder within a radius of 3 m around a tree had the greatest negative effect on the radial increment. The findings confirmed that the passage of forestry machinery has a substantial negative effect on the productivity of trees occurring in the vicinity of passages. Hence, minimising the impact of heavy machinery on forest ecosystems by following operational rules with regard to weather conditions, spatial and temporal planning of forestry operations, and development novel technologies with reduced negative impacts on forest soils is highly recommended to ensure long-term ecosystem sustainability.

Influence of trees age, heights, social classes, silvicultural management and tissue types on the growth rates and chemical elements content

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: White spruce has always represented a significant part of biomass feedstock used by the Canadian wood industries. The end-use of a species requires a certain wood quality attribute (WQA), known to be influenced by climate and forest management. Unfortunately, there still have many uncertainties. For example, the accuracy and precision with which carbon (C) amounts have been accounted for in forests have been questioned. As countries seek to comply with agreements to reduce global warming and industries seek to maximize bioenergy potential, this matter has increased international concern. White spruce (*Picea glauca* (Moench) Voss) stand density management trials (thinning and spacing) in the Petawawa Research Forest, Ontario, Canada, were sampled to evaluate carbon, nitrogen and other chemicals concentration variation within trees and plots of differing stand density. Many parameters, including trees' age, sampling heights, social classes, silvicultural management and woody tissue types were tested on nine wood quality attributes (ring width, ring density, tracheid length, tracheid diameter, latewood proportion, intra-ring density variation, ring area, earlywood width, and latewood width) and eight wood chemical attributes (freeze-dried carbon, freeze-dried nitrogen, freeze-dried hydrogen, oven-dried carbon, oven-dried nitrogen, oven-dried hydrogen, volatile mass fraction and volatile carbon). Tests were performed in both the juvenile wood area and the mature wood area. Growth rates was found to be influenced by both thinning and spacing, but the impact of silvicultural management on WQA was limited. The variations in the juvenile wood and the mature differed with WQA. The variations in WQA associated with sampling heights were stronger than those associated with spacing. The spacing intensities impacted wood chemical attributes, with C content being higher in wider square spacings, while the reverse was true for N and H, which exhibited higher content in smaller square spacings. The results also suggested that when it comes to the content of chemical elements, bark and knots should be treated as separate fuel types, whereas other woody tissues can be aggregated. Finally, the results suggested that oven-dried carbon should continue to be used within the bioenergy industry, while freeze-dried carbon must become the preferred standard for carbon accounting protocols.

Insights from a chronosequence study: conifer-to-broadleaf forest conversion drives nitrate leaching in winter

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: From the 18th century onwards, extensive deforestation of native broadleaved species and subsequent reforestation with coniferous species took place in various regions of Europe. However, in recent decades, there has been a growing interest in converting these coniferous forests back, driven by the need for climate adaptation, enhancing biodiversity, and improving water quality. While coniferous plantations contribute to the economy through timber production, they often lead to increased levels of soil nitrate leaching, particularly after prolonged exposure to high levels of NH_3 and NO_x deposition. In contrast, broadleaved forests in the same location typically show lower level of nitrate leaching. However, the impact of such conversions on sites previously occupied by coniferous plantations on soil solution chemistry remains largely unknown.

In this study, we examined a chronosequence of 26 plots representing the process of converting coniferous to broadleaf forests in Thetford Forest, United Kingdom. During July-August 2021, we observed an increased rate of in situ net soil nitrification in the top 10-30 cm of soil in plots that were converted 5-8 years ago. Additionally, plots converted 10-13 years ago showed an accumulation of total nitrogen (N) in deep soils (30-90 cm). We found a negative correlation between nitrification rate and soil carbon (C) and N stocks, as well as pH. Conversely, we observed a positive correlation between nitrification and the thickness of the organic layer. Soil solution and throughfall samples were collected and chemically analysed monthly from August 2021 to July 2022. Peak nitrate leaching values occurred in February, and the order of decreasing values was as follows: stands converted 10-13 years ago > stands converted 5-8 years ago > mature coniferous stands > mature broadleaved stands.

Since there was no significant relationship between total annual nitrate leaching and nitrification or soil C and N stocks, we propose that changes in nitrate leaching fluxes were primarily driven by alterations in water fluxes. The association between nitrate leaching, leaching of base cations, soil acidification, and aluminium toxicity suggests that elevated levels of nitrate leaching prior to the growing season may have implications for the health and growth of broadleaf forests on converted coniferous sites.

Invasive pest effects on tree demographics and equilibrium carbon storage capacity across the northeastern US

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Nonnative pests and diseases have dramatic negative effects on forests that are particularly acute in northeastern North America where the density of invasive forest pests and pathogens is highest. The short and medium-term consequences of these invasions on host trees are well established. However, the ways in which the introduction of these organisms influences long-term structure, composition, and biomass storage capacity of affected forests are considerably less well understood. We used Forest Inventory and Analysis data from the USDA Forest Service to examine temporal trends and/or newly established equilibria in demographic properties of forests impacted by dominant forest pests introduced into northeastern North America over the past 140 years. Analyses to date have shown that tree demographic shifts in response to beech bark disease (BBD) significantly reduce carbon storage capacity of impacted eastern hardwood forests, while for green and white ash, forest recovery (albeit with a dramatically reduced ash component) is more likely in the wake of the Emerald ash borer. More specifically, beech baseline relative morality is twice as high in forests with the longest duration of BBD and beech small-stem abundance is ten times higher than in forests without BBD. This suggests that BBD has caused a shift in the forests' demographic equilibrium from normal maturation and self-thinning to smaller, denser stands over time. Using cross-validated estimates of the carbon storage capacity and sequestration rates for forests within the region in light of established and currently spreading invasives, we are building a more comprehensive understanding of how specific biological, ecological, demographic traits of host trees and invasive pests interact to determine rates of change and the potential for the ultimate return to pre-invasion equilibrium biomass and productivity.

Is afforestation for carbon sequestration an effective way to achieve carbon neutrality-The Case of Northwest China

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Afforestation is considered to be a promising way to mitigate climate change. However, its cost-effectiveness should be carefully evaluated, especially for regions with fragile environment and vulnerable ecosystem. This study develops a geographic-economic-ecological integration framework to evaluate the cost-effectiveness of afforestation for carbon sequestration in Northwest China. Based on the overlay model of natural factors and the economic optimization model of land use, the marginal land suitable for afforestation is identified. Then, the Richards growth function is employed to estimate the carbon sequestration potential of afforestation. Based on this, the carbon supply curve is fitted and the cost-effectiveness of afforestation for carbon sequestration is investigated. The results show that: (1) In Northwest China, 499.58×10^4 hectare of land is ecologically available for afforestation. However, only 102.71×10^4 hectare of these lands are economically feasible for afforestation, accounting for about 1/5 of ecologically available land. The lands suitable for afforestation are primarily grasslands and unused lands, which are mainly distributed in Qinghai and Gansu provinces. (2) Afforestation has a potential of carbon sinks with 9.37 million tons of CO_2 per year in Northwest China. By 2060, this potential will cumulatively be 374.88 million tons of CO_2, which can contribute 9.70%–15.06% of the region's carbon neutrality. (3) The marginal cost of forest carbon is 22.28–217.36 \$/tCO_2 in Northwest China, with an average cost of 137.52 \$/tCO_2. Compared with industrial emissions reduction, afforestation does not have cost-effectiveness to mitigate climate change in Northwest China. Additionally, afforestation would become even less cost-effective when consider the urgency of government to address climate change. These findings provide policy implications in designing and implementing carbon neutrality strategies.

LAND COVER AND CARBON STOCK DYNAMICS IN FINIMA NATURE PARK, BONNY ISLAND, NIGERIA

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The accurate evaluation of carbon dynamics due to land cover changes is crucial for the effective management of forest reserves as carbon sinks, particularly in a changing climate. This study analyzed the relationship between land cover (LC) changes and carbon dynamics in Finima Nature Park from 1987-2021. Thirty 30mx30m plots were randomly laid, and tree species with diameter at breast height (dbh) ≥10cm were enumerated. Tree height, dbh, diameter at the base, middle, and top were measured. Aboveground carbon (AGC) was estimated using the field data, while a model incorporating field data, spectral variables, and vegetation indices was developed to estimate AGC for 1987, 1999, 2010, and 2021, including their spatial distributions. The LC classes were dense vegetation (DV), sparse vegetation (SV), bare land, water body, and built-up, which exhibited changes over the study periods. The total tree population enumerated was 1696, of which *Anthostema aubryanum* (302) was dominant. *Pierreodendron africanum* had the highest concentration of AGC. DV and SV covered a total area of 801.76ha, and 167.92ha in 1987, 773.14ha and 170.98ha in 1999, 776.65ha and 147.34ha in 2010, 718.87ha and 189.7ha in 2021, respectively. Spatially, DV exhibited high carbon densities across most areas, while other LC types had low to no carbon concentrations. DV stored 77634.42tons, 80058.65tons, 108622.27tons and 99779.16tons of AGC in 1987, 1999, 2010 and 2021 respectively. SV stored 7853.62tons, 10428.07tons, 10480.29tons and 16562.71tons in 1987, 1999, 2010 and 2021 respectively. No AGC in other LC types. AGC storage exhibited an upward trend during 1987–2010 and a downward trend during 2010-2021. Overall, 85488.04tons, 90486.72tons, 119102.56tons and 116341.86tons of AGC were estimated in 1987, 1999, 2010, and 2021, respectively. The slight increase in DV cover in 2010 positively affected carbon density, whereas the sharp decrease in 2021 had a negative impact. Positive changes in the SV area contributed to net carbon, while negative changes had a negative effect. The LC changes in the park have influenced the concentration of AGC over the study periods. DBH and height, also contribute to this effect. Therefore, targeted management interventions are recommended to maximize carbon storage in the park.

Leaf Phenological Responses of Juvenile Beech and Oak Provenances to Elevated Phosphorus

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The few studies dealing with leaf phenological responses to elevated nutrients in forest trees have given ambiguous results, i.e., while some reported delayed leaf-out and autumn leaf senescence, others reported advanced leaf phenology caused by increased nutrition. This study aimed to determine the effects of experimentally increased phosphorus (+P treatment) on the leaf phenologies of two juvenile provenances of common beech and sessile oak. Other objectives were to determine whether there were interspecific differences as well as intraspecific variations. Saplings were excavated in two mixed beech–oak stands and transplanted into four wooden boxes filled with a commercial soil substrate. Phosphorus fertilizer was added to two of the boxes, while the remaining boxes served as controls. Both species responded to +P treatment with advanced autumn leaf senescence in the first year of the experiment. Leaf senescence in common beech began significantly earlier, while in both species, the process was accelerated compared to that in the control. In the second year, the leaf senescence response to +P treatment was even more pronounced in both species. The +P effect on leafing phenology was absent in both common beech provenances and in an oak provenance. However, the other oak provenance showed advanced leafing, indicating the existence of intraspecific differences.

Leaf traits of understory species are changing in response to climate change in the Congo Basin Forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Background– While tropical forests play an important role, in carbon sequestration, tropical species are assumed to be sensitive to rising temperatures and prolonged drought predicted to occur in the region. Plant functional traits are useful tools for understanding and predicting possible changes in plant communities.

Objective– We analysed the variation of foliar traits of woody understory species of the Yangambi Man and Biosphere Reserve and verify if this variation is potentially related to recent climate change.

Methods – Leaves of five shrub species were collected, in the 2019-2022 period in Congolese old-growth forest (Yangambi MAB Reserve, DR Congo), from different positions on the shrub to evaluate the variation within individua and as such test the possibility to use (historic) herbaria for the study of foliar traits. These leaves were compared to herbarium specimens collected in the same area in the 1935-1960 period. In both studies we assessed leaf size, specific leaf area, stomatal size and stomatal density for all species.

Results –This study shows that the variability of the functional traits of the woody understory species are independent of the position of leaves in the crown. This makes it possible to use historic herbarium for trait analyses from tropical undergrowth shrubs. Characteristics of the recently collected leaves were notably different as compared to the herbarium leaves collected between 1935-1960. Recent leaves were significantly larger, had a higher SLA, and a smaller stomata pore length as compared to historical herbarium specimens.

Conclusion – The difference in measured trait characteristics over time correlates with the upward trend of the average temperature measured in the area over the last 80 years in Yangambi, while average annual rainfall had remained unchanged.

Our results provide a first insight into the response of forest species to climate change in the forests of the Congo Basin, and how the undergrowth species and the ecosystem will react in the longer term when temperature further increases. However, as our study is based on a limited number of species and only for one region a more extensive study is needed.

Keywords: Climate change, leaf traits, understory woody species, Congo Basin Forests, Yangambi

Litter decomposition and stabilization as affected by soil fauna functional group and tree species shift in a temperate forest soil

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Soil represents the largest terrestrial carbon (C) reservoir, where C is stored in the form of soil organic matter (SOM). Temperate forest soils in particular have a great potential to store C. Soil fauna generally facilitates litter decomposition and helps stabilize available C in temperate forest soils. However, the specific effects of different soil fauna functional groups (micro-, meso-, and macrofauna) are less known. Limited knowledge is also available on the effect of a tree species shift (from coniferous to deciduous) expected as a result of climate change. Here we present preliminary results of our laboratory mesocosm experiment focused on the decomposition of litter of variable quality (higher-quality beech and lower-quality spruce litter) affected by soil microorganisms and microfauna, mesofauna and macrofauna (*Armadillidium vulgare*). We also focus on incorporation of C from these litters into the SOM fractions of variable availability (more available particulate organic matter (POM) and less available mineral-associated organic matter (MAOM)) in temperate mixed forest soils and discuss possible future implications under climate change scenario.

Litterfall production and associated elemental flux in cool-temperate stands with contrasting functional types in Daejeon, South Korea

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Litterfall provides a dynamic pathway for carbon and nutrient entry into the forest soil, thereby influencing the movement of biomaterials within and between terrestrial ecosystems. However, our comparative understanding of litterfall and elemental fluxes in broadleaf deciduous and coniferous evergreen forests growing in similar localities remains limited. Here, we quantified the long-term litterfall production patterns and nutrient inputs at a broadleaf deciduous stand located in Daejeon (hereafter, BDF_A) and compared these estimates with stands exhibiting a different dominant functional type (CEF) and sub-canopy composition (BDF_B). Seasonal and annual litter debris, including foliage, twigs, bark, reproductive structures, and miscellaneous components, was collected for at least two calendar years using circular litterfall traps. Intercepted litter during periods of high litterfall was composited per fraction and analyzed for carbon and macronutrient concentrations. The mean annual litterfall production in BDF_A was identical to that in BDF_B and CEF, ranging from 841.47 g m^{-2} to 990.24 g m^{-2}. Foliar litter accounted for 63% to 69% of total litter debris in all three sites. Litterfall exhibited pronounced seasonal fluctuations caused primarily by relative humidity, wind speed, and solar radiation. Except for carbon, macronutrient concentrations were consistently higher in BDF_A and BDF_B compared to CEF. Macronutrient input from litterfall was the highest in N (943.76–111.14 kg ha^{-1} yr^{-1}) and the lowest in P (3.26–4.14 kg ha^{-1} yr^{-1}) across all investigated stands. BDF_A and BDF_B returned higher amounts of potassium (K), calcium (Ca), and magnesium (Mg) to the forest soil relative to CEF. Nutrient use efficiency in CEF was higher than that in BDF_A and BDF_B for all macronutrients, following the pattern P > Mg > K > Ca > N . The effect of forest functional type on nutrient cycling via litterfall is more strongly dependent on nutrient returns than litter quantity due to the differences in the mechanisms by which broadleaf deciduous and coniferous evergreen communities acquire, utilize, and resorb nutrients prior to litter formation. Our findings are relevant to the understanding of biogeochemical cycling dynamics in various cool-temperate forest zones in South Korea and other areas alike.

Long-term dynamics of the carbon budget in loblolly pine plantations

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Intensively managed pine plantations in the southeastern US could not only meet the increasing demand for traditional wood products and biomass for energy, but also play a critical role in meeting US GHG emission reduction goals through additional carbon sequestration. Adapting forest management to mitigate climate change requires an understanding of the long-term effects of silvicultural treatments on forest production and carbon sequestration. A loblolly pine (*Pinus taeda* L.) silviculture-by-density study was initiated in 1995/96 with 40 installations across the southern US. Each installation contains 12 large plots planted at six levels of planting density (ranging from 740 – 4448 trees/ha) in combination with two levels of silvicultural intensity (operational vs. intensive management). With the long-term data from this study, we assessed the impact of site quality, cultural intensity, and planting density on temporal dynamics of aboveground net primary production in carbon (ANPPC), total carbon uptake, aboveground living tree biomass carbon (AGC) stocks, and cumulative carbon released back to the atmosphere. Silvicultural intensity and planting density significantly affected ANPPC before age 15 years. Total carbon uptake was significantly affected by site quality at early ages, and by both culture and planting density over the study period. Carbon released back was significantly affected by site quality during mid-rotation, by planting density after age 6, and by silvicultural intensity over time. AGC stocks were significantly affected by site quality at early and late ages, by silviculture intensity before age 15, and by planting density over time. After age 20, stands on higher quality sites stored higher amounts of carbon, but higher-planting density stands might store less carbon, with no significant differences between silvicultural intensities. Our results indicate that management practices that enhance growth and carbon absorption in young stands do not necessarily result in more carbon storage at later developmental stages. The relationships between management practices and carbon sequestration in plantations need more research to further develop climate-smart forest management practices.

Long-term effects of Norway spruce and European beech on soil properties and carbon stocks

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) are among the most ecologically and economically important tree species in Europe. Historical afforestation policies led to the extensive planting of spruce in Slovenia and other European countries. However, the species now faces severe pressure from global warming and forest disturbances. As a result, forest management strategies in Central Europe aim to convert spruce-dominated forests into mixed forests, with beech being a promising deciduous species for this purpose. Climate change is also expected to drive the migration of deciduous tree species to higher elevations currently dominated by spruce.

This study aims to compare the long-term effects of these two tree species on soil properties and carbon stocks. Forest soils play a crucial role in supporting forest growth, carbon sequestration, and climate change mitigation through long-term carbon storage. Trees influence soil properties through litter inputs, water dynamics, nutrient uptake, and other processes. Understanding the relationships between tree species and the soil environment is essential for sustainable forest management, carbon sequestration, and addressing issues like soil acidification.

This study will focus on two sites in Slovenia, one on siliceous (Pohorje area) and one on carbonate parent material (Snežnik-Javorniki plateau) with similar stages of soil development, which had the same forest stand species composition for over 50 years. Soil chemical properties (pH, cation exchange capacity, base saturation, total organic carbon (C_{org}), total nitrogen (N), dissolved C_{org}, mineral N, plant-available P and K) and soil physical properties (texture, bulk density, mechanical resistance, and water holding capacity) will be measured. The findings will enhance our understanding of the influence of tree species on soil properties and soil carbon stocks in selected areas. The results will be valuable for developing forest management strategies, improving carbon storage, and addressing undesirable soil-related phenomena. Considering the changing climate and potential shifts in forest composition, it is also crucial to assess the ecological impacts of the transition from spruce- to beech-dominated forests.

Long-term forest stability: Mode of tree mortality matters.

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The biomass in a forest is a function of the productivity and mortality rate of the trees that compose it. Under increasing abiotic disturbance (e.g., windstorms, fires) or physiological stress (e.g., droughts, pests), forests will first change in age, composition and could ultimately tip over into other ecosystems such as grasslands. We are using an ensemble of seven vegetation models to investigate the effect of changes in tree mortality rates on the resilience of forest ecosystems. These state-of-the-art demographic vegetation models explicitly resolve the size structure of trees within forests and their processes of growth, death and establishment. These models scale from leaf to population to region and are a powerful tool to explore different scenarios of forest futures. They are increasingly integrated within Earth system models to improve climate projections. Because these

models directly simulate forest structural (e.g. tree diameter classes) and dynamical variables (carbon content over time) which are widely observed in the field, it is possible to more tightly constrain their behaviour to real forest dynamics than more abstract representations of vegetation. In this study we first verify model outputs against observations from forest inventory plots across boreal, temperate and tropical forests. We then explore how the increase of mortality affects the new emerging dynamic equilibrium of these ecosystems. Our results highlight that the mechanism of mortality has a strong impact on the biomass trajectory of the ecosystem. For example, increases in stand-replacing disturbances lead to a very different level of resilience than an increase in overall background mortality rates, even for the same unit increase in tree mortality. Therefore, large-scale assessments of forest carbon balance in light of changing mortality regimes need to take account of the “how”, as well as the “how much”.

Modelling nitrogen limitation of litter decomposition

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The dynamics of belowground organic matter has been widely studied due to its association with forest management, environmental sustainability and climate change mitigation. White carbon and nutrient stocks ultimately depend on rates of input, decomposition losses are just as important in stock regulation of stocks, but are notoriously difficult to assess reliably. Different approaches have been used to address constraints on decomposition.
Mathematical modelling is one of the tools to understand and predict soil organic matter dynamics and its association with other soil processes. Most of the widely used soil organic matter models have been developed with a focus on carbon dynamics rather than on element interactions. However, in many regions of the world, particularly at high latitudes, soil organic matter decomposition is constrained by low nitrogen availability, but this phenomenon is usually not explicitly incorporated in the decomposition models. Nitrogen dynamics is pivotal in regulating aboveground productivity, and retention of nitrogen in soil may hamper availability to trees. However, the mechanisms behind belowground retention and release of nitrogen are poorly understood.
We formulated a process-based model of decomposition of plant litter to investigate the effect of nitrogen limitation on decomposition. The model describes the dynamics of a single litter unit over time, as it is decomposed by fungi. It has five pools with different C:N ratios. Unlike most other decomposition models, our model reflects the microbial (fungal) dynamics explicitly. Fungal biomass is divided into two different fractions describing the different state of fungal cells, 1) cytoplasmic cells with high decomposer activity and 2) vacuolised cells with a lower N content and lower activity. The fungus adapts to N limitation by increasing the proportion of vacuolised cells. The model is capable of predicting mass loss trajectories of a variety of litter types from information about initial nitrogen and lignin content, based on single set of global parameters. In order to predict patterns of nitrogen retention/release, decomposition of fungal necromass has to be slow, with decomposition rates more similar to those of recalcitrant lignin. The model will be used as a component in future ecosystem models with trees and mycorrhizal interactions.

No increased mortality from drought stress in thinned stands: results from a meta-analysis

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forest researchers are confronted with the challenge to propose appropriate and evidence-based silvicultural options that mitigate negative effects of droughts induced by climate change. Water stress may be alleviated by reducing the number of transpiring trees in a stand through thinning. So far, it has been comprehensively studied how thinning influences stem growth of trees during and after droughts. Mostly positive, but also mixed effects of thinning on growth response indicators were found but also a high dependence on confounding factors. Here, we conducted a meta-analysis on thinning effects on tree mortality after drought to assess thinning as an adaptation option fostering drought resistance. Additionally, we investigated whether thinning changed mortality patterns among tree dominance classes for a subset of studies that provided the necessary data.

We found 29 thinning experiments from 10 studies in Europe and North America that assessed mortality before and after a drought event. Our analysis indicates that mortality rate in unthinned control stands was more negatively affected by drought compared to thinned stands. Also, there was a weak negative relation between thinning intensity and mortality. However, owing to the high heterogeneity between studies due to differences in study design and forest types, we cannot provide robust evidence that there is an effect, but state that thinning does not alter mortality after drought substantially. In both thinned and control treatments mainly suppressed trees died; there was no shift in mortality to more dominant trees that are more exposed to radiation in thinned stands.

While thinning did not clearly mitigate drought-related mortality, it also did not exacerbate it. Thus thinning, which has been previously shown to improve growth in relation to drought and has other benefits such as reducing production times and risk of wind-throw, would not come with higher mortality risk. After all, our meta-analysis was characterized by high heterogeneity. To allow for more general statements and more precise identification of confounding factors a much higher sample size would be necessary. This calls for more standardized reporting of results from thinning studies to compile a global database.

Nutrient mobilisation from forest floors along four elevation-related temperature gradients in European beech forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Slow turnover of the forest floor (FF) is often assumed to be related to immobilization of nutrients within the organic matter. However, the FF is also assumed to be an important nutrient source at sites with low nutrient concentrations of the mineral soil. Yet, little is known about the availability of nutrients present in the FF and how it is related to FF turnover.

Within the DFG-funded Research Unit FOREST FLOOR weidentify processes that control the relevance of the FF for tree nutrition as compared to the mineral topsoil in European beech (Fagus sylvatica) forests with admixtures of Norway spruce (Picea abies) and maple (Acer pseudoplatanus). Wequantify resin extractable macronutrients at lab conditions in the FF and the mineral topsoil along four elevation-related temperature gradients with different P status of the mineral soil on silicate and on carbonate rock. We hypothesize that nutrient availability in the FF at high mean annual temperature (MAT) sites is lower compared to low MAT sites due to temperature-enhanced immobilization of the nutrients by the microbial biomass and leaching into the mineral soil. Consequently, we expect a higher nutrient availability in the mineral soil at high MAT compared to low MAT sites due to faster nutrient mineralization of the litter. Furthermore, we argue that temperature dependency of nutrient immobilization depends on the P status of the mineral soil. Among the three tree species, spruce, maple and beech, we expect that the FF will contribute more to nutrient uptake in spruce than in maple, while FF in beech will take an intermediate position.

Preliminary analyses on P poor sites (< 300 g P/m2) in the Black Forest showed that higher temperatures decrease not only the stock of available P (Pres) of the FF but also the Presstock of the upper 10 cm of mineral soil (Kandel, MAT 5 °C, 10 g Pres /m²]; Waldkirch, MAT 9 °C, 8 g Pres/m²]). These first results support the crucial role of the FF for beech forest nutrition and its vulnerability under climate change.

Nutrient uptake, microstructural changes and antioxidative mechanisms in Phyllostachys vivax transplanted into coastal site

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Chinese timber bamboo (*Phyllostachys vivax* McClure) has been successfully intro-duced to the coastal belt of eastern China. However, the mechanisms of nutrient uptake and antioxidative protection of *P. vivax* in response to salinity adaptation in coastal areas remains unclear.*P. vivax* forests were studied in their native and coastal transplantation sites within the coastal belt of China. In particular, nutrient allocation, anti-oxidative enzyme activities, biomass accumulation, water contents, water potentials, and root system morphologies vs. microstructures were evaluated in plants from the two sites.

Plant morphology adapted to the coastal saline soils by increasing root/shoot ratios and the length of large diameter rhizome, increasing vascular numbers, and lightening epidermal cells within rhizomes. The ratio of Ca^{2+}/Na^{+} increased, while K^{+}/Na^{+}, Mg^{2+}/Na^{+} decreased after transplanted to the coastal sites. Nitrogen nutrient contents were significantly positive correlated with plant growth characteristics of *P. vivax*. The Mg^{2+}, Na^{+}, and Ca^{2+} concentrations contributed more significantly to differences among organs, while N, Mg^{2+}, Na^{+}, and Ca^{2+} contents contributed more to root systems. Nutrition uptake regulation by *P. vivax* primarily occurred via tissues that limited the excessive absorption of Na^{+} and the complementary reduction of ion toxicity. The activities of superoxide dismutase (SOD), peroxidase (POD), and ascorbate peroxidase (APX) decreased, while the levels of glutathione (GSH) and ascorbic acid (AsA) increased in belowground tissues. The contributions of catalase (CAT) and proteins were higher for the principal components explaining variation among different organs, the protective enzymes played indirect roles in the growth of *P. vivax*.

Overall, our investigation shows that *P. vivax* maintained normal growth after transplantation to the Yancheng coastal beach. The root system should be protected and the water balance of root system should be maintained when *P. vivax* is transplanted to the salinity site. It is very important to maintain the nutrient content in the soil around underground root system. Nevertheless, these results are preliminary, and further investigation should be conducted to understand the adaptive mechanisms and nutrient uptake of bamboo plants in coastal belt sites, particularly over longer time scales.

Old-growth forests get nitrogen saturated – what does this imply for their climate effect?

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Many European forests are exposed to nitrogen (N) deposition above critical loads. In old-growth forests or forest reserves, where no N is removed in products, this may lead to N enrichment and with time N saturation.

In the longest unmanaged forest in Denmark, Suserup, soil water monitoring has shown a constant high nitrate leaching for 20 years, with N-leaching at or higher than the N-input from throughfall. Thus, this ecosystem is clearly N saturated. Since carbon (C) and N are closely related in biomass and soil organic matter, this may signal that the forest ecosystem is also C saturated. Repeated biomass inventories indeed indicate that the forest has reached its maximum biomass. Thus, this old-growth forest is likely neither a sink nor a source of CO_2.

However, with high N availability and acidic topsoil there is risk that N_2O is formed in the soil during nitrification. In a pilot study we have measured high N_2O-emision in Suserup forest (significantly higher than in a nearby managed forest) and at levels that could turn the forest into a source of CO_2-equivalents.

In this presentation we will report a full year of N_2O-emission observations from Suserup forest and a nearby managed forest to evaluate the potential contribution of N_2O-emission to the overall greenhouse gas balance of these forests. Further, we will report on short-term comparisons of N availability, nitrate leaching and soil N_2O-emissions in other paired (managed and unmanged) forests to infer if N saturation and elevated N_2O-emissions generally occur in old unmanaged forests.

Post-fire vegetation dynamics in southwestern forest at Saudi Arabia (KSA)

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forests in the southwest of Saudi Arabia had severe wildfire in October 2020, endangering their natural vegetation, especially Al-Mufrah mountain. It is one of a group of mountains in Al-Soudah, has a substantial amount of flora covering it, and is the first destination for tourists visiting Saudi Arabia. Post-fire vegetation dynamics is examined over an extended timescale, to investigate the effects of fire on plant diversity and to verify the ability of plant species for regeneration naturally. Permanent plots were sampled at three locations along a gradient from 2500 to 2700 m. Plot locations corresponded to three community types: *Dodonea* sp.- *Acacia* sp. (low slope); *Acacia* sp. (mid slope); and *Juniperus* sp. (high slope). vegetation measurements were used to determine the effects of fire on the mortality and regeneration of trees, shrubs, and herbaceous species.

The findings demonstrate that mortality was greatest in the high slope position, significantly decreasing in the trees level. The mid-slope position had a lower death rate than the high-slope position, while the low-slope position had the lowest mortality. These death rates were correlated with the severity of the fire and the type of plant community. Species richness and diversity varied over the hillside gradient according to the ability of plants to regeneration naturally. The diversity of the herb-layer on the ridge greatly increased, but the diversity of the trees declined. The trees on the midslope showed little sign of alteration, although they have the capacity to naturally regenerate. Trees, shrubs, and the herb layer did not alter on the low slope. This will help to focus conservation efforts and provide a framework for research, conservation, and policy development for post-fire vegetation dynamics in the forest.

Recovery of ecosystem carbon pools 35 years after whole-tree harvesting a balsam fir – red spruce forest

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Long-term data on the contribution of forests in mitigating the impacts of anthropogenic CO_2 emissions across different climates and site conditions is needed to inform forest management and policy. This study reports on the effect of whole-tree (WTH), stem-only (SOH) and no-harvest for a balsam fir-red spruce forest at the Weymouth Point Study Area in Maine, USA. The field work took place on various occasions from 1979 to 2016 in two adjacent watersheds with similar species composition and disturbance history. One watershed was clearcut harvested in 1981 and the other was left as a reference. Despite different levels of harvest residue inputs in WTH and SOH, there was no significant difference between the treatments for deadwood, forest floor and mineral soil C pool 35 years after harvesting, and the impacts on living biomass C was not consistent across drainage class groups. However, living biomass, deadwood and forest floor C pools of the 35-year-old forest were significantly smaller than the corresponding pools of the reference forest, while the mineral soil C pool tended to be larger. The recovery ratios for living biomass, deadwood, forest floor and mineral soil C of the 35-year-old forest were 62-67%, 38-39%, 55-64%, and 115-124% relative to the corresponding pools in the reference forest (Mean±SE135±11, 15±2, 44±3, and 78±8 Mg C ha^{-1}, respectively). Comparison with previous results from WPSA and the scientific literature across northeastern North America suggested that recovery of living biomass C is rapid, that recovery of forest floor C pools may largely take place within a single rotation of typically 80-100 years, while recovery may take longer for the deadwood C pool. The further development in the C recovery ratio will depend on the occurrence of future natural disturbances in the 35-year-old forest, and the extent to which the C pools of the reference forest fluctuate around a steady-state or a trend. It is a political decision if assessment of the climate change mitigation potential of forests is only based on the development in forest C pools, as reported in this study, or also forest product C pools, and substitution effects.

Simulating drought responses of European forests with a process-based model

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The unprecedented extent and intensity of hot and dry weather conditions in Europe in recent years is considered a new benchmark for drought conditions for the region. Additionally, the frequency and intensity of such hot drought (or compound) events are expected to be exacerbated in future conditions characterized by higher temperatures, leading to wide-spread forest decline driven by increased tree mortality. Forests store large amounts of carbon in biomass and soils and provide wood which can replace carbon-intensive materials and fuels. The protection and expansion of forests therefore is a crucial feature of climate mitigation pathways, but at the same time critically affected by climate change. Thus, understanding the negative effects of drought on European forests is of high relevance. Estimating the future impacts of drought on the carbon cycle and other related ecosystem processes and services – *e.g.*, forest regeneration and timber production, is a major challenge. The task requires robust modelling frameworks and theoretical understanding of how vegetation responds to changing environmental conditions. Here, we present the implementation of a new plant hydraulic framework in the well-established dynamic vegetation model LPJ-GUESS. It simulates the mechanism of water potential regulation of individual trees and drought-induced carbon losses from tree mortality. Hydraulic parameters for seven common European tree species were estimated from the literature and plant trait databases. A sensitivity analysis of model outputs (primary productivity, evapotranspiration, drought mortality) and a benchmark of historical model runs were performed. The model successfully reproduces carbon and water fluxes at FLUXNET sites and identifies hotspots of carbon losses during the European droughts in 2003, 2018, and 2022. We conclude that the model is suitable for evaluating future drought risks and present simulation results from a range of forest conservation, reforestation and forest management scenarios using e.g., CMIP6 climate projections. Based on these simulations we can assess the carbon dioxide removal potential of land-based mitigation efforts and identify adaptation strategies which ensure the continued provision of manifold forest ecosystem services.

Soil carbon dynamics during the first years following pseudo-steppe afforestation by Eucalyptus robusta trees on tropical highlands

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Afforestation is known as an efficient climate change mitigation option by the ability of forests to store carbon in tree biomass and soil. However, data on soil carbon storage, sequestration capacity and dynamics in planted forests are scarce in Sub-Saharan African countries, particularly in highlands. This work aims to assess the potential of eucalyptus plantations (EP) on soil carbon sequestration during the first years following the afforestation of grassland. EP are the primary fuelwood source in Madagascar where one of the main drivers of deforestation is the need for fuelwood. Our hypotheses were: i) soil carbon stocks increase with tree biomass ii) mineral fertilizer improves biomass production and so soil carbon sequestration iii) soil carbon contents vary spatially depending on the distance from the tree. The study was conducted in Anjozorobe in the Central Highlands of Madagascar with average annual rainfall and temperature of 1295 mm and 18.7°C respectively. The soils are Ferralsols. Natural vegetation is characterized by a pseudo-steppe dominated by *Aristida sp* grasses. A four-age chronosequence (2, 4, 5 and 6 years old) of *Eucalyptus robusta* plantation with and without mineral fertilization was selected with two controls as the initial (pseudo-steppe) and final (more than 60 years old EP) state of land use change from grassland to planted forest. These ten treatments have three replicates. In each inner plot, soil samples were collected at six depths (0 - 5 cm, 5-10 cm, 10-20 cm, 20-30 cm, 30-50 cm and 50-100 cm) at three different distances from a tree. Determination of soil carbon content and bulk density calculation will permit the estimation of soil carbon stocks in different soil layers according to the spatial position at the plot level and the fertilization application. Aboveground tree biomass was estimated by measuring circumferences at breast height and height of each tree and sampling destructively eight trees per treatment. Allometric equations were established to estimate the biomass of all aboveground tree compartments and the relation between soil carbon storage and tree biomass will be deducted. The results will give insights into the capacity of EP on tropical highlands to improve soil carbon sequestration.

SOIL CARBON, NITROGEN, SULFUR, AND C/N RATIOS IN PERMANENT FORESTS RESERVES OF TERENGGANU, MALAYSIA

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Carbon and nitrogen are two vital components that play a crucial role in preserving the health and productivity of forest ecosystems. The permanent forest reserves managed by Terengganu State Forestry Department are essential in maintaining the natural habitats of diverse flora and animal species. Also, these reserves offer beneficial ecosystem services like nitrogen cycling and carbon sequestration, which are crucial for reducing the effects of climate change. However, there is a significant lack of documentation on the soil carbon and nitrogen distribution in the forest reserves including sulphur and C/N ratios. This information is essential for maintaining the health and productivity of these ecosystems. By studying the cycling of this element, we can gain insight into how these ecosystems function and how they may respond to environmental changes or the effect of logging and it will benefit the decision-makers, who need to make informed decisions about forest management strategies. Therefore, evaluating the current carbon and nitrogen distribution is crucial in making suitable plans to rehabilitate and conserve the forests. This study aims to assess the soil carbon, nitrogen, sulfur, and C/N ratio distribution as part of evaluating the soil health of Terengganu permanent forest reserves. Soil sampling was carried out at the research plots of endangered timber species. Composite soil samples were collected from 0-40 cm depth and were air-dried for 48 hours at room temperature prior to analyses. Analyses carried out include bulk density, soil pH, and carbon, nitrogen, and sulphur analyses. The soil analysis is currently underway, and the results will provide valuable insights into the distribution of carbon and nitrogen in the protected forests of Terengganu. These findings will contribute to our understanding of how these ecosystems function and respond to environmental changes, ultimately helping to maintain their health and productivity.

Soil moisture controls the partitioning of carbon stocks across a managed boreal forest landscape

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Boreal forests sequester and store vast amounts of carbon (C), with likely important feedbacks potential to climatic warming. To understand climate change impacts on carbon stocks it is important to assess the controlling factors determining the magnitude and partitioning of different C pools within different scales. The boreal landscape is heterogonous, consisting of a mosaic of forests and peatlands with large variations in total C stocks within small distances. We quantified the total C stocks including the organic layer, mineral soil and the tree biomass in 430 plots across a 68 km^2 boreal catchment. We could show that the organic layer constituted the largest C pool, accounting for 39% of the total C storage, followed by tree and mineral C pools constituting 38% and 23%, respectively. Modelled soil moisture conditions revealed a clear increase in the magnitude of total C stocks with increased soil moisture, which was especially pronounced for the soil organic C pool (R^2=0.50). In contrast, the tree C pool followed a unimodal relationship with the highest storage at intermediate wetness conditions. The partitioning between tree and soil carbon pools were also highly dependent on soil moisture conditions, which in the small spatial scale of this study is mainly driven by topographic variation. In addition, we revealed a similar magnitude and variation in the total soil C stocks compared to those found at the national level in Sweden, suggesting that the local scale variation, primarily driven by soil moisture conditions is far more important than regional differences in climate, nitrogen deposition and parent material for C accumulation in the boreal landscape.

Soil organic carbon in high karst Dinaric fir-beech forests is influenced by site morphology, soil type and harvest intensity

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Close-to-nature (CTN) forest management has traditionally been applied in fir-beech forests of high karst Dinaric regions. CTN management preserves soil organic carbon (SOC) through low levels of forest stand disturbance and changes in a microclimate with a relatively high amount of growing stock. SOC storage was used as an indicator for the valorization of the effects of CTN forestry management in beech and fir forest stands. The same methodology was applied to four selected plots in Slovenia and Bosnia and Herzegovina with applied different harvest intensities. The designed forest experiment resembled large-scale disturbances taking place in 2014 and 2017, such as sleet, windthrows, and consequent bark-beetle attacks. SOC varied in relation to site micromorphology and soil type. Higher harvest intensity, including 50% and 100% reduction of growing stock resulted in variations of SOC and nitrogen in the forest floor and upper mineral layer. The analysis did not confirm any significant differences in SOC storage on sites with applied low-intensity harvests (less than 20 % of the growing stock). Provided results explain soil organic carbon storage related to CTN forest management, prior to and after harvests which resemble to natural disturbances, and may serve as a reference for the future comparisons of similar highly productive forest sites.

Soil organic matter fractions and soil carbon storage as affected by forest type and climate change

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Temperate forests have a great potential to store soil organic carbon (SOC). Coniferous forest topsoils generally store more SOC than deciduous forest topsoils. However, less is known about C distribution in subsoils. Also important is the partitioning of SOC into fractions of soil organic matter (SOM), which differ in terms of formation, persistence, and function. Few studies have compared the proportions of C in SOM fractions between coniferous and deciduous forest soils or the influence of C inputs of variable quality and of soil community composition on SOM fraction formation and persistence. Fraction formation and persistence might also be greatly affected by climate change, which includes an increase in temperature and a shift in the distribution of tree species. Here we present results of our field study focused on the partitioning of SOC into fractions of SOM in temperate forest topsoils and subsoils under spruce, beech, and mixed forest stands. We also discuss results of our laboratory experiments focused on the effects of C inputs of variable quality and climate change on SOM fraction formation and decomposition.

SOM-mineral association and interaction in forest floors of silicate vs. calcareous soils

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: In forest ecosystems, the accumulation of plant residues on the soil surface creates a unique zone rich in soil organic matter (SOM) known as forest floor (FF). Forest floor SOM plays an important role in forest vitality and productivity because it drives a variety of physical, chemical, and biological soil functions. Its properties and susceptibility to mineralization are strongly affected by the extent of organo-mineral association and formation of SOM-mineral assemblages. The content of mineral compounds in FF layers can be considerable (theoretically up to 70 mass percent). The accumulation of mineral compounds in FF can be attributed to several pathways, including abiotic mineral particle deposition, bioturbation, etc. Information about the relative contribution of organic and mineral compounds in FF layers and their structural and spatial arrangement provides useful insights into the mechanisms involved in their formation and turnover, FF resistance to microbial decomposition, and FF stability in a warming climate. However, our current knowledge about inorganic FF constituents and SOM-mineral association in FF is scarce.

Within the framework of the DFG-funded Research Unit "Forest Floor" (RU 5315), we investigated the effects of parent material and climate on biochemical and/or physicochemical FF properties (SOM C speciation, FF nutrient, and mineral content, SOM-mineral association) by analyzing O layers of German and Swiss forest soils with different parent material (silicate, carbonate) and climate conditions (elevation/temperature gradient). We combined the application of a novel density fractionation method optimized for FF characterization (Prietzel et al. 2020) with a detailed chemical characterization of the different density fractions, including cutting-edge methods such as synchrotron-based XANES spectroscopy. Density fractionation has been proven a powerful method to distinguish SOM fractions with different extents of SOM-mineral interaction and/or occlusion within aggregates in mineral soil samples. However, its utilization for FF characterization at present is still limited. Our study for the first time compares SOM-mineral interaction and association patterns in O layers of silicate and calcareous soils. The results will enhance our understanding of parent material effects on FF properties and FF resilience to climate warming.

Spruce and aspen density treatments within the boreal forests and their effects on soil carbon and nutrients.

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Mixed conifer-deciduous species forests are a promising step towards climate change adaptation and mitigation as coniferous forests are increasingly damaged by abiotic and biotic disturbances that are related to climate change. In Canada, a common forest mixture of the western boreal forests is trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss). Key benefits to mixed-species forests include higher resilience to climate change, potential higher total biomass and enhanced long-term site productivity. Increased resilience results from complementarity in resource use, increased productivity, and the presence of aspen litterfall forming moder humus. This leads to improved mineralization and decomposition for more nutrient-rich soil. This study explores how aspen density in mixed stands affects the carbon storage potential and nutrient content above and below ground. Testing was conducted at the Western Boreal Growth and Yield (WESBOGY) Long-term Study site located in Prince Albert, Saskatchewan in Canada. This site was established in 1990 with white spruce planted in clearcut areas where aspen was regenerating. At age 5, aspen was thinned to a range of densities (0, 200, 500, 1500, and 4000 sph) along with an unthinned control. Soil samples were taken over two summers along with spruce and aspen foliage in each treatment to analyze macronutrient and soil carbon content. Comparing the different density treatments will contribute to our understanding of mixed-forest stand dynamics, nutrient cycles, and soil properties in boreal forests. The findings of this study will be used to guide forest managers to make informed decisions regarding silvicultural treatments to enhance carbon storage capacity, optimize forest health, productivity, and resilience in the face of climate change.

Stand-scale carbon dynamics modelling in deciduous temperate forests under climate change

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Forests ecosystems can help mitigate the effects of climate change since they can assimilate atmospheric carbon and store it in the living biomass, dead organic matter and soil. The Net Ecosystemic Productivity (NEP) of a particular forest stand can inform us on the net carbon flux that will be added or subtracted to the total Stand Carbon Storage (SCS) over time, as a positive value indicate a carbon sink and a negative value indicate a carbon source. To help estimate those values, many models have been developed over the last years to couple stand-scale forest growth dynamics to forest carbon dynamics using empiric methods. Under climate change however, these models need to integrate finer-scale processes and fluxes to correctly represent the future behavior of forest ecosystems under those conditions. The goal of this research project is to evaluate stand-scale carbon dynamics in deciduous temperate forests of Southern Québec, Canada under different sylvicultural strategies in interaction with current and future climate. We first calibrated the HETEROFOR model to simulate spatially explicit forest growth dynamics for several types of stand associations typical of the temperate forest of Québec. This model was then joined with the dead organic matter, decomposition and soil organic carbon modules of the CBM-CFS3 model and validated with long-term stand survey data to simulate long-term carbon dynamics (NEP/SCS) of forest ecosystems under numerous different factors. We used this new complete model to generate stand carbon assessments (NEP/SCS) curves over a 100-year period for several temperate forest stands under many current or alternative silvicultural strategies and in interaction with several climate variables linked to current and future climate conditions. We used an ANOVA analysis to identify scenarios with better carbon uptake and storage at any given time during the simulation and an HGAM analysis to identify which scenarios had the best total SCS for the whole simulation period. These simulations have allowed us to identify which strategies can help optimize stand NEP and SCS depending on future climate interactions and which ones should be favored to help mitigate climate change impacts in the future.

Sustaining forest carbon sequestration following disturbance: What have we learned from a quarter century of coupled field-modeling experiments?

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Disturbances from extreme weather, insects and pathogens, fires, and harvesting are increasing worldwide, with uncertain consequences for the forest carbon cycling processes that are crucial to climate stabilization and timber production. At the University of Michigan Biological Station, in northern Michigan, USA, we have used large-scale experiments, long-term observations, and simulation models for the last quarter century to understand how climate and a variety of disturbance sources affect forest carbon cycling processes, and to identify the factors that promote ecological stability. Decades-long observations from carbon flux towers suggest that a warming climate and changing forest composition initially increased carbon sequestration. However, temperature extremes may be eroding the forest carbon sink by accelerating organic matter decomposition and soil carbon losses. Experimental chronosequence studies suggest that clear-cut harvesting significantly reduced rates of carbon sequestration for a century, but subsequent fire had no compounding effect on long-term carbon cycling processes. In contrast, stem girdling experiments and observations during insect outbreaks indicate that forests can be surprisingly resistant to slower-acting partial disturbances that disrupt vascular tissue, sustaining carbon sequestration, in some cases, at tree mortality levels of 85%. Simulation modeling of our field experiments suggests that carbon cycling responses to disturbance are modulated by climate during recovery, highlighting the importance of disturbance-climate interactions when forecasting ecological stability.

Across experiments, multiple factors promoted carbon cycling stability, suggesting a common set of mechanisms sustained carbon sequestration through disturbance. First, the retention of growth-limiting resources played a crucial role, with more abrupt and severe disturbances causing carbon and nitrogen losses through leaching or volatilization. Secondly, the retention of biological legacies in the form of residual live vegetation supported rapid compensatory growth as disturbance-impacted trees declined. Lastly, greater biological and canopy structural diversity enhanced temporal stability, buffering carbon sequestration from high interannual climate variation and age-related tree mortality. Our collective results provide three critical insights: forest carbon sequestration can remain stable following relatively high levels of tree mortality; a suite of complementary ecological properties and mechanisms support stability; and management that cultivates these properties could mitigate the effects of disturbance and climate change on forest carbon sequestration.

The context-dependent role of ectomycorrhiza in decomposition

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Ectomycorrhizal fungi are an essential component of soil biota in northern forest ecosystems. They live in tight symbiosis with trees and are particularly sensitive to forestry practices. It is crucial to understand the consequences of changes in their abundance and community composition for belowground carbon and nutrient cycling.

Some ectomycorrhizal fungi have retained significant decomposer capabilities during evolution from free-living ancestors, whereas other species lack decomposer enzymes. When ectomycorrhizal decomposers are abundant, they may drive decomposition particularly when other decomposers are scarce. However, dominance by ectomycorrhizal fungi may also hamper decomposition if they suppress more potent, free-living litter degraders (the Gadgil effect). The role of ectomycorrhizal fungi in driving or hampering decomposition is, thus, likely to depend on the functional capabilities of other actors in the fungal communities, and thereby on the over-all ecological context.

We have found support for this theory in a series of field experiments and surveys across subarctic, boreal and nemo-boreal forests in Sweden. In a gradient from more fertile/southern to less fertile/northern forests, the contribution of litter decomposing basidiomycetes decreased, whereas root-associated ascomycetes (including ericoid mycorrhizal associates) increased in relative abundance. Depending on this overall shift in fungal communities, the role of ectomycorrhizal is likely to change from hampering in more fertile soils to driving in less fertile contexts.

Forestry-related losses of ectomycorrhizal fungi may, thus, stimulate decomposition and nutrient cycling in more fertile soils, as potent free-living decomposers become free to proliferate in the absence of mycorrhizal competition. This Gadgil effect may favor seedling establishment and growth of young trees, but can also lead to losses of belowground carbon stocks. In more harsh environments, ectomycorrhizal decomposers may be essential drivers of organic matter turnover. When they decline, their role may not be taken over by the residual community of stress-tolerant ascomycetes with relatively low decomposer capabilities. This may lead to significant accumulation of carbon below ground, but hampered nutrient cycling may put long-term ecosystem productivity at risk.

The effects of forest management on water quality: the issue of carbon

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Water scarcity and contamination are the greatest pressures on global water resources, directly impacting upon our social and economic well-being and ecosystem health. Inappropriate land use management is contributing to these pressures and so there is a need to evaluate and improve how we manage land including forested areas.

Water draining forests is generally high quality, but forest management and operations can lead to deterioration and adverse impacts upon the aquatic environment. Key concerns include diffuse pollution, harmful effects on freshwater ecology, and carbon transport.

We undertook a global review of the effects of a range of forestry activities on water quality, attempting to summarise the literature across a wide geographical area focusing on empirical studies.

The review highlighted a wide range of water quality impacts after forest operations including sediment delivery, nutrient losses, changes in water temperature and dissolved organic carbon (DOC) transport, which contributes to browning of freshwaters.

Here, we focus on the question of aquatic carbon fluxes presenting the findings from our review and data from studies investigating the effects of forestry on dissolved organic carbon (DOC) transport; we also present management practices that have been shown to mitigate impacts.

Furthermore, we highlight knowledge gaps and discuss whether forests inherently contribute more carbon from terrestrial environments to surface waters and oceans than other land uses, a subject that is currently of great interest and debate due to concerns over drinking water treatment, global warming and climate change.

The effects of tree species identity and traits on soil carbon sequestration and stability in a large mature common garden in Belgium

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The climate is changing due to elevated CO_2 concentrations in the atmosphere, therefore there is a need for climate change mitigation practices. Forest ecosystems contain vast amounts of carbon (C), and their soils have the potential to sequester C and therefore act as a C sink. Understanding the mechanisms influencing C sequestration, and more specifically its stability, are crucial for optimisation of forest management. This research aims at identifying the effects of different tree species traits and identities on C sequestration and stability. The research makes use of a Common Garden experiment, situated on loamy soils and located in the Geographical Arboretum Tervuren, Belgium. This setup provides a unique study area in which different tree species are located within a similar edaphic context, and therefore the environmental variation within the study area is limited. Twenty-two monoculture stands with unique tree species are selected and soil samples of the topsoil (0-10 cm) and subsoil (10-20 cm) are taken and analysed on their total and organic C stocks, dissolved organic C, total N, and pH. Using a density fractionation method with a density cut-off of 1.8 g/cm^3, soil organic matter is fractionated into particulate organic matter (POM), occluded POM and mineral-associated organic matter (MAOM) to determine the C stability. With the use of pyrolysis-GC/MS the molecular composition of these different fractions will be determined, to identify the effects of tree species on the stability of C. The results of this ongoing experiment will be presented. The first, very preliminary results show indications of higher soil organic C content, but less stable C fractions, underneath coniferous tree species compared to broadleaved species. Additionally, we hypothesise that the differences in molecular composition of organic matter correlate with the stabilised fractions of C, based on the properties of the functional groups and their capacities to interact with mineral surfaces. To conclude, tree species have a substantial effect on C stability, and having insight in the specifics will make it possible for forest management to choose tree species based on their ability to stabilise C and therefore help in mitigating climate change.

THE IMPACT OF CONSEQUENCES OF WAR IN UKRAINE ON CARBON-SEQUESTERING FUNCTION OF FORESTS

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The full-scale armed aggression of the bloody regime of the Russian Federation against independent Ukraine causes irreparable losses not only to the population and infrastructure, but also leaves deep wounds in the natural environment of the country. As a result of rocket strikes and hostilities in large areas, an instantaneous loss of forest resources has occurred; the induced forest fires significantly deteriorate environmental functions (carbon sequestration, oxygen production etc.), whose restoration will take decades.

The daily war statistics testify to growing losses of forest fund in both geographical and economic dimensions. According to the data of the State Forest Resources Agency of Ukraine, as of April 1, 2023, the area of forested land affected by the armed aggression was over 1 million 700 thousand hectares. At the same time, 14.2 thousand hectares have suffered from forest fires, of which 906 hectares were crown fires. The total amount of damage and losses amounted to 42 million 242 thousand UAH.

In this research, we focused on losses of carbon-sequestering function of forest ecosystems, which is important for combatting climate change. The losses occurred because of damage to tree stands, mainly – due to forest fires.

The methodological approach to assessing losses of environmental functions of forests, caused by forest fires as a result of the armed aggression of Russian Federation, consisted in prognostic modeling of current increment in live biomass of stands based on mean biometric indices by their location (*Lakyda, 2002*), carbon content in wood (wood, bark) and photosynthesizing (foliage) crown fractions, and live ground cover (*Matthews, 1993*).

Forest areas affected by crown fires were considered as having completely lost the productivity of environmental functions, for ground fires – only a third of their total area. The results show that annual loss of the carbon-sequestering function in forests of the State Forest Resources Agency of Ukraine amounts to 12.39 thousand $t \cdot year^{-1}$ (including 2.08 thousand $t \cdot year^{-1}$ – due to crown fires, 10,31 thousand $t \cdot year^{-1}$ – ground fires). The annual losses of sequestered carbon will have a significant impact on the gas balance of the atmosphere and will decrease over time if the affected areas are afforested.

The interacting effect of climate change and herbivory can trigger large-scale transformation of European temperate forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Climate change and natural disturbances are driving the fast transformations of many European forests. Regionally, populations of large wild herbivores exceed the environment`s carrying capacity and shift forest community composition through their foraging preference. We focused here on managed temperate forests dominated by *Picea abies,* which have been cultivated across Europe and often replaced native broadleaved forests; these forests have recently experienced an unprecedented disturbance level from wind, drought, and bark beetles. Many disturbed areas are exposed to climatic stress and herbivory, potentially leading to large-scale forest degradation, including critical loss of climate regulation function. We used the individual-based forest landscape and disturbance model iLand to evaluate the long-term impact of this combination of stressors on forest demography, carbon, and species composition.

A high browsing pressure maintained *P. abies* in species composition by reducing the competition of naturally dominating and more palatable broadleaved species. A browsing reduction or exclusion caused the fast replacement of *P. abies* by other species. This transition was accelerated by warmer and drier climates, increasing *P. abies* mortality from climatically sensitive bark beetle outbreaks. Under the reduced browsing, the forests converged to the new equilibrium characterized by an unchanged level of landscape carbon, a large number of smaller-diameter trees, higher carbon uptake, and significantly lower vulnerability to natural disturbances. On the contrary, increased browsing pressure combined with warmer and drier conditions resulted in a fast transition to the conditions characterized by reduced landscape carbon, reduced carbon uptake, and high disturbance susceptibility.

We conclude that the success of game management can make a difference between climate-adapted stable forests preserving high carbon stocks and degraded vulnerable forests with low carbon stocks and diminished provision of ecosystem services.

The responses of soil microbial characteristics to nitrogen addition and biochar amendment in a Larix kaempferi plantation

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Nitrogen (N) deposition is an important environmental factor that can change soil chemical properties. It can also alter the characteristics of microbial communities. The incorporation of biochar into soils is considered a potential strategy to enhance carbon (C) storage in soil and modify the impacts of N deposition. However, the impacts of biochar on the microbial characteristics of soil after short-term N deposition in subtropical plantations remain poorly understood. Here, we investigated the effects of biochar application (0, 5, 10 t ha^{-1}) on soil chemical traits and microbial characteristics (extracellular enzyme activities, microbial community and microbial biomass) in a *Larix kaempferi* plantation in Shennongjia, China, under N addition (0, 50, 100 kg N ha^{-1} yr^{-1}) during two growing seasons. We found that simulated N deposition significant increased soil total nitrogen (TN), nitrate nitrogen (NO_3^--N) and total phosphorus (TP) concentrations, while heavy N deposition (100 kg N ha^{-1} yr^{-1}) significant decreased soil microbial biomass nitrogen (MBN) concentration and β-glucosidase (β-GC) activity. Biochar amendment significantly increased soil microbial biomass, TN and soil organic carbon (SOC) concentrations. Both N addition and biochar amendment significantly altered *Ascomycota* and *Basidiomycota* relative abundance, with biochar amendment increasing *Ascomycota* relative abundance and decreasing *Mortierellomycota* relative abundance under heavy N deposition. Fungal diversity showed a positive correlation to TN, TP and NO_3^--N concentrations, but a negative correlation to MBN. Biochar addition inhibited the increase in soil NO_3^--N concentration caused by high N addition in the plantation, and influenced the change in the composition of microbial community caused by N addition. Our piecewise structural equation model suggested that N addition affected MBN and fungal diversity directly or indirectly via its effects on soil enzyme activities and properties. In contrast, there were no significant direct or indirect effects on bacterial diversity among all factors. These results improve our understanding of the influence and mechanisms of N addition and biochar amendment on soil microbial characteristics in subtropical coniferous plantations in the short term, and can provide a valuable reference for predicting the future effects of N deposition on soils in this region's plantation.

The significance of tree retention at harvest of boreal forests on belowground storage of carbon and nitrogen after twelve years

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Management practices have significant impacts on carbon and nutrient cycling in boreal forests. In Sweden, forested land is dominated by secondary forests planted after clear-cutting, and the impacts of these practices on belowground carbon and nutrient cycling are of particular importance. On recent clear-cuts, microorganisms may encounter carbon limitation due to the loss of carbon input from roots and litter fall. This limitation can potentially lead to accelerated carbon loss and increased rates of nitrogen mineralization. On the contrary, disruption of ectomycorrhizal symbiosis in clear-cut areas could potentially hinder the turnover of organic stocks, resulting in carbon sequestration and retention of organic nitrogen belowground. To test these ideas, we established a long-term experiment in a low-productive pine forest in northern Sweden that was visited after twelve years, which comprised four levels of harvest intensity: fully clear-cut (0%), 30% or 60% of evenly distributed trees retained, and unlogged (100%) plots. In fully clear-cut plots, carbon storage was significantly lower, with partially harvested plots showing similar carbon stocks to the unlogged plots. Nitrogen stocks were marginally lower in the clear-cut plots, whereas in partially harvested plots nitrogen stocks remained more similar to the unlogged plots. Ammonium levels were consistently low across all plots (and nitrate was not detected), suggesting that any remaining trees (including saplings) and understory vegetation maintained the ecosystem in a nitrogen-limited state. Potentially contributing to the observed 1.45% and 1.32% average increase in growth post-harvest by the 30% and 60% partially harvested plots, respectively. Thus, tree retention may be a means to mitigate soil organic matter losses and promote carbon storage without limiting the availability of nitrogen for tree growth, as shown by increased tree growth post-harvest. Overall, this study highlights the influence of management practices on carbon and nutrient dynamics in northern boreal forests.

The Silva Nova Project - Restoring soil biology and soil functions to gain multiple benefits in new forests

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Afforestation and forest restoration are seen as key factors to mitigate climate change and biodiversity loss given that forests host a major part of the species pool. In Denmark, most of the areas intended for afforestation are former cropland, and their agricultural legacies (high nutrient availability, altered soil biota structure and function) constrain the development of forest-adapted species, tree growth and stability, ecosystem functions and biodiversity.

The central hypothesis of Silva Nova is that inoculation of former arable land with soil (including microbiome, fauna and seeds/rhizomes of understory vegetation) from old forests will improve productivity and more rapidly restore forest-adapted communities.

The project will test this hypothesis by 1) evaluating temporal and spatial responses in biomass production, soil biota and soil functions to afforestation in existing chronosequences and sites with increasing distance to other forests; 2) quantifying the effects of inoculation methods regarding donor, amount and application mode to different soil types and tree species through mesocosm experiments; 3) expanding knowledge of inoculation methods from mesocosm to new and existing field-scale experiments; 4) incorporating the landscape context into guidelines and tools for spatially explicit prioritization of areas for promoting dispersal.

Our methodologies will link results from state-of-the-art eDNA analyses for above and below-ground microbiome characterization (bacteria, fungi and insects) to vegetation analyses, forest structure (LiDAR), in-situ and laboratory measurements of soil functions (e.g. greenhouse gasses and soil metabolic activity) and soil and plant chemical properties.

The aims of Silva Nova are to resolve barriers for successful restoration and develop landscape-scale afforestation strategies that optimize productivity and biodiversity, while generating knowledge on the trees, ground vegetation, soil fauna, and microbiome nexus and its effects. Silva Nova is a collaborative effort between the universities of Copenhagen (DK), Leiden (NL) and Tartu (EE), that received a six years grant from the Novo Nordisk Foundation.

Towards a model of forest soil carbon dynamics under tree species composition shift

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: As forest management responds to climate change, temperate forests will experience a shift from coniferous to deciduous species. Predicting the impact of such shift on soil carbon dynamics will require soil C models that include all relevant mechanisms, e.g., changes in litter quality and soil biota, belowground input quantity and distribution, stability of soil organic matter and priming effect.

To model stability of soil organic matter, advancing from the use of theoretical, kinetically defined SOM pools to empirically defined SOM fractions such as particulate organic matter (POM) and mineral-associated organic matter (MAOM) has been suggested as a way to improve C models. Both POM and MAOM decomposition may be increased by DOC inputs via the priming effect (PE) which is stronger in less-protected fractions (i.e., POM) and is also influenced by the DOC input quality. Even though PE effects could reduce SOC gains from enhanced ecosystem productivity under global change, the PE has been introduced to few models only recently; none of them, however, considers how C input quality affect the PE. The recently introduced KEYLINK model allows to model the interaction between C dynamics, soil biota and soil structure, but requires further validation with experimental data.

Here we review which mechanisms should be considered when predicting soil C dynamics under tree species composition shift and which of the currently available models of C turnover include empirically defined SOM pools (POM and MAOM), priming effect and effects of soil biota. We propose how to combine these into a model that is capable of modelling the impact of shift in tree species composition on forest C stocks.

Tree Species Composition and Carbon Stock in Biomass of Young Forests at a Post-Disturbance Area in Tatra National Park, Slovak Republic

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Long-term records in Slovakia show that the large-scale disturbances in the forests have increasing tendency since the 60's. The evidence further proved that windstorms have been the severest destructive factor in most of the years. The largest wind disturbance within the present millennium in the Slovak Republic occurred in November 2004 (windstorm Elisabeth). The wind impacted the northern and central parts of Slovak territory particularly hard, with the epicenter of forest destruction in the Tatra National Park (TANAP). The wind destroyed forests dominated by Norway spruce at elevations from 700 to 1400 m a.s.l. Since the windstorm dramatically modified the forest stands in TANAP, our research team approached to quantification of tree species composition and carbon pool in whole-tree biomass of young forest stands in 2007, 2010, and 2016. We recorded that the number of tree species was significantly greater at lower (below 900 m; i.e. foothill sites) than higher elevations (above 900 m; i.e. mountain sites). The number of species increased between 2007 and 2010, and after 2010 almost stabilized. In 2007, estimates showed an average of nearly 2.0 tons of carbon per hectare, but only 0.4 tons per hectare in the lower and the higher sites, respectively. Between 2007 and 2016, carbon stocks in whole-tree biomass grew to 11.5 tons per hectare in lower sites and 5.3 tons per hectare in higher ones, with an average for the entire area of about 8.0 tons per hectare. Our estimates also showed that the amount of carbon in whole-tree biomass before the calamity (in 1996) was 101 tons per hectare. After the wind disturbance, higher biomass stock was found among conifers (especially Norway spruce) at lower elevations and among broadleaves (mostly rowan and birches) at higher elevations. The tree species composition twelve years after the wind disturbance was more diverse than that before forest destruction. We can conclude that the current tree species composition in TANAP seems to be a positive consequence of disturbance, especially given the forest stand's resistance to harmful agents**.** We suggested that continuous monitoring of forest development based on a network of plots would be important.

Tree species diversity and size inequality of Akure Strict Nature Reserve, Nigeria

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Interaction among tree species contributes to maintenance of species diversity in forest structure. Size structure and species structure do not have the same effects on ecosystem functions and services. Understanding the coexistence of tree species diversity requires knowledge of inter- and intra- specific interaction. Therefore, this study investigated tree species diversity and size inequality in Akure Strict Nature Reserve. Eighteen and twelve plots (30m x 30m) were laid on parallel transects of 400m long in identified Old-growth and Riparian forests, respectively. Six (6) sample plots (30m x 30m) were demarcated alternatively with 30m intervals on a line transect of 400m long. Trees with diameter-at-breast-height (dbh) ≥ 10cm were counted and identified to species level. Tree diameter at base, middle and top and total height were measured using Relaskop. Tree species diversity (Shannon-Weiner, Simpson and Margalef indices) and dbh inequality measures (Gini coefficient, Gini; Coefficient of Variation, CV; Skewness Coefficient, Skewness) were computed for each plot and compared for each forest type. Stem biomass were computed and converted to carbon stock. Data were analysed using descriptive, and correlation analysis at $\alpha_{0.05}$. Fifty-five (56) tree species representing 17 families were found in the forest. Species diversity indices were higher in Riparian while size inequalities in Old-growth forests. CV correlate with skewness (r=0.810) and Shannon (r=0.735) in Old-growth while GC correlate with CV (r=0.716) in Riparian forests. The size inequality measures were strongly related with each other in Riparian while species and size inequality measures were strongly related with each other in Old-growth forests. The carbon stocks of Old-growth and Riparian forests were 117.21Mg/ha and 43.47Mg/ha, respectively. *Triplochiton scleroxylon* and *Bridelia micrantha* contained highest carbon stock in Old-growth and Riparian forests, respectively. Asymmetric mode of interaction in the absence of competition shows competition for below-ground resource, especially presence of moisture and nutrient gradient. Size inequality among different and within the same species determined coexistence tree communities in Old-growth and Riparian forests of Akure Strict Nature Reserve, respectively.

Unveiling the Role of Mistletoes as a Potential Drought Accelerator for Host Plants in Arid Environments

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Global warming has far-reaching consequences beyond temperature rise, including increased aridity in various regions, imposing significant drought stress on trees. European mistletoe (*Viscum album*), a widespread species found throughout Europe, has exhibited an increased severity of infection in central Europe in recent decades, accelerating drought stress in its host plants.

In this study, conducted in Switzerland, we investigated the physiological responses of mistletoes and its host plants to long-term irrigation. Surprisingly, mistletoes exhibited reduced carbon assimilation compared to its host, suggesting a decreased carbon incorporation capacity under irrigation conditions. Additionally, a needle-removal experiment carried out as part of a whole crown ^{13}C pulse labeling experiment, revealed a higher presence of ^{13}C assimilates in mistletoe leaves in dry control plots compared to the irrigated, indicating that the mistletoe's photosynthetic capacity is driven by the water availability of the host. Morphologically, mistletoe displayed smaller leaf size and higher LMA, indicating an adaptive strategy to enhance water uptake capacity during dry periods. Our results signified that host needle removal not only affected source–sink carbon relationships in the girdled branch but might also result in more available water for the mistletoe due to discontinued host transpiration. The alleviated competition for water may allow the mistletoes to keep stomates more open, thus facilitating higher photosynthesis rates. However, an assessment of multiple mistletoe-host pairs with different host tree species demonstrated relatively stable leaf morphological traits for *V. album*, suggesting a more responsive nature to water availability rather than host specificity. Overall, our findings indicate that *V. album* employs aggressive strategies to maintain a stable water potential gap and higher transpiration rate compared to its host, allowing to effectively compete for water resources under drought conditions.

Our findings strongly support the notion that European mistletoe and its host plants maintain a harmonious coexistence relationship in habitats characterized by adequate hydration levels. However, as global warming is likely to drive more severe and frequent drought events across the terrestrial ecosystems, such equilibrium of coexistence relationship may become disrupted and

mistletoe would exhibit a strong potential in exacerbating the already challenging drought conditions faced by the host plants.

Warming influences the carbon-nitrogen exchange between a widespread understory shrub and its root-associated fungi

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: Boreal forests are warming faster than other forests and are often dominated by a ground layer of Ericaceous shrubs, which are a key ecosystem components that may respond positively to warming. As a result, heightened competition from shrubs under warming could drastically modify tree regeneration and stand development. Along with woody plants worldwide, boreal shrubs form symbioses with mycorrhizal fungi, which forage for nutrients that can be transferred to the host plant in exchange for photosynthetically-derived C. The carbon-for-nitrogen (C-N) exchange between Ericaceous shrubs and ericoid mycorrhizal symbionts may underlie shrub responses to warming, but is not well understood.

We performed three parallel and complementary greenhouse experiments to investigate the effects of warming on the C-N exchange between the Ericaceous shrub *Empetrum nigrum* and its root-associated fungi. We applied different ^{13}C and ^{15}N isotope labels, including a simple organic N form (i.e., the amino acid glycine), and a complex organic N form (i.e., moss litter), and quantified the assimilation of the labels into soil, plant biomass, and root fungal biomass pools. We found that warming lowered the ^{13}C cost of glycine ^{15}N (for *E. nigrum*), but only in the short-term. This suggests that positive warming effects on the C-N exchange rate disappears when a pulse of free amino acid ^{15}N is depleted, implying that any positive effects of warming are contingent on the availability of free amino acids. In contrast, warming increased the ^{13}C cost of ^{15}N from moss, indicating that the effect of warming also depends on the form of organic N. In contrast with glycine, moss litter is highly recalcitrant and N incorporated therein first requires liberation before being assimilated.

Given that *E. nigrum* is abundant in boreal forests, the effects of warming on nutrient acquisition efficiency that we observed may have consequences for how boreal forest ecosystems respond to warming. Lower C costs for amino acid N uptake could allow *Empetrum*, and perhaps also other Ericaceous dwarf shrubs, to redirect C toward other functions such as growth, respiration, or defense. Hence, in understanding forest responses to climate change, we should not forget about the understory.

Wildfire impacts on a managed boreal forest: an interdisciplinary perspective

S1.3 Forests in a changing world – impacts on carbon and nutrient dynamics

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Abstract: The interactions between forest management decisions and the impacts of wildfire have rarely been studied in the Eurasian boreal forest. Yet the increasing frequency and severity of wildfire threatens the ability of this ecosystem to continue providing the carbon sequestration, wood production and cultural services that millions of people depend on. In 2018, an extreme drought in central and northern Europe caused an unprecedented number of wildfires across Sweden. We present the results of an interdisciplinary team of researchers studying the impacts of the largest fire that year, the Ljusdal fire. In combination with the fire impacts, we investigated how forest management decisions after fire (e.g. salvage-logging versus creation of nature reserves) have affected the recovery of these forests. During the first four years since the fire we measured soil microbial dynamics, nutrient cycling, vegetation growth, tree transpiration and greenhouse gas fluxes.

Our results indicate that the stands were net carbon emitters for at least four years after fire and may take over 30 years to recover all the carbon lost during the fire. Decisions on how to replant the forest after fire had no notable impact on the rate of recovery of the forest carbon budget. However, the decision to salvage-log or leave the trees standing had a significant effect on the ecosystem greenhouse gas emissions, microclimate, soil microbial growth rates and soil nutrient cycling. Combining these findings with further experimental work, we will highlight the mechanisms influencing how wildfire and forest management decisions impact the recovery of the forest carbon budget. Our results lay the foundation for identifying best practices to sustainably manage commercial European boreal forests at risk from climate extremes.

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

Combined Effects of Seasonality and Forest Harvesting on Evapotranspiration

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: The effects of forest harvesting on watershed exports (i.e., streamflow and evapotranspiration) are often not predictable across catchments or time. This is likely due to subsurface storage dynamics and the complexity of climatic controls on the remaining vegetation. Moreover, watershed processes may not behave as expected following extreme wet or dry conditions, as hillslopes become hydrologically connected or plants become stressed. Here, we use data from a long-term harvesting study at the Caspar Creek Experimental Watersheds in coastal California, USA to explore the complex interactions between climate, timber harvesting, and water budgets. We present eight years of climate, soil moisture, and transpiration data from four coast-redwood (*Sequoia sempervirens*) forest watersheds exposed to 0%, 35%, 55%, and 75% reduction in pre-treatment basal area. We analyzed climate and transpiration responses to forest harvesting in this Mediterranean climate in the wet season (Dec–Mar), dry season (Jun–Sep), as well as during transitional seasons. We compared post-treatment responses (2018–2022) to the pre-treatment calibration period (2015–2017) and hypothesized that transpiration differences would be greatest during the driest periods, when soil moisture was limiting. We also expected transpiration differences among the treatment levels during the wet season when light was limiting as coast redwood transpires year-round at this site. We indeed found this to be true, but the degree of harvest did not always determine the response in transpiration. Our results suggest that many climatic and ecohydrological factors must be considered when determining the impacts of forest harvesting on watersheds.

Comparative Assessment of Forested Watersheds: A Nexus Approach for Correlates between Forest, Climate and Water Indicators

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Forested watersheds provide various ecosystem services, including water (quality & quantity), soil moisture, ecological integrity, biodiversity, and enhanced livelihood opportunities while moderated and influenced by climate variables. Degradation, deforestation, and changing climate variables have created severe imbalances in the already sensitive eco-hydro-meteorological phenomenon implicating the sustainable flow of water in forested watersheds. The attribution of changes in water quantity to the underlying climatic and vegetation drivers is warranted for effective water management. This entails a focus on understanding the multiple impacts of climate change on the forest-water nexus of river ecosystems. In the Indian context, the majority of Southern and Central Indian rivers are forest-fed, and the climate-forest dynamics constantly threaten their perennial flow. The Narmada River is the largest west-flowing Indian river, supporting over sixteen million people of four Central Indian states. Our study explores the nexus of forest-water-climate for two watersheds (Dindori and Barwani) with different forest cover (Very Dense, Moderately Dense), types (Tropical Moist Deciduous with Sal dominant), Tropical Dry Deciduous with Teak dominant) in the upper and middle zone of Narmada. We analysed the relationship between forests and climate change and their influence on the streamflow of the selected watershed using remote sensing and secondary datasets. Suitable indicators of climate variables (temperature, rainfall, Standardized Precipitation Index, and Standardized Precipitation Evapotranspiration Index); forest and soil (forest cover change, evapotranspiration, Normalized Difference Vegetation Index, Enhanced Vegetation Index, Soil Adjusted Vegetation Index, and Soil Moisture Index) were analysed for both watersheds from 2001-2020. Multivariate analysis using multiple hypotheses was conducted to explain changes in water quantity and attribution to associated parameters. The results suggest climate variables have a major influence on changes in streamflow for both Dindori and Barwani watersheds. Vegetation indices also influenced the stream flow in both the study watersheds. Multidimensional perspectives involving several contributing variables build a holistic understanding of eco-hydrological balance. Therefore, developing countries like India must focus on integrating biotic dynamics with climatic factors for the sustainable management of forest and water resources.

Effects of Road-Stream Crossings on the Eco-Hydrological Connectivity of Amazonian Streams

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Road construction threatens the Amazon by driving deforestation and fragmentation of the remaining forests. The effects of these dynamics on the landscape result in various impacts on ecosystems, however, the consequences for the streams of the planet's largest river basin, the Amazon, are still poorly known. The interaction of rural and forest roads with the streams causes punctual alterations on aquatic ecosystem and its riparian zone, but the cumulative impacts to aquatic connectivity span along the hydrographic network. The objective of this study was to quantify and characterize road-stream crossing in agricultural landscapes in the Brazilian Amazon region. We used RGB Planet satellite imagery (3m resolution) to manually map roads (approx. 9.000km in extension) and thus identify crossings at 1st to 3rd Strahler's order streams in the Santarém municipality region, Pará state. We also collected field data to characterize the infrastructure associated with the road-stream crossings (e.g. structure type, presence of lentic habitat caused by the crossing, channel unevenness downstream the structure (i.e. perched culvert), etc), these data served as a basis to adjust the calculation of the Stream Continuity Index (SCI) to the reality found. We identified 2.048 road-stream crossings in the study area (approx. 11.000km²), most of which in agriculture land use. During the field validation, we found that 30% of the mapped intersections were absent, highlighting the importance of cross-checking the available imagery with the ground data. The most common structures associated with road crossings were culverts (56%) followed by single span crossings (i.e. bridge without support column) (28%). The predominance of culvert crossings threatens ecohydrological connectivity, as indicated by SCI. Moreover, the majority of culverts were perched (53%), which are particularly harmful to the movement of aquatic fauna (e.g. fish, acroinvertebrates, etc.). Advancing the knowledge about the road-stream crossings is crucial to understand and mitigate their ecological, social, and economic impacts. Both roads and streams play fundamental roles in the lives of Amazonian populations, and the harmonious interaction between these two factors is essential to ensure a sustainable future for the region.

Extensive reforestation activities lead to significant hydrological alteration in China

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Over the past decades, China has implemented several large reforestation initiatives to combat land degradation, soil erosion, air pollution, and climate change. Satellite data showed that a striking increase in forest cover in China has significantly contributed to the Greening Earth. Yet, such a credible increment in forest has intensified hydrological cycles and reduced soil erosion, while reduced total runoff and increased soil moisture deficit, particularly in the Yellow River basin, a semi-arid region. In turn, the decreased water availability has negatively affected water availability for forest growth in some regions, leading to a rethinking of the reforestation programs. This talk will first synthesize the effects of reforestation on the key hydrological processes (e.g., evapotranspiration, runoff, soil moisture, and groundwater recharge) in China over different climatic zones. Then, the status quo and lessons learnt over the historical reforestation programmers will be presented. Finally, future forest management focusing on water sustainability in the context of future reforestation initiatives and climate change will be recommended and discussed.

Forest response to drought: Applying lessons learned to managing the forest-soil-water nexus for hydrologic

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Forests provide critical hydrologic services related to soil water storage and regulating streamflow and climate. Increases in the frequency and intensity of drought due to climate change threaten these services; however, we lack a mechanistic understanding of how drought affects the forest-water-soil nexus. Vegetation is the key mediator of water flows between the soil and atmosphere via transpiration; thus, understanding the mechanisms by which plants control water fluxes – from leaves to whole trees to ecosystems – is of paramount importance to accurately predicting forest response to drought and managing forests for their hydrologic services under climate change. Here, we present the results from six studies that examined the response of different forest ecosystems to severe drought, including two throughfall exclusion experiments that reduced throughfall by 50-100% (temperate mixed pine-oak forest; montane tropical cloud forests), one cloud reduction experiment (montane tropical cloud forest), and two studies that assessed forest response to naturally occurring droughts (tropical rainforest; paramo woodlands).

We used a combination of ecophysiological techniques (e.g., sap flow, foliar gas exchange, plant water potential, stable isotopes) together with micrometeorological and soil moisture measurements to assess plant controls on water fluxes. We also examined plant functional traits and physiological processes to enhance understanding of how drought response varies among different plant functional types and the implications for potential shifts in species composition. Finally, we synthesize our findings within the context of global research on the forest-water-soil next across diverse climate, soil and forest types, and local conditions to derive broader conclusions about the relevance for managing forest hydrologic functions in the face of drought.

Key findings include (1) tree species exert differential controls on water fluxes that reflect their water use strategies and functional traits; (2) drivers of vegetation water use dynamics vary across geographic region and forest type, with atmospheric drivers dominating in ever-wet tropical environments, soil moisture and atmospheric conditions interacting in seasonal temperate and tropical environments, and soil moisture prevailing in dry environments; and (3) knowledge of plant physiological controls on water fluxes provide insight into forest drought response and managing the forest-soil-water nexus for climate adaptation and resilience.

From the Soil to the Sky The power of the red mangrove to move up water and contribute water to the atmosphere.

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Mangrove forests are great allies in combating climate change effects in coastal regions, mainly by their ecosystem services related to carbon, water, and energy processes. Even if these ecosystem services have impacts at regional and global scales, they are based on plant physiology and anatomy of the mangrove species and its continuous feedback with the micro-environment. Due to their geographical distribution, mangrove forests receive a high amount of energy by solar radiation that is transformed by plants into heat conduction and convection (*i.e.,* temperature) and latent heat (*i.e.,* transpiration). Moreover, mangrove forest must dissipate that energy without compromising their growth and maintenance at a very low water cost. Thus, during periods of high solar radiation incidence and high vapor pressure deficit (VPD), mangrove trees must regulate the water loss by transpiration and deal with water uptake by roots in a hyper-saline flooded environment, increasing, in turn, the leaf osmotic potential. Therefore, we analyzed the effect of the micro-environment on sap flow in dwarf mangrove forests dominated by red mangrove (*Rhizophora mangle* L.), during dry and rainy seasons in the Ría Celestún Biosphere Reserve, Yucatan (Mexico). In this regard, continuous measurements of air temperature, wind speed, photosynthetic photon flux density, solar radiation, and VPD were taken to characterize the micro-environment. Furthermore, sap flux density, leaf osmotic potential, and leaf–canopy transpiration were obtained using Granier's thermal dissipation method, a plant canopy analyzer, and a steady-state porometer. We found a maximum VPD and sap flux density in the dry season up to 2.88 kPa and 129.9 L m^{-2} h^{-1}, respectively; while during the rainy season, values were 1.65 kPa and 263.8 L m^{-2} h^{-1}. Greater transpiration rates and lower osmotic potential were found during the rainy season, which could have an impact on the ecohydrological processes modulation, affecting climate regulation at the local scale. Consequently, the study of water exchange and transport in mangrove forests – at leaf and canopy levels – is crucial for a better understanding of ecosystem services provided by mangroves, especially in semi-arid regions where water is for more, the most important resource for forests and societies.

impacts of native forest replacement by pinus plantations on water consumption and groundwater recharge in a Mediterranean context

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: The continuous expansion of exotic pine plantations has replaced native vegetation such as thorny dry forests; this could have consequences in the hydrological cycle of the areas where this land cover change occurs. We aim to evaluate the effect of replacing *Acacia caven* dry forest with *Pinus radiata* plantations on actual evapotranspiration (ETa) and groundwater recharge (GWR) in a Mediterranean river basin of Chile. We implemented The HYDRUS-1D water transfers model to quantify ETa and GWR in both kinds of forest with three replications under different past, present, and future periods including climate change scenarios. We contrasted simulations against soil moisture and transpiration sap flow measurements, with satisfactory results with $R2 > 0.9$, $KGE > 0.85$ and $PBIAS < 10\%$ for soil moisture, and $R2 > 0.7$, $KGE > 0.55$ and $PBIAS < 15\%$, for transpiration. The results indicate that from 1979 to 2022, there has been a significant decrease in the ETa rate and GWR in both land covers, especially during the mega-drought period (2010-2022). The yearly differences between forests showed that ETa was between 180 to 214 mm $year^{-1}$ more in pines than in the dry forest and that the latter percolates between 184 to 237 mm $year^{-1}$ more than pines, regardless of the period analyzed. For the future climate change period, both coverages will decrease their GWR, regardless of the climate change modeling scenario. In some dry years, pines simulations showed suppression and even negative values of GWR related to the access to the local shallow water table to maintain their ETa rates. The historical replacement of shrubland by pine trees within the basin (corresponding to 7,751 ha) in the three-time period analyzed yielded amounts of 15 to 19 million m^3 $year^{-1}$ additional water consumption as ETa and between 14 to 18 million m^3 $year^{-1}$ decrease in GWR. Those amounts represent around 1.4 to 1.9 million water trucks per year, the currently available water supply for the rural population in the basin. Results reported in this study and the projected water scarcity in the region impose challenges to opting for carbon neutrality to which Chile is committed.

Influence of forest thinning on total suspended solids in headwater streams covered by Korean pine

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: We examined changes in total suspended solids (TSS) after a forest thinning in headwater streams draining a Korean pine (Pinus koraiensis) plantation forest. We applied a paired-catchment analysis to treated (K_T: 0.8 ha) and control (K_C: 0.7 ha) catchments. The K_T catchment was subjected to 50% random thinning from December 2016 to March 2017, while the K_C catchment remained as a reference. Thinning operations were conducted by forest workers using chainsaws and non-heavy machinery. We conducted field observations using an automated water sampler (ISCO) and gauging stations with a V-notch (90°) at 1-hour intervals during rainfall events in the outlets of catchments. The paired-catchment analysis revealed that the TSS in the K_T catchment was increased compared with the K_C catchment within one and two years after thinning. However, the TSS in the K_C catchment appeared to decrease in three years after thinning. These results indicated the TSS could be increased due to hydrological connectivity via the magnitude of soil surface disturbance area in the immediate post-thinning period. After that, the TSS could be decreased by the protective effect of vegetation trapping and settling. Hence, forest thinning for mitigating increases in TSS can require appropriate site-specific management of land preparation with water conservation. Further study should develop essential to improve our understanding of the transported mechanisms in TSS based on process-based investigations, including the identification sources of TSS within headwater catchments.

Integration of remote sensing in watershed studies: A case study of Chawia & Fururu forested watersheds in Taita Hills, Kenya

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Increased water demand due to population growth and climate change have resulted in drying up of springs, and a reduction in their discharge volumes in the forested Taita Hills, hence need for this study. The objective of the study was to evaluate the potential of integrating both Geographical Information Systems (GIS) and Remote Sensing (RS) in studying the status and spatial distribution of recent springs in the fragmented Chawia and Fururu forest watersheds. Physical mapping of the springs was done by demarcating the location using GPS. Data for mapping of springs was sourced from Landsat 7, 8 and Sentinel 2 which were processed and analyzed. For watershed delineation, data was examined using ArcMap GIS Hydrology tool from (ESRI), and image classification done using the Maximum Likelihood algorithm, with classification accuracy verified using the confusion matrix approach. Hydrological network was developed using Digital Elevation Model (DEM) data. From the results; ninety-one (91) springs were mapped; from which 68 were active. All the thirty-eight (38) springs in Fururu watershed were active. Six land use classes were identified within the watershed; Built-up (66.3%), Forest land (26.1%), Agriculture (7.13%), Water bodies (0.23%), Grassland (0.04%), and Bare land (0.01%). In addition, Chawia forest cover had reduced by 10% between 1987 and 2022; Fururu had increased by the same amount in the same period. From the results; the study recommends adoption of integrated forested watershed management and alternative water sources to communities for sustainability of both water and forest resources within the forested watersheds.

Keywords: Springs, Land use; Cover Change; watershed; GIS, remote sensing; Chawia, Fururu

Interaction of forest-patch graph theory connectivity indicators with river water quality in the Caspian Sea Basin

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Landscape structure is one of the most important factors affecting food and organic matter in rivers and the spatial pattern of landscape patches, because differences in the length, width and gaps of patches have a great impact on food and organic matters in rivers. The present study was conducted with an aim to study the effects of forest-patch connectivity and landscape corridors on water quality in the Greater Caspian Basin. The ability of contiguous/unfractured landscapes in the promotion of acceptable water quality was evaluated with respect to ten landscape metrics and eleven water-quality indicators developed from graph theory. The degree of association between the various indices of forest-patch connectivity and water quality was determined with independent calculations of Pearson's and Spearman's correlation coefficients. Stepwise regression was also used to generate allometry-based power, exponential, and logarithmic models. The results of correlation between forest-graph theory connectivity indicators and water quality parameters showed that, several graph-theory-based indicators, dLCP (Landscape coincidence probability), dIIC (Integral index of connectivity)) had a significant negative correlation with water quality. This means that with increasing connectivity indexes, the amount of water pollution indicators is reduced and as a result, water quality is improved. The modeling results also showed that almost all selected models with acceptable AIC coefficients were nonlinear models. Therefore, the results of this study showed that graph theory indicators can describe changes in water quality parameters. As the connectivity of forest patches decreases, and the more fragmentation occurs in a watershed, the parameters of water pollution increase and the quality of water decreases, which some models, have highest level of explanation of water quality (i.e., R^2) such as CO_3 (0.82), water discharge (0.73), Ca (0.77), and TDS (Total Dissolve Solids) (0.70).

Length versus severity: The drought resilience potential of Norway spruce seedlings

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: A climate change-driven increase in drought frequency and severity is expected to have negative impacts on tree vitality. Reduced water availability can cause xylem embolism, thus blocking water transport and subsequently cause reductions in gas exchange and growth. Resistance and recovery to drought are thus decisive for tree survival during and after drought. In this study, we address the resilience of juvenile Norway spruce trees to different drought duration and severities by focusing on both, drought resistance and recovery.

In a greenhouse experiment, we continuously measured stem diameter changes, whole-tree gas exchange separated in above- and belowground, and leaf water potential in trees. To test the impact of drought duration we applied four treatments: control, short-term drought, intermitted drought, and long-term drought. Following drought release, micro-CT scans enabled visualization of persisting embolism in the xylem and thus percentage loss of water conductive xylem area.

Net assimilation, stomatal conductance, and growth rates diminished with critical water potentials. Days after drought release, water potentials and growth recovered, while gas exchange recovery was incomplete. We observed pronounced embolism in the xylem of stems, apical shoots, and roots. Prolonged drought exposure to critical water potentials resulted in slower recovery of gas exchange alongside a higher degree of embolism, while more severe yet short-term drought led to comparably less embolism and a faster recovery rate of gas exchange. In summary, this indicates that not only drought severity in terms of water potential reached before re-wetting is decisive for drought recovery, but also that the drought duration has an important impact on tree functioning and overall stress resilience.

Insufficient restoration of the hydraulic system, evidenced by reduced xylem conductive area after the recovery phase, likely resulted in incomplete recovery of gas exchange, especially during prolonged drought exposure. A limited resilience may render juvenile spruce trees more susceptible to more recurrent and/or severe droughts.

Less pronounced drought responses in ring-porous versus diffuse-porous temperate tree species

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Tree species differ in their physiological responses to drought, but the underlying causes are often unclear. Here we explored responses of radial growth to centennial drought events and sap flow (F_s) to seasonal drought in four mixed forests on either moist or drier sites in northwestern Switzerland. While the diffuse-porous species (*Fagus sylvatica, Prunus avium, Tilia platyphyllos*) showed marked growth reductions in 1976 and 2003, two known marker years of extreme drought, growth of the two ring-porous species (*Quercus petraea, Fraxinus excelsior*) was less severely affected. During a dry early to midsummer, diffuse-porous species strongly reduced F_s at the two drier sites but not (or less so) at the two moister sites. The deep-rooting, ring-porous trees invariably down-regulated F_s to 60–70% of their maxima in response to vapour pressure deficit (VPD) and maintained similar fluxes across sites, irrespective of upper soil moisture conditions. Generalised additive modeling of F_s as a function of VPD and soil matric potential yielded a drought-sensitivity ranking led by the two insensitive ring-porous species followed by the diffuse-porous trees (ordered by increasing sensitivity: *Fraxinus excelsior* < *Quercus petraea* < *Prunus avium* < *Acer pseudoplatanus* < *Fagus sylvatica* < *Tilia platyphyllos*). In conclusion, ring-porous tree species exhibited stronger VPD-driven stomatal control over F_s, and tree-ring formation was less sensitive to severe drought than in neighbouring diffuse-porous species. Disregarding biotic hazards, our findings imply shifts in forest structure towards greater basal area of deep-rooting, ring-porous species in a drier future. With stronger reliance on deeper-lying soil moisture reserves and more frequent topsoil desiccation under drier future conditions, hydraulic redistribution may play an increasingly important role in nutrient dynamics and soil microbial activity in the upper soil horizon.

Limited connection between forest vegetation and groundwater level at Kecskemét-Méntelek study site, Hungary

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: One of the most serious consequences of climate change is the decline in available water resources around the globe. Meanwhile forest vegetation as a carbon sink is considered as an useful tool to mitigate those consequences, it has generally higher water demand than herbaceous vegetation. This conflict generates a serious dilemma for decision makers according to land use policies.

This problem is also very acute at the Sand Ridge Region of the Great Hungarian Plain, where a decrease in the groundwater level is observable since the 1970's. Among other causes, the high water demand of the local forest vegetation was also mentioned behind the phenomena by various authors.

Our aim was to investigate the assumed connection between forest stands and the groundwater level decrease at our study site at Kecskemét-Méntelek. Soil moisture content at 200 cm and groundwater level (GWL) data was collected between 12.05.2021 and 12.07.2022 in every 10 and 15 minutes respectively at a study point surrounded by forests. Daily GWL changes were also calculated from the data.

According to the results there was no connection between GWL and daily GWL change and the photosynthetic activity or soil moisture content. There was also no observable recharge period although occasionally relatively high daily recharge was measured.

We concluded, that the above-mentioned factors have no impact on GWL or on groundwater recharge therefore the water-uptake or interception of the (forest or herbaceous) vegetation is negligible. This could be explained by the depth of the groundwater (approx. 8 m).

Mapping watercourses using AI – key for managing the forest-soil-water nexus

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Small watercourses have been overlooked during mapping, aquatic research, and forest management, but new research highlights the importance of these channels as sources of greenhouse gas emissions and provisioning ecosystem services. They form the capillaries of the forest-soil-water nexus and are the largest contact area between the terrestrial and aquatic environment. Hence, whether naturally eroded or dug by humans in the form of ditches, small watercourses need to be considered during forest management in order to maintain the integrity of both water quality and the carbon balance of the boreal ecosystem.

However, a problem for practical management is that most channels less than 6 m wide are missing from traditional maps (in Sweden, only 22% are mapped). There is a gap in knowledge that not only reduces the understanding regarding the channels' placement but hinders the assessment of their environmental impact and consideration during forest management. This also concerns Agenda 2030's Target 6 about water systems protection and restoration: their management could require the filling of ditches in order to support the original ecosystem, affecting forest owners.

In this study, we combined aerial laser scanning with deep learning to develop a method for mapping small-scale watercourses, additionally evaluating several digital terrain indices as predictors. From the digital elevation model and the deep learning model, we were able to map 82% of the small watercourses across the entire boreal and nemoboreal landscape of Sweden. The method had a better performance mapping ditches – the most common channel type across the Baltic Region. Detailed mapping of the location and extension of ditches in the boreal forest is a primordial step towards supporting science-based management decisions on the forest-soil-water nexus.

Phloem carbon-isotope discrimination and carbon balance of Eucalyptus genotypes under contrasting water availability regimes

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Identifying *Eucalyptus* taxa/genotypes that show better adaptability to increasing drought conditions is critical in the context of climate change in many regions of the world. Use of physiological traits may provide insights on characterizing above and belowground (C) carbon fluxes of intensively managed plantations and their response to limitations on water resource availability. Our study evaluated the relationship between $\delta^{13}C$ and C fluxes of selected *Eucalyptus* genotypes under contrasting water availability regimes. The experiment was located in a sandy soil (Xeric Passament) in the Central Valley of Chile (37º1269´S, 72º4733´W) under a mediterranean climate with an average annual temperature of 13.8°C and annual rainfall of 1071.1 mm. The experiment was established in 2013, with a 3 x 2 m planting spacing, under a completely randomized factorial design with three blocks. Main experimental factor considered summer irrigation at 2 levels: (i) High (close to 75% field capacity) vs Low (close to 25% from wilting point to field capacity). Minor plots considered 8 genotypes: (ii) 2 *E. globulus* (high yield: EgH vs low yield: EgL), 2 *E. nitens x globulus* hybrids (high yield: EngH vs low yield: EngL), 1 *E. nitens* (En), 1 *E. camaldulensis x globulus* (Ecg), 1 *E. badjensis* (Eb), and 1 *E. smithii* (Es). Gross primary production (GPP), total belowground carbon flux (TBCF), aboveground net primary production (ANPP), wood primary productivity (WNPP), autotrophic respiration (Ra) and $\delta^{13}C$ in phloem were evaluated between 2020 and 2022 (7 to 9 years old). Results showed that under High irrigation regime GPP values reached in average of 3931 $gCm^{-2}yr^{-1}$ and a $\delta^{13}C$ of -30.2%o vs the Low irrigation regime with average GPP values of 2984 $gCm^{-2}yr^{-1}$ and -28.4%o for $\delta^{13}C$. Both irrigation regimes showed, positive and significant ($p<0.01$) linear relationship between $\delta^{13}C$ and GPP (R^2=0.63-0.79), ANPP (R^2=0.62-0.81), WNPP (R^2=0.65-0.82), Ra (R^2=0.63-0.81) and TBCF (R^2=0.36-0.63). Our results suggest that phloem $\delta^{13}C$ may provide a valuable key physiological assessment estimating C balance response of Eucalyptus genotypes and support selections under contrasting water availability scenarios.

Quantitative assessment of the impact of forest change and permafrost degradation on streamflow in Northeast China

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Forest change and climate variability are generally considered to be the two most important drivers of runoff change in forest watersheds. However, in the context of global warming, the degradation of permafrost has also become an important factor affecting river runoff. The Da Hinggan Mountains is the southern margin of the Eurasian permafrost distribution area, which is the one of the most sensitive area response to climate warming. At the same time, the boreal forest Da Hinggan Mountains has experienced a dynamic process of deforestation and forest restoration in the past few decades. The impact of the changes in forest, climate and permafrost on hydrological processes and water resources has become a scientific question that needs to be revealed urgently in this region. In this study, the meteorological, hydrological and permafrost data of the past 50 years were used to analyze the climate variability, forest coverage change, and permafrost degradation that occurred in the past few decades and their relationship with runoff. We quantitatively evaluated the relative contributions of climate variability, permafrost degradation, and forest vegetation change to changes in annual runoff. It has accurately and quantitatively revealed how river runoff in the permafrost distribution area of Northeast China responds to changes in forests, climate, and permafrost. It is of great significance to the sustainable management of regional forests and water resources in the context of global climate change in the boreal foerst regions.

REMOTE SENSING FOR FORESTRY ASSESSMENT AND QUALITY OF WATER RESOURCES: THE CASE OF DZALANYAMA CATCHMENT (MALAWI)

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Water quality is the measure of the chemical, physical and biological suitability of water in relation to natural effects and intended purpose which may affect human health and aquatic life. Assessment of water quality is very essential for the management of water resources as well as human health. Forestry plays a major role in protecting water resources, as forests provide 75% of the world's accessible water. Over the years forests have been under heavy depletion due to anthropogenic activities and this has also affected the quality of water in water resources originating from forest catchments. Monitoring of forests is usually done using traditional methods that are laborious and time-consuming. However remote sensing has shown that it is a reliable tool for forest monitoring and assessment. Remote sensing provides extensive spatial extent and large temporal variations. This abstract reiterates the significance of remote sensing in forest management and its impact on water quality. With the help of remote sensing methodologies, the extent of forest degradation and its effect on water quality could be measured. The anticipated results of heavy forest degradation would be an increase in harmful water quality parameters in water bodies. Some of these water parameters are; suspended solids, turbidity, and chlorophyll a. The results will then help determine the interventions that could be put in place to tackle this issue.

Remote sensing for water quality monitoring: a reservoir case study

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Continuous monitoring of water resources is crucial for ensuring sustainable urban water supply. Remote sensing techniques have proven to be valuable in monitoring various water quality parameters with optical characteristics. The study focused on the Marateca reservoir located in central inland Portugal. The objectives were as follows: (1) to investigate the water quality parameters at different monitoring points within the Marateca reservoir that could explain certain events; (2) to validate optical water quality parameters using the data collected from the monitoring points; and (3) to model the water characteristics of the reservoir, including its depth, trophic state, and turbidity.

The parameters of total phosphorus, total nitrogen, and chlorophyll-a were utilized to calculate a trophic level index. Sentinel-2 imagery was employed to compute spectral indices and image ratios for different bands, obtain spectral signatures for the monitoring points, and model the water characteristics. The analysis revealed that the water parameters exceeded the recommended values at the entry point of the reservoir from the Ocreza river. The trophic level of the reservoir was classified as Hypereutrophic and Eutrophic. The spectral signatures confirmed a Hypereutrophic pattern at the entry point. The modeling of the Marateca reservoir's water characteristics predicted zones of contamination issues.

The developed methodology can be readily applied to other reservoirs and serves as a valuable decision-making tool for policymakers. This study was funded by CERNAS-IPCB [UIDB/00681/2020] funding from the Foundation for Science and Technology (Fundação para a Ciência e Tecnologia-FCT); and by ICT [UIDB/04683/2020] also funding from FCT.

Restoring water-related ecosystem services by forestation: Practices in China

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Widespread deforestation has greatly degraded water-related ecosystem services provided by forests in China in the last century. The nation-wide catastrophic floods in China in 1998 is a good example of severe ecological consequence of forest loss. Since then, China has launched a series of forest restoration projects including Natural Forest Protection Program (NFPP) and Sloping Land Conversion Program (SLCP) to combat deforestation. The massive forestation makes China the country with the largest contribution to land greening on Earth in the past two decades. Water-related ecosystem services such as flood control, water supply, soil erosion control, flow regulation, and climate regulation provided by forests have been enhanced accordingly due to national-wide efforts in forest restoration in China. Here we will use the studies in the Upper Yangtze River basin and the Loess Plateau as examples to demonstrate how we restore water-related ecosystem services of subalpine and temperate forests by regional-specific forest management practices in China. These findings can provide important scientific supports for restoring water-related ecosystem services of forests by adaptive forest management under a changing environment in China and other countries.

The interaction of water and nitrogen uptake by trees from deep soil in pure and mixed stands of Douglas fir, European beech and their mixture

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract:
Planting non-native conifers and admixing them to native broadleaves is a highly interesting climate change adaptation strategy of forestry in temperate Europe. Forests here are expected to face lower water availability and altered nutrient cycles in future. The acquisition of nitrogen by trees is dependent on water flux due to mass flow, but the uptake of the two resources is not necessarily coupled. The increasingly popular introduced species Douglas fir is associated with drought tolerance and a risk of nitrate leaching on some sites, however, these traits are site-specific and have not yet been studied together.

In a mature forest experiment, we isotopically labelled water and nitrate in soil solution below the main rooting depth of Douglas fir, European beech, and their mixture on sited with contrasting soil texture. We monitor tree sap travel times using sap flow sensors installed on each tree and trace the ^{2}H and $K^{15}NO_3$ label in xylem water and in top-canopy foliage. Firstly, we expect that the strength of the coupling of water and nitrogen uptake, indicated by xylem water enrichment in ^{2}H and ^{15}N, varies with site conditions (soil texture), species identity (root characteristics) and is further modulated by species mixing (facilitation). Secondly, we expect that nitrate leaching under some Douglas fir stands, found in our previous study, is not a consequence of the trees' inability to take up excess nitrate from deep soil solution, which will be reflected in similar foliage enrichment among the stands. Thirdly, we expect to find a larger facilitation of water and nitrogen acquisition, indicated by larger cumulative tracer recovery in biomass in the mixed stands at the poorer sandy site due to the stress gradient hypothesis.

We anticipate more molecular experiments illuminating the mechanisms behind water-dependent nitrogen uptake at the root surface, which would complement our *in-situ* experiment and help understand tree resource acquisition strategies. Experiments evaluating the importance of other biotic drivers of resource limitation and excess (in the form of leaching) would also be relevant to predict this species' behavior in a changed climate, for example, the role of mycorrhiza and the rhizosphere.

The quality of water from forest landscapes under pressure in the Anthropocene

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Forests in a landscape are often beneficial for water quality. But contemporary forests are subject to a nexus of new influences characteristic of the Anthropocene – climate change, pollution and increasing societal demands to provide a range of ecosystem services including, but by no means limited to provision of timber, fiber and energy. This talk will examine the degree to which forests can supply water-related ecosystem services under these circumstances, with a focus on water quality in the context of Agenda 2030 and the Sustainable Development Goals (SDGs). While the availability of relevant data is not evenly spread over forest biomes, the talk will seek to take a global view of the situation. This will not only recognize the variety of different ways a forest can influence water, but also bring out the generally applicable findings that play out differently depending on the specific setting. A central issue will be the degree to which forest landscapes have already been, or will soon be impaired in their ability to deliver water with quality that can support endemic aquatic ecosystems and the drinking water for human communities. This leads to consideration of how management practices that consider water quality interact with other goals, including mitigation of climate change, adaptation to climate change and the incentives to manage forests. To conclude, payment for ecosystem services with respect to water quality will be explored in the framework of Agenda 2030 and the SDGs.

The role of terrestrial productivity and hydrology in regulating aquatic dissolved organic carbon concentrations in boreal catchments

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: The past decades have witnessed an increase in dissolved organic carbon (DOC) concentrations in the catchments of the Northern Hemisphere. Increasing terrestrial productivity and changing hydrology may be reasons for the increases in DOC concentration. The aim of this study is to investigate the impacts of increased terrestrial productivity and changed hydrology following climate change on DOC concentrations. We tested and quantified the effects of gross primary production (GPP), ecosystem respiration (RE) and discharge on DOC concentrations in boreal catchments over 3 years. As catchment characteristics can regulate the extent of rising DOC concentrations caused by the regional or global environmental changes, we selected four catchments with different sizes (small, medium and large) and landscapes (forest, mire and forest-mire mixed). We applied multiple models: Wavelet coherence analysis detected the delay-effects of terrestrial productivity and discharge on aquatic DOC variations of boreal catchments; thereafter, the distributed-lag linear models quantified the contributions of each factor on DOC variations. Our results showed that the combined impacts of terrestrial productivity and discharge explained 62% of aquatic DOC variations on average across all sites, whereas discharge, gross primary production (GPP) and RE accounted for 26%, 22% and 3%, respectively. The impact of GPP and discharge on DOC changes was directly related to catchment size: GPP dominated DOC fluctuations in small catchments (<1 km2), whereas discharge controlled DOC variations in big catchments (>1 km2). The direction of the relation between GPP and discharge on DOC varied. Increasing RE always made a positive contribution to DOC concentration. This study reveals that climate change-induced terrestrial greening and shifting hydrology change the DOC export from terrestrial to aquatic ecosystems. The work improves our mechanistic understanding of surface water DOC regulation in boreal catchments and confirms the importance of DOC fluxes in regulating ecosystem C budgets.

Tree water relations as drought stress indicators in a changing world

S1.4 Global water provision: Understanding the forest-soil-water nexus under forest management, climate change and increasing disturbances

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Abstract: Climate change is expected to increase the frequency and severity of droughts and thus affect forests and their numerous benefits globally. Limited water supply leads to temporal reductions of tree internal water reservoirs and stem shrinkage of elastic tissues typically measured with high-resolution point dendrometers (tree water deficit; TWD). When drought stress becomes severe and internal water storage depletes, embolism formation (air bubbles in the xylem preventing water flow) starts. This can cause long-term hydraulic damage to trees, loss of functionality and, ultimately, tree death. Knowing a tree's water status and its development under different environmental conditions is crucial to predict forest health conditions and helps in management decisions regarding thinning and species selection. In this work, we investigate water-related tree traits to evaluate their potential for quantifying, monitoring and projecting drought stress impacts on temperate tree species.

Two wide-spread temperate tree species *Pinus sylvestris* and *Larix decidua* were exposed either to drought-recovery cycles or to lethal drought until complete dehydration under controlled experimental conditions. To improve mechanistic understanding of tree water relations we investigated the correlations between tree water deficit, water potential and embolism occurrence (using an *in-vivo* optical method). We will provide relationships between these traits across the full range of dehydration and rehydration in order to link high-resolution dendrometer data to forest drought stress development. Further, we will highlight possible ways to integrate such relationships into an already existing process-based model to address and project drought-stress-induced forest decline and drought-recovery dynamics.

S1.5 President's Discussion "Translating scientific research into effective forest management to meet multiple societal objectives: challenges and opportunities"

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

A theory of change for sustainable management of commercial medicinal plants in a Himalayan bioeconomy

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: There is a huge and growing legal and illegal international trade in Himalayan medicinal plant products. In Nepal, as many as 300 species are traded annually in tens of thousands of tons worth hundreds of millions of USD. Evidence shows that past and current attempts at promoting sustainable management in Nepal through a centralised approach to resource monitoring and trade regulation have failed, leaving species vulnerable to commercial harvesting and threatening rural household incomes and government revenues. The purpose of this paper is to develop a theory of change to allow an explicit move towards sustainable management of medicinal plant resources in Nepal as part of the bioeconomy. Building on a systematic review of proposed interventions in the literature and annual dialogue meetings with key stakeholders in 2016, 2017, and 2018, we characterised interventions by type (supply-side, transactional, demand-side), governance approach (centralised vs decentralised), and choice of institutional arrangement (positive vs negative: incentives for changed behaviour vs punishments for breaking restrictions). We identified five foundation stones upon which to build future interventions (e.g. a long tradition of successful community management of natural resources) and grouped existing interventions into five explicitly described development pathways to increase sustainability: increase cultivation, strengthen local management, support domestic industries, improve sector governance, and establish regional collaboration. Each pathway consists of a number of mechanisms: actions (from 2-5 per pathway) that lead to outputs (2-4) and outcomes (2-6), e.g. the "strengthen local management" pathway can be pursued through hand-over of high-altitude areas to local communities (action) leading to an increased area under local management (output) and better resource monitoring (outcome). We identified pathway assumptions and feedback loops. This draft theory of change was then discussed and finalised with key stakeholders in 2023, resulting in prioritised pathways and mechanisms to promote sustainable management and trade as part of the bioeconomy.

Assessing the timber harvesting potential of Europe's forest

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: Forests cover around one third of Europe's land area and are beneficial to society by providing numerous goods and services such as water supply, biodiversity, recreation, and welfare. They are further of increasing importance for mitigating climate change effects due to their potential to store carbon and to provide the renewable material wood. Europe, in order to achieve the climate targets and reduce greenhouse gas emission from the combustion of fossil fuel, is aiming to transform towards a sustainable bio-economy. Wood, especially in the form of long-lived wood products, will play an integral part in such an economy and an increase in the demand for wood is expected. In our study we assess the timber harvesting potential of Europe's forest by combining terrestrial information from repeatedly observed forest inventory plots with remotely sensed net primary production (NPP) and other European data. With these data we assess the availability of Europe's forest for wood supply and estimate increment, a key figure regarding sustainable harvesting. The results show that around 75 % of the total forest area in Europe has the potential to be harvested under current economic and technical harvesting conditions and can thus be considered as 'forest available for wood supply' (FAWS). The estimated growing stock in FAWS is around 25 billion m^3. Preliminary results suggest that around 600 million m^3 are potentially available for sustainable harvesting.

Bioeconomy in countries of the Mekong region and its role in forestry sector

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: The approach to the bioeconomy concept is relatively much explored in developed countries, especially in Europe and North America. In other parts of the world, it deserves more scientific and practical attention.

The aim of our research was to analyze, evaluate and compare the status of the bioeconomy concept in the Mekong region in three countries, namely Thailand, Vietnam and Laos. The research questions were focused on the perception of the bioeconomy concept by representatives of the administration and industry, on the barriers to its development and on the prerequisites for its development in the region, and also determined whether it is reflected in the official related strategic existing documents.

Our study used a combined methodology that included qualitative document analysis and an online questionnaire distributed to public and private sector representatives in all countries. The results showed that while the bioeconomy is recognized in many institutions in Southeast Asian countries and is closely linked to sustainable development and the circular economy, a clear vision of the bioeconomy is lacking, resulting in the absence of specialized bioeconomy strategies in these countries. The results showed that the bioeconomy concept is an emerging concept in these countries and was perceived as the most important obstacle to its development. Unfortunately, there is limited bioeconomy expertise and insufficient support from the state, followed by low technological development. The study also highlighted the irreplaceable role of the forestry sector in the bioeconomy concept. We propose further research into the economic valuation of the bioeconomy to support its adoption, as well as greater involvement of key politicians in individual countries for its further development, specifically in Thailand, Vietnam, or further comparison with selected European countries.

Exploring Scientific Discourse on Climate Change and Forest Governance in Indonesia

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: Climate change is causing rapid changes and profound uncertainties that pose a threat to human life. Considering its complexities and urgency, a wide range of mechanisms has been undertaken, from global to local, involving a variety of actors and stakeholders. As a powerful discourse, it also shapes the way forests are governed. Indonesia, which harbors large tropical forests, has forest governance heavily driven by international discourse, including climate change. We analyzed scientific discourse on climate change and forest governance and found 218 articles using the Scopus Database, combining the keywords 'forest', 'climate change', and 'policy and governance' within the Indonesia region. The results were further scrutinized by employing categorization that reflects the storyline of climate change and forest governance, following the logic of discourse. Subsequently, we employed sub-categorization to explore the linkage of the scientific discourse to more specific themes, such as governance design and internationality. The results show rising trends in climate change and forest governance research starting from 2007 onwards, with both strong theoretical and empirically-driven research. The major research theme in Indonesia is found to be dominated by REDD+ research. The latest research trends imply that research problematization is underpinned by Indonesia's Forest and Other Land Use (FOLU) Net Sink strategy to correspond to the Nationally Determined Contribution (NDC) commitment. Through a discourse perspective, the results suggest that the scientific discourse of climate change and forest governance in Indonesia is profoundly endorsed by international concern that has been institutionalized nationally. This may lead to limited scientific narratives of climate change and forest governance and reduce scientific options in the science-policy-praxis nexus. Consequently, newer research themes, such as sustainable development and bioeconomy, are relatively absent in climate change and forest governance research in Indonesia due to lacking institutionalization in Indonesia's context.

Keywords: climate change, forest governance, discourse analysis, systematic literature review

Fixing the meaning: discourses and network analysis in the bioeconomy policy processes in Argentina and Uruguay

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: The concept of bioeconomy has spread globally as a floating signifier leading to multiple policies and strategies. As an ambiguous and polysemic concept, bioeconomy policy agendas at national levels draw on a variety of discourses and visions later reshaped by the particular political and social contexts of each country or region. From the broad boundaries of the overarching bioeconomy meta-discourse, local dominant discourses emerge, created and transformed by supranational and national social actors in the frame of power relations displaying discursive struggles. Understanding the body of social dimensions of forest-based bioeconomy, particularly from less studied Global South countries, remains crucial for the critical comprehension of ongoing bioeconomy policy processes. In recent years, efforts to develop bioeconomy and forest-based bioeconomy strategies and related policy-making were observed in Argentina and Uruguay, two neighbouring countries with similar forest sectors development. Against this background, our study aims to explore these ongoing forest-based bioeconomy policy processes. In order to do so, discourse analysis tools were used to identify current dominant visions regarding bioeconomy. Additionally, the main social agents dealing and promoting forest-based bioeconomy as well as discourse coalitions were identified with social network analysis techniques. Our findings revealed general scarce activity of bioeconomy policy debate in medias, predominantly conducted by a narrow number of legitimatized actors. Whilst in Argentina private sector and interest groups appears as main actors promoting forest-based bioeconomy, in Uruguay the predominant type of actors were the government and political parties. Dominant visions reproduce elements from the European bioeconomy as a strategy to incorporate new forms of enunciation and authority argumentations, namely the pro-growth economic visions driven by local current forestry model sustained in industrial forest plantations silvicultural paradigm. International actors were found to be strongly related to Uruguay forest-based bioeconomy development, while the Argentinian forest-based bioeconomy is embedded in the national agricultural bioeconomy discourse. Dominant storylines on both countries reproduce the power situations of the forestry policy subsystem where central actors not only exert structural power indicated by their network centrality as a parameter of their social capital but also prominently generate dominant information excluding alternative actors and their visions.

Future scenarios for forestry sector within Turkey's sustainable circular bioeconomy transition

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: Sustainable circular bioeconomy is accepted by many nations as a boundry concept and is supported by relevant strategy documents. In various countries, especially in those subject to European Union implemantation, the process progresses rapidly and even renewed strategy documents are encountered. As a country that is in the process of preparation for EU harmonization laws, Turkey has been seen as a preparation stage of bioeconomy strategy in various international processes for many years. However, when the local reflections of national efforts are examined, they do not cover all relevant bioeconomy sectors. In addition to the observation of the leadership of the agricultural sector and related actors in Turkey, this research was designed on the need to create future scenarios about the effectiveness of forestry sector actors in circular bioeconomy strategies. The process of creating future scenarios was carried out by examining all relevant policies, strategies and reports of forestry sector actors like industry representatives using wood products, forest resource managers, forestry academia, non-governmental organizations, biomass-based renewable energy representatives. Twenty influential factors determined in the STEEP category and with their interaction matrix, active, passive, dynamic and buffering factors were determined. Wood material supply and demand, national circular bioeconomy knowledge infrastructure, wood value chains and innovations and finally climate change factors and alternative projections of these factors with various assumptions were taken into account. Four plausible scenarios were developed around two uncertainty axes with the 2x2 scenario development technique. The first of the selected uncertainty axes was determined as Turkey's adaptation to the circular bioeconomy and the second was the participation of the forestry sector, future scenarios for 2035 were created. These scenarios, named as biotransformation of forestry (1), missed opportunity for forestry (2), forestry potential in the shadows (3), unchanging future (4), contribute to Turkey's national strategy preparation processes. It will be beneficial for the relevant stakeholders to integrate the forestry sector potential into their decision processes. It also contributes to Turkey's forest based circular bioeconomy scientific discussions.

Governance of the bio-based bioeconomy in Latin America: considerations from Uruguay with a focus on the forestry sector

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: This analysis presents the results of an R+D project funded by the Sectoral Commission for Scientific Research of the UDELAR (Uruguay) from a governance perspective with a multilevel and multistakeholder approach, which implies a highly political process.

At international level, governance frameworks related to the bioeconomy paradigm have not been developed as such, although it is undeniable that the paths of bioeconomic transformations tend to involve various transboundary effects with global effects. However, there are some approaches that outline possible future governance schemes or regimes, framed within the needs and strategies developed by many countries in order to respond to the challenges of sustainable development.

In Latin America there are no bioeconomy regimes in a strict sense, although there are some national bioeconomy strategies, with different proposals and policy documents that promote the transition towards greater sustainability. In this context, the bioeconomy as a political project within the government agendas is framed according to the actions, interests, values and visions of diverse actors, whose discourses represent a primary factor in the implementation and development of public policies.

In the Southern Cone, Argentina and Brazil are key players. In Uruguay, the concept of bioeconomy has become increasingly important. This represents a challenge, including the implementation of possible guidelines for a National Bioeconomy Strategy.

The Uruguayan State has played a fundamental role in this process: through public policies to promote the bioeconomy and inter-institutional cooperation among different ministries and government agencies, considering diverse perspectives and initiatives of non-State actors. The private sector and foreign investment have been drivers of the development of certain bioeconomic sectors. In the debate on the bioeconomy in Uruguay forestry is a fundamental sector. Studies regarding the coalitions of actors that emerge around sustainability issues linked to this sector, identify a so-called "weak sustainability coalition", that prevails in this discussion. In contrast, the so-called "strong sustainability coalition" emerged in the late '90s, made up of certain sectors of the 'critical' academy and environmental non-governmental organizations.

Governing Bioeconomy Pathways: regional analysis, engagement and dialogues in East Africa, Southeast Asia and Latin America

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: The *core* of a *modern* and *sustainable* bioeconomy is found in the *cross-cutting*, *value-adding*, *innovative* perspectives and approaches that are integral to long term sustainability transformations through the use of bio-resources and the application of biological processes. The wide variety of stakeholders involved in shaping future bioeconomy *pathways* seek to translate their *visions* of the bioeconomy into concrete programs to develop the *bio-resource base* into new bio-based products, biological processes and ecological services. As different localities, countries and regions develop strategies and policies, they must also develop the means for effective *implementation* and *governance.* The *contested* objectives, difficulties of *measuring* sustainability and the sometimes *conflicting* bioeconomy visions must be reconciled through analysis, dialogue, mediation and synthesis. Although bio-resources may be seen as local, transnational transfer of technologies, resources, knowledge and regional capacities remain critcal for advancing a global bioeconomy. Bioeconomy governance is therefore a *multi-level* undertaking encompassing all scales from local to global.

We employed the above conceptual model in assessing the terrestrial (land-based) bioeconomy in a five-year program of research, stakeholder engagement and policy dialogue in the global South, entitled "Governing Bioeconomy Pathways" in East Africa, SE-Asia and Latin America. In this paper, we present key results, using the framework of bioeconomy visions and pathways to analyse and compare developments in the three regions and in selected countries. Our analysis has three inter-linked levels, namely micro, meso and macro perspectives. At *micro* level, we undertook selected sustainability case studies on the transformation of bio-resources into value-added bio-based products and services, including croton in East Africa, acai in Latin America, sugarcane in SE-Asia, embedding these within forest, agricultural and mixed landscapes. At the *meso* level, we compared bioeconomy strategies and evaluated enablers and barriers in the means of implementation in the three regions. At the *macro* level, we considered the three regions in a global context and with particular reference to key global goals for biodiversity, climate protection and sustainable land use. By conducting analysis and engagement across multiple landscapes, themes, institutional levels and geographical regions, we developed a broad comparative assessment and synthesis on the governance of bioeconomy pathways.

How do multinational enterprises shape the socio-technical regimes in the Global South? - Case pulp industry in Uruguay

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: The pulp and paper industry is one of the largest industries in the world. The industry's main actors comprise of a few multi-national enterprises traditionally from Global North, who operate in global markets. The industry is increasingly moving its production to the Global South. This alters the global pulp value chains and more so the national socio-technical regimes of target countries of these massive investment operations. In addition to industry-internal activities, the operational environment changes too, thus challenging the pulp and paper industry's current operations. These factors are for example the sustainability paradigm and the transition to bioeconomy. We analyzed scientific, technical, and popular documents and conducted semi-structured research interviews through the multi-level perspective framework to investigate the pulp industry in Uruguay and how the Finnish multinational enterprises have influenced the developments within the Uruguayan regime. Our aim was to study 1) how the local socio-technical regime in Uruguay has developed since the emergence of the multinational enterprises until 2018 when the data was collected, and 2) what is its role in the global pulp industry's value chain. Our findings suggest that the emergence of the pulp industry in Uruguay has changed the national socio-technical regime dramatically. The developments within the Uruguayan regime were highly influenced by the Finnish multinational enterprises and the way they organized their global value chains. Uruguay's role in the global pulp industry value chain is to produce raw material. The integration of the industry to local research, innovation and education actors is rather weak and the emergence of industry has not improved the innovation capacity of the country and thus it has not led to the development of a strongly sustainable bioeconomy. We suggest that a transition to a sustainable bioeconomy or pulp industry regime in Uruguay would require steps forward in the immaterial resource base with closer cooperation between the industrial and the national research and education actors. Thus, the Global South should not directly adopt the regimes and ways of operating in the Global North, but a deeper collaboration between the global value chain actors is needed.

Inherent complexity of conflicts creates uncertainty for forest based bioeconomy

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: Globally, since the beginning of the 2000s there has been a rapid expansion of community forestry, small and medium-scale commercial tree growing. The increasing demand for timber has attracted both local inhabitants and translocal investors to capture this new resource frontier. The context of forest landscape has radically changed because of the expansion of forestry activities while also the interest towards carbon sequestration and forest conservation is growing. The increased occurrence of conflicts between the various actors has created challanges for forest governance. The inherent complexity of forestry related conflicts creates uncertainty, the issue, which impacts transformation to a sustainable bioeconomy. My experience is based on 20 years field data collection in Global South to map a diverse range of interpretations related to forest governance in general and to community forest and small and medium-scale commercial tree growing specially. A mixed method research design integrates individual interviews, focus group discussions (FGDs), direct participant observations, the expertise of a co-researcher and going back method. The underlying driving forces for forest conflicts are related to ambiguous and conflicting social processes in forest management and conservation. The conclusion is that there is an uncertainty of collaborative actions to discuss the causes, the effects, and the prevention of conflicts between the different actors. Actors know the causes of the conflicts and the measures needed to prevent the conflicts but too differently.

Integrating new environmental paradigms to ensure sustainable management of forest ecosystems: What opportunities for the bioeconomy in Africa?

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: In recent years, circular economy and bioeconomy have become predominant approaches to encourage sustainability, gaining traction and uptake by an ever-increasing community of governments, non-governmental organizations, civil society organizations and businesses. In this new paradigm of sustainable and responsible growth, Africa has an important potential and several major opportunities to increase circular economy based on ecosystem service, cultural services, regulating services, supporting services, provisioning services, etc. Considering forests as the most important biological infrastructure and main source of renewable biomaterials and bioenergy as well as the main host for biodiversity and terrestrial carbon sink, Africa has then a high potential to build a sustainable and circular economy. Globally, forest conservation has the potential to create a total of ~16 million jobs. With Africa's share of the world's forest standing at 17%, forest management could generate about 3 million jobs across the continent. Africa has a great asset to create green jobs. In spite of all these potentialities, it is noticed, a weak actively promoting of bioeconomy notably by the deficiency of collective agenda and drive ambitious action in favour of circular economy. In addition to the governance problems, there is a poor involvement of scientific actors and research institutions on circular economy issues in Africa. The adoption and implementation of policies that can accelerate the transition to a circular economy are still in their early stages in African countries. Even if several African countries have integrated the promotion of circular economy principles at some level in their national sustainable development or 'green economy' strategies, policies, and legislation real action on the ground, however, remains irrelevant. Despite all these, the sustainable use of these forest and tree products and services such as building materials, food and energy therefore provide unique opportunities for a transition to a sustainable circular economy in Africa.

Land and feedstocks availability for liquid biofuel production and associated emission in some eastern Africa countries: a review

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: Liquid biofuel utilization is required to keep global warming below 2°C as stated in 2015 Paris agreement. In eastern Africa, countries like Ethiopia, Kenya, Tanzania, Sudan and Uganda have great potential of liquid biofuel production. The objective of this review was to show suitable land and feedstock availability for biofuel crop production and in turn to determine their role in emission reduction. Data was obtained from published and unpublished country documents. In Ethiopia, 23.3 million ha land area was suitable for biodiesel crops and 333,500 ha for bioethanol crops. Sudan has more than 60 million hectares of cultivable land for biofuel crops. In Tanzania, about 435,000 ha of land was allocated for biofuel production. In Uganda, 50% of the arable land area was suitable for sugarcane production. In Kenya, 20% of the poten-tial arable land was suitable for croton and jatropha. However, poor productivity of jatropha diverted attention to ethanol production from sugarcane. Soon after the launch of the strategy, in 2009, Kenana Sudan Sugar Company (KSC) launched 65 million liters annual ethanol production. Tanzania produced jatropha biodiesel for electricity. Uganda commercially produced ethanol from sweet sorghum. Increasing productivity was needed to obtain sufficient food and biofuel crops. Ethiopia and Tanzania can produce 35.588, and 7.089 billion litres of lignocellulosic ethanol from crop residues, respectively which is higher than their annual import of petroleum. Then eastern Africa countries have no problem of land and feedstock competition with agricultural practices for biofuel production. Biofuels could reduce deforestation and GHG emissions by 10 to 90% when compared with fossil fuels. Therefore, land and feedstock are widely available in eastern Africa to produce more biofuel crops for clean energy development.

Optimizing the Forest Bioeconomy: Balancing Biological Limits and Empowering Local Communities.

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: Climate change raises significant concerns for global economies as the current economic model assumes unlimited resources, leaving them increasingly vulnerable to the impacts of global warming. In response, the bioeconomy has emerged as a sustainable alternative that prioritizes responsible production, use, and conservation of renewable biological resources, encompassing knowledge, science, technology, and innovation. However, the bioeconomy faces a significant challenge in meeting the growing demand for biomass, which leads to adverse effects such as overexploitation of natural resources, agricultural expansion, competition for land use, soil erosion, deforestation, and biodiversity loss. These issues are more pronounced in certain regions where legal frameworks for ecosystem protection and sustainable management are lacking. Consequently, some countries prioritize exporting large quantities of low-value commodities, significantly transforming natural ecosystems. Notably, the production of soybeans, palm oil, and other crops in the Amazon region exemplifies this situation. Regrettably, economic considerations often precede environmental concerns, leading to unsustainable practices that harm ecosystems and the quality of the services they provide. To address these challenges, this study builds upon previous research and proposes improvements in circular bioeconomy strategies through a systematic literature review and qualitative content analysis. Preliminary findings underscore the importance of empowering local communities to restore a harmonious balance within ecosystem limits. Close-to-nature and agroforestry practices are highlighted as effective approaches.

Additionally, it is crucial to establish clear boundaries to prevent the over-exhaustion of natural resources and to respect biological cycles and regeneration processes. Addressing these critical issues is vital for understanding the implications of unsustainable biomass utilization and providing valuable information to policymakers. By promoting more sustainable practices within the bioeconomy, we can protect ecosystems, safeguard our planet, and ensure the well-being of its inhabitants.

Renowned concepts, new players? How the bioeconomy is politically formulated in African countries as compared to the Global North.

S2.1 Governance of a Bio-resource-based Bioeconomy in the Global South

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Abstract: Since the early 2000s the term “bioeconomy” has been rapidly taken on by politics, science and industry in the Global North. In the tradition of ecological modernization discourses, it describes an innovation-based transformation to a sustainable economy based on renewable resources. As such the dominant bioeconomy narrative is grounded in the ecological modernization discourse. Slowly, the bioeconomy is gaining popularity in African countries. The paper presents a comparative analysis between selected bioeconomy strategies from Africa and the Global North (Europe, Germany, Finland). Aim is to find out whether common narratives from the Global North are repeated or new specific approaches are gaining political attention in Africa. In the analysis, special attention is given to definitions of bioeconomy and its resource basis, as well as it is being associated with buzzwords such as “sustainability” and “green growth”. We also investigated how the forest sector is being addressed. We found that there are similarities in the definition of bioeconomy as well as in the framing of problems and proposed solutions. Regional differences exist in the type of biomass to be used as the basis for the bioeconomy as well as in the instruments that are suggested for bioeconomy implementation. Social aspects of the bioeconomy and conflicted goals related to issues such as land use and access to bio-resources, are not addressed in the African bioeconomy policies. The political focus on economic growth is mirrored by many recent scientific publications on bioeconomy coming from African countries. There are few critical voices in science who demand the inclusion of local and indigenous knowledge in bioeconomy approaches. European-African collaborations exist in form of joint scientific projects and development cooperation, e.g. for the elaboration and implementation of existing African bioeconomy strategies. The findings lead us to the assumption that there are indications that the European concept of bioeconomy serves as a role model for new bioeconomy approaches developed by African countries. This must be discussed critically since the bioeconomy model from the global North itself is very contested and follows an economy-driven approach whose contribution to sustainability has lead to controversial debates.

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

Advancing Technologies for Sustainable Forestry and Workforce Development

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: Forest-dependent rural communities in the United States face significant challenges in replacing lost jobs, effectively managing forestlands, and fostering economic development. Outdated forest practices and a fragmented supply chain often result in operational inefficiencies and waste of resources. The forestry workforce is aging, and the demanding and hazardous nature of the job, coupled with low wages, discourages new entry into the field. While various industries have embraced technology advancements, the forest sector has been slower to adopt innovative technologies.

This presentation highlights ongoing research efforts focused on modernizing forest production systems, enhancing health and safety of forest workers and providing advanced training for the forest workforce using cutting-edge technologies. Key areas of discussion include: 1) Safety, efficiency and environmental impact of mechanized harvesting operations on steep slopes, 2) machine vision technology for real-time tree detection and measurement, 3) assistive wearable devices designed to reduce forest workers' fatigue and injury, and 4) digital tools for enhancing workforce education and training. By exploring these key areas, this presentation provides insights into ongoing developments and their potential to drive sustainable growth, economic revitalization and the development of the next-generation forest workforce through the adoption of advanced technologies.

Co-creating the Future of Forest Work: A multidisciplinary methodology for the Youth Visioning Workshop

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: A major challenge for those working at the nexus of environment and development is gaining a holistic, systemic understanding of the decisions and practices of people and communities in relation to their environment. This paper describes how diverse fields, such as *systems thinking*, *design thinking*, organizational development *architecture, urbanism and design education*, can contribute to methods of engaging local people about global issues in a meaningful and culturally relevant way.

Our focus issue is the outmigration or disengagement of young people from forest communities to cities, a reality which calls into question the future of community-driven forest management, conservation, and restoration. The Future of Forest Work and Communities (FoFW) community of practice was established to better understand the perspectives of young people with regard to employment, life goals, migration and the forests they live in or near to. It also aims to engage youth in a transformative process, and co-create new awareness, interest and exciting opportunities for working in and with forests, especially relative to the emerging global demand for forest conservation. In this paper, we describe the structure of and theory behind the "Youth Visioning Workshop", a methodology developed for the FoFW project. Within the workshop we look at the role of co-design as a means of expanding the sphere of dialogue, opening up latent ideas and perspectives, shaping new ideas and perspectives in concert with peers, and responding to new information from local and global leaders and sources. Results from the 14 workshops held to date led to a high level of engagement from participants, rich diverse data, and deep insights into the perspectives of these young people. It also engendered a high level of engagement and collaboration on the part of the leaders, coordinators and facilitators of the workshops, strengthening the FoFW community of practice. We conclude the paper with examples of the outcomes of the Youth Visioning Workshops that demonstrate the effectiveness of this methodology, and with some challenges and learning opportunities for further development.

Developing smart forest logistic strategies in serious-game-based simulation workshops

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: A sustainable development based on renewable raw materials demands increasing amounts of wood, but the supply security is massively threatened by climate change and frequent forest calamities. Smart forest logistic strategies are needed to manage supply chain risks, uncertainties and complexities resulting in transport, storage and handling bottlenecks. Consequently, serious-game-based simulation workshops were developed to innovate forest education, transfer knowledge between science and industry as well as train the forest workforce to apply digital technologies and quantitative decision support models for the development of sustainable, resilient and efficient logistic strategies.

Scientific discrete event simulation models for forest logistics, storage as well as unimodal, multi-echelon and multimodal transport were further developed to provide intuitive usability for practical decision support in serious-game-based workshops. Discrete event simulation provides an excellent methodology for the digital representation of forest supply chains focusing on straightforward business processes to facilitate stakeholder participation and establish credibility through visualization and animation. Didactically sophisticated, hands-on game-scenarios challenge stakeholders to develop smart logistical strategies and directly assess their performance on the basis of key performance indicators such as lead and queuing times, transshipment volumes, emissions, utilizations and costs. This simulation setting allows experiencing effects of taken decisions as well as their complex interrelations with other supply chain actors to reflect on the achievement of self-set goals. The virtual simulation setting establishes a sustainable learning process through playing a serious-game without having to fear negative, dangerous and costly real-world effects, which commonly occur during crisis and uncertain system environments, where simple trial and error approaches still dominate business practice.

Consequently, the innovative simulation workshops drive the establishment of collaborative supply chain management through digital simulation technologies and smart logistic strategies. The competence-oriented, cooperative serious-game settings can be applied in scientific, educational and managerial environments to set the stage for advanced risk management (analyse and prepare), contingency planning (decide and act) and knowledge management (reflect and learn). This showcases a sustainable innovation path, where latest scientific findings are directly passed to target groups, which apply quantitative decision support models to implement smart forest logistic strategies enabling an environmentally, economically and social sustainable development.

DEVELOPMENT OF QR CODE SYSTEM FOR TROPICAL RAINFOREST TREE SPECIES IDENTIFICATION

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: Trees are an essential part of our natural environment, they provide a wide range of benefits to humans, other living organisms, and the environment. An accurate method of tree species identification and description will improve their management and conservation, it is also crucial for genetic study, biodiversity conservation measures, inventories, regeneration strategies, among others. The conventional methods of tropical rainforest tree species identification require examining and knowing their morphological, physiological and phenotypic characteristics. Due to the large number of tree species in tropical rainforests, the conventional method of tree identification is time-consuming, laborious, expensive, and requires a high level of expertise. Consequently, it has become imperative to develop a more efficient and easy means of tree identification. To address this problem, we developed a QR code system for tropical rainforest trees identification. Tree data was collected from two tertiary institutions in Akure, Nigeria with high concentration of trees. The QR system was built around a three-tier architectural model. PostgresSQL was used as the Relational Database System, which is the back engine and the lowest tier. The Middle tier was the Web Server, which is the Apache HTTP Server. Php 8.1 was the scripting language used to communicate with the database. For the highest tier, which is the Client tier, HTML, CSS, and Javascript were used. The barcode generator system was developed using PHP 8.1. A QR code library was utilized by the PHP script to generate the QR code image. The QR code is linked to the website and database which contains all tree species information. The generated QR codes were attached to trees, and when scanned with smartphone camera or barcode reader, the website is automatically launched and the tree information displayed. The results of end-users survey conducted within the 2 tertiary institutions revealed that the QR codes are accurate, easy to use, and made tree identification more interesting and engaging. This will, in turn, increase the interest and knowledge of people about trees, improve tree management and make it easy for people to easily identify tropical rainforest tree species.

Keywords: Tree identification, QR code, Database, Management, Tropical rainforest.

Economic Behaviour and Livestock Production in the Forestry Zones of Abuja, the Federal Capital Territory of Nigeria.

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: Agricultural practices can be carried out in a variety of ways that lead to results that are focused, as well as by combining various technologies to lower production costs and maximize profits. Agricultural practices are not well-documented and most farmers are unaware of the technology underlying the various practices, these practices are becoming increasingly important. The needs for the general use of land for animal production, which is now challenging. Since these innovations have the ability to "address various urban concerns such as young unemployment, environmental protection, income generation and social inclusion, and shortage of land for farming operations, they should be duplicated throughout the majority of the forested Zone. The world's growing cities can be transformed into cleaner, healthier environments by utilizing a variety of clever agricultural approaches. From enhancing environmental conditions and reforesting flood-prone areas to figuring out how to manage food waste, agricultural production, the development of green cities, and the expansion of forest zones. That can Initiative gives each community the chance to empower its people by utilizing local expertise and exchanging best practices. We must make urban living and livestock farming sustainable if they are the future's dominant lifestyle choices. Through observation and oral interviews. Additionally, I was able to find a small wooded area where residents were involved in cow and sheep farming activities. These activities included varied mixes of farming, forestry, and housing in addition to several other economic tasks including feeding the cattle, sheep and giving the animals a place to live. Eat and sleep outside, and the farmers also create their own unique farm dwellings for themselves. This encourages cooperation, multipurpose technology, and the use of animal manures like as feces, as well as the knowledge of the kinds of animals that are being produced. Mr Sule, 32, who has been using the forest zones for his livestock production claims, "With this knowledge, my sales have increased, and I've been able to establish its and in selling. I was able to feed my family through the livestock production. other agricultural practices

Keywords: Forest Zones, farmers, livestock, Smart Agriculture, Federal Capital Territory

Effects of trees to radio wave propagation in forest areas

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: Smart forestry is not enforceable if moble network doesn't work.In Japan,there are no network on half of a forest area. Therefore, it leads to less secure of work environment and low productivity.that's why it is important to know and develop the connection environment in forest area for smart forestry. this report shows the effect of trees to radio wave propagation in forest area, the good practice of communication, and information communication technology tools to share locational information for safety works. we measured the signal strength of with distance, trees between propagation line. We showed that the signal strength depends on the distance and the wood dense. we also analize the effect of radio wave frequancy to communication. the low frequancy radio wave reached on longer distance than high frequency radio wave. finally, we show the one of smart forestry application for safe working environment. this is the system to share the worker's location and the noticed information. this report conclude that smart forestry need the network communication and some alternative communication are also available in forest area.

Experimental Native Tree Seedlings Establishment for Restoration and Agroforestry in Burkina Faso: effect of irrigation and soil amendment

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: This study aims to generate knowledge that supports forest recovery on fallows to enhance ecosystem services and goods accrued from restored forests. The effect of four treatments on survival and growth of seedlings of twelve native species was tested in degraded land in Burkina Faso. A total of 504 seedlings were planted in randomized complete block design with three replicates combining four treatments: control, irrigation, manure and manure+irrigation. Soil samples were taken from the holes prior to tree planting (2012) and after 4 years' growth (2016). Survival and growth rates evaluated beyond 4 years were significantly higher using manure+irrigation, irrigation compared with the manure and control. Survival rates of plant species planted using manure+irrigation were 100% for *Piliostigma reticulatum* and *P. thonningii*, 99.07% for *Balanites aegyptiaca*, 94.44% for *Prosopis africana* and *Tamarindus indica*. Survival rate of *Detarium microcarpum* was 25.92%, 29.17%, 39.81%, 44.44%, respectively control, irrigation, manure and manure+irrigation. These results showed that except *D. microcarpum*, the other species can be considered and recommended as the suitable candidates to restore degraded land. Results for comparison between sample taken in 2012 and 2016 revealed an increase in total C, N, P, K and exchange cation capacity confined to the different soil layers. These results testified that reforestation impacted on soil properties and contributed to increase soil fertility. Furthermore, our results showed that restoration of degraded soil by native seedlings plantation is possible and could permit at long term biodiversity conservation, soil fertility, availability of forage, carbon sequestration and mitigate climate change.

Forest workers for the future – young students' view of their working life in a transforming forestry sector

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: The young generation of forest workers is a crucial group for the transition towards more sustainable forest futures. Despite young people's decisive role as agents for change, few studies have addressed their view of the challenges and opportunities connected to future work in the forestry sector. In Sweden, where clear-cut forest management is the dominant practice, there is a need to increase understanding of how this practice affects young people's view of the future and the meanings and norms that are associated with the continuation of such practices. The study is based on seven focus groups of high school students in their first, second and third years of a programme with a particular focus on forestry. It emerges from the study that the ideas and norms of clear-cutting are challenged during their education, even though the view that Sweden is a leading country in sustainable forestry remains. A main challenge for future operators of tree harvesters is the stress generated from having production goals. The students also recognise the potential health problems from sitting still for long periods and that working alone in the forest could make them vulnerable in case an accident or technical incidents occur. Together with late and long working hours, this imagined work situation made most of them think that they could only work as tree harvester operators for a limited time. To attract more young people and change the gender-coded division of work in the forest sector, students suggest more targeted initiatives towards primary school pupils. This should include a broader view of possible work tasks, where pupils are able to visit forests and try out different practical tasks. The results show that the dominant practices create challenges: new operators of tree harvesters have to be constantly trained for only a few years in service. Education and training of the future workforce need to address the challenges facing students in a clear way. Moreover, the study suggests a close collaboration between education and forest companies to develop long-term sustainable and attractive forest employments, as an important contribution towards the transformation to sustainable forestry.

GNSS through the trees: Smartphone capabilities under forested conditions

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: Smartphones are pervasive in today's society serving as communication devices, navigation systems, and data collectors. Recent graduates of forestry and natural resource programs as well as young professionals in the field will undoubtedly be a generation very savvy with smartphone technologies. Workforce training and education about the GNSS systems in these devices would likely benefit from incorporating and promoting technologies that are familiar to these digital natives. As GNSS antennas and capabilities of smartphones improve, these non-traditional GNSS receivers may be approaching a level of accuracy that makes their integration into field data collection and analysis a reasonable alternative to traditional handheld GNSS receivers. Modern smartphones are often equipped with more than one transmission frequency in recent years, some allow access to raw GNSS data for post-processing differential correction, and some have the capability of being coupled with external antennas which potentially can increase positional accuracy of data collected with these devices.

An extensive research effort is underway to investigate the horizontal positional accuracy of two types of smartphones, an iPhone 13 Pro and a Google Pixel 6 Pro, to understand potential positional error encountered under both leaf-on and leaf-off forested conditions. In addition to independent data collection with these devices, the iPhone 13 Pro will also be connected to a Juniper Geode antenna using bluetooth technology, turning the smartphone into an interface for collecting GNSS data with the antenna. Early results from this research suggest that smartphone technology may now provide sub-meter positional accuracy in forested conditions, improving efficiency and safety in forest management as well as possibly reducing the costs associated with mapping-grade GNSS technology. More extensive results will be provided during the presentation. Understanding the positional accuracy smartphone devices provide, and the associated uncertainty, is important as they become more commonly used in natural resource management. Continued assessments of smartphone GNSS technologies, as they evolve, benefit not only researchers but those professionals who use smartphones for normal work activities.

Integrated forest and wildlife management – a prerequisite for climate-smart tree species mixtures in natural regeneration

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: Sustainable forest management includes not only the preservation and management of tree populations, but also the management of the various game species belonging to the forest habitat. This dual management regularly leads to conflicts of objectives between hunters and foresters, as the type and intensity of hunting has significant effects on natural regeneration, tree species composition and biodiversity in the forest. Moreover, the selective browsing of specific tree species might affect the suitability of the next tree generation and thus the vulnerability of the regenerated forest.

Austrian harbours a broad range of forests types ranging from low elevation mixed hardwood forests up to high elevation Alpine forests. Several forests types already face signs of climate change induced disturbances and forest pest. Natural regeneration is therefore seen as an efficient nature-based solution to support mixed species forests and to reduce the vulnerability of forest to climate change based forest hazards. The objective of the present study is to disentangle the role of prerequisites for climate-smart natural regeneration in terms of adult species compositions, forest management and structure, wildlife habitat and game management. Across 21 pilot forest areas, detailed assessments of forest structure, regeneration ecology and wildlife ecology were undertaken using grid-based inventories. The recorded composition of natural regeneration was tested for its vulnerability to future climate using tree species distribution models. Moreover, hunters and forest owners were interviewed for their management behaviour, management objectives and cooperation as integrated forest and wildlife management.

Our results demonstrate that on average, tree species diversity decreased from the adult stage to the natural regeneration. Moreover, intensive browsing on species which are less vulnerable to climate change further reduced the diversity of the future forest, despite common interests and significant efforts of both forest managers and hunters. The most successful pilot areas showed a long-term commitment to active forest management and hunting as supporting service. Such cooperations not only reached high tree species diversity but also higher wildlife habitat quality. We conclude that climate-smart tree species mixtures from natural regeneration are not likely to be reached without strong cooperations among forest managers and hunters.

Single-tree level optimization model for cable-based forest operations planning in steep terrain

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: A common challenge in planning forest operations with cable-based systems in steep terrain is to maintain the expected harvesting efficiency such that the revenues exceed logging costs. One of the difficulties in realizing a positive economic marginal return is the spatial distribution of the trees selected for harvesting. Indeed, selection scheme, generally must comply with strict silvicultural constraints, also limiting the volume of timber to be harvested. Using spatial optimization at single-tree level can address the operational problem maximizing the profit under given constraints.

In this study, a decision-support optimization model based on integer programming (IP) was implemented to select trees to be harvested, according to economical and spatial objectives. To create a base to apply the optimization approach, field data and StanForD 2010 data from a Mounty 5000 cable yarder were used to develop efficiency and productivity models using multiple linear regression method. Tree parameters, as spatial input scenario, describing a specific forest stand, were derived by means of high-resolution airborne laser scanning at individual tree level. Trees were further rated by financial value and then connected with the productivity models to run the optimization process.

Our preliminary results show that an improving in key-performance indicators of forest operations, such as the economic marginal return, could be achieved by pre-selecting the most suitable trees to cable-based harvesting system, while still respecting the timber volume reported in the harvest plan.

Keywords: Cable yarder, optimization, integer programming, airborne LiDAR

The development of artificial intelligence and visualization technology promotes the application of smart forestry

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: Artificial intelligence and visualization technology, as core technologies driving the digital transformation of the modern forestry and grass industry, will continue to deeply integrate with and empower the business, widely applying in areas such as forestry and grassland resource monitoring, biodiversity conservation, and forestry and grassland disaster prevention and control, promoting the high-quality development of forestry and grass industry. The report introduces the latest research progress and application prospects of artificial intelligence, 3D visualization, digital twins, and metaverse technology in the three-dimensional modeling of forestry and grassland resources, intelligent monitoring of flora and fauna, intelligent supervision of forest resources, national park construction, ecological industry development, and digital cultural heritage protection. The report elaborates on the integration between Artificial Intelligence Generated Content (AIGC) and the forestry and grassland metaverse, especially in the generation of virtual environments and scenes for forestry and grassland, the creation and generation of digital content for forestry and grassland, real-time interaction and natural interaction generation, forestry and grassland simulation, prediction, and decision-making generation, which can provide content generation for forest structure optimization, quality improvement, ecological protection, and industrial development, enabling intelligent analysis, comparison, optimization, and improving decision-making capabilities. AIGC can provide the forestry and grassland metaverse with richer and more diverse creative and generative capabilities, accelerating the development of the metaverse.

Visualizing forestry Linked Open Data and producing biodiversity annotations with EducaWood

S2.2 Smart Forestry – Transforming Forestry and the Future Forest Workforce

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Abstract: EducaWood is a web application designed for environmental education and the creation of biodiversity repositories. It can be used to support learning activities based on the social annotation of trees and other ecosystem structures; it also allows the exploration of forestry information in an area of interest. EducaWood exploits existing semantic datasets of land use and dendrometric information from Spain and Portugal that we have released as Linked Open Data (LOD). Teachers can check these sources to propose contextualized activities of environmental education, e.g. find a holm oak in a nearby dehesa and annotate it. Students can then go to the target site and perform the proposed activities with their mobile phones. EducaWood provides an interactive map with typical navigation controls like panning or zooming to easily explore the zone of interest. Beyond the visualization of forestry data, registered users of EducaWood can create new trees or enrich existing ones with new annotations. A geolocation annotation is always required, while the rest of annotation types are optional and include species, dendrologic measures, photos and tree status. To define the necessary terms we reuse some forest ontologies (species, locations, measures) and we have developed the Simple Tree Annotation (STA) ontology to allow social annotation of trees. STA supports multiple and possibly inconsistent annotations from multiple users, including primary properties that are purposed for conflict resolution. Annotations are introduced through simple web forms, thus hiding the intricacies of ontologies and data formats to users. All produced annotations are published as LOD and shared for the community of EducaWood. As a result, the application enables the creation of a crowdsourced biodiversity dataset that expands beyond the areas covered by institutional forest inventories, e.g. urban forests. This dataset can also be exploited in follow-up learning activities such as virtual field trips or citizen science projects. We have tested a first version of EducaWood with a reduced set of users. With the collected feedback, we are currently completing a production version that will be released soon. Future plans include pilot studies in forestry courses at University level and the integration of environmental data from OpenStreetMap.

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

Sustainability Beyond Functionality – A Study Of Past 25 Years In Central Indian State Madhya Pradesh

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: The Central Indian state of Madhya Pradesh is having the largest forest area in the country. The forest management is based on sustainability and yield from forest which is regulated by selective felling along with regular plantations in the suitable areas. Other than timber production the non-timber forest products are a major activity along with multiple uses of them.

Since 1992, Rio summit for sustainability till 2016 the timber production has reduced almost to half in past 25 years. Dwindling forest wealth is attributed to many factors such as over exploitation, over grazing, illegal encroachments, unsustainable practices and forest fires.

During this period the state had many management and legislative changes like, World Bank added project, Joint Forest Management, Forest Rights Act, Green India Mission and Biodiversity Act.

The study reveals that although the production has shown a down trend, the management of forests has continuously changed towards participatory and decentralized decision making. Still there is insufficient economic promotion of forest goods and services. Additional resources are required for environmental education, awareness and women participation along with understanding of indigenous knowledge. The conservation of bio resource along with the needs of the society and ecology are at the cross roads for the future adaptation of the natural wealth.

The revenue generation from the production forestry is vanishing with time vis a vis the social needs and the role of forest wealth is increasing for the present need of climate change and for the betterment of the people living and surviving in and around the forests and dependent on the forest wealth.

The paper deals with the critical analysis of the local issues along with the priorities of the National Policy draft and the International Conventions. The paper also critically analyze the risks of the socio ecological conflicts arising due to the present and future need of the precious forest wealth and the ever increasing pressure of the people's needs and urbanization.

A Brief Overview of the Marketing of Firewood in the Federal Capital Territory of Abuja, Nigeria

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: The numerous needs to improve the forestry industry, the necessity to rethink the various marketing and distribution strategies of the various firewood products, and involvement in the manufacturing of charcoal, chewing sticks, and sculptured wood items. As a result, Nigeria possesses approximately 600 potential timber species. Less than 300 are currently being commercially utilized for international trade. However, if the informal firms of tiny wood-based industries were conducted with official inclusion into the national economy, the industry could contribute significantly to local and worldwide trade. These businesses include diverse craftspeople, cabinet manufacturers, and timber converters who sell various types of firewood. More research is required to provide varied costs; information; networking; seller connection; and documentation of best practices in firewood marketing. If there are better ways of enhancing and assisting persons involved in various uses, such as residential and industrial, The numerous investigations were carried out in two regions of the Federal Capital Territory of Abuja, namely Gwagwalada and Municipal, and the varied methods of marketing the various firewood's were observed. According to the findings of the field survey, the firewood. was being marketed in an open setting, divided into different sizes, and assembled. However, there is no precise information regarding the various prices. This article so advocated the necessity for re-strategizing the style of marketing the various types of forestry products; techniques of presenting; community seller involvement and cooperative society building; and the need for reforestation and forest protection programs.

Keywords: Firewood, Marketing, Selling, Federal Capital Territory

An Estimation of National Charcoal Production: the case of Ghana.

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: Accurate data on the production and sources of woodfuels is necessary to ensure sustainability. National level data is scanty in most sub-Saharan African countries. This research aimed to provide accurate data on charcoal production in Ghana and to develop, and put fort a methodology that could serve as an inspiration for future assessments, in Ghana and beyond. The study compiled data over two years from Ghana Forestry Commission's records on charcoal quantities transported on the road (Charcoal Conveyance Certificates). This data was validated by mounting sentries 24 hours daily for two weeks in 2016 and 2018, respectively, along major charcoal transport routes to capture charcoal being transported without the certificate. Charcoal production not captured through the Charcoal Conveyance Certificate and the sentries was quantified from field observation and expert panel validation. Using these three methods, the study estimated a total annual production (2018) of 1 100 000 tonnes of charcoal for Ghana. This corresponds to 15.7 million m 3 of round wood equivalent. The comprehensiveness and robustness of the methodology hints of possibility of a more accurate data to inform decision making and planning on charcoal production and trade. This however requires improvement in the Charcoal Conveyance Certificate regime by the Ghana Forestry Commission to capture more of the charcoal conveying vehicles and their load (carrying capacity). This can be done through periodic mounting of sentries as demonstrated in this study to monitor the charcoal conveyance data. We suggest that the proposed method could serve as inspiration for regulatory bodies in Ghana, notably the Ghana Energy Commission and Ghana Forestry Commission, to generate regular updates on annual charcoal production and consumption, perhaps in tandem with estimates obtained through other methods, for example consumption studies. Finally, it is suggested that the method demonstrated here can serve as inspiration beyond Ghana, in countries where national permit systems are implemented, but only capture a share of the total production and movement.

Assessment of stocking, productivity, and aboveground biomass of tree species used as fuelwood in Rwanda's agricultural landscapes

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: Trees-based systems (TBS) in the agricultural landscape have the potential to supply wood biomass as the source of cooking energy to the local communities in Rwanda, but there needs to be more information on the current most cultivated tree species suitable for fuelwoods supply and available wood biomass. We assessed the most cultivated species preferable for fuelwoods supply and their aboveground biomass (AGB) stock in five TBS, which are home gardens, mixed cropping, intercropping, live fences, and woodlots, through a survey of 130 transects covering an area of 130 ha, systematically distributed in Musanze and Bugesera Districts. Considering the total inventoried tree species, tree density covered 132 trees/ha in Musanze and 74 trees/ha in Bugesera. In Musanze, Eucalyptus spp were the most cultivated trees in all TBS constituting 68.3% of all trees. In Bugesera, 6251indivudual trees were found, of which eucalyptus spp was the most common tree (31.9%) ,followed by senna spectabilis (28.5%).Overall, the total AGB was 2.77t/ha in Musanze and 1.08t/ha in Bugesera. AGB was higher in intercropping in both Musanze and Bugesera (0.86t/ha and 0.36t/ha). The four species that contributed the most to the total AGB were Grevellia robusta (0.34t/ha), Eucalyptus spp (1.97t/ha), Alnus acuminate (0.42t/ha), and Markamia lutea (0.04t/ha) in Musanze District while in Bugesera District were Grevellia robusta (0.79t/ha), Eucalyptus spp (0.20t/ha), Senna spectabilis(0.06t/ha) and Markamia lutea (0.03t/ha).

Combined application of biochar and deficit irrigation enhanced growth of commercial agroforestry woody species seedlings in the drylands

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: Water availability is the main problem for the growth and expansion of commercial agroforestry woody species in drylands. Biochar (B) and deficit irrigation (DI) can be used to enhance soil moisture in drylands. Growth of commercial woody species seedlings were evaluated for about two years using the combined effect of B and DI treatments. Biochar was applied to the plantation pits during plantation with a rate of 10 ton ha^{-1}. The irrigation applied covered 59.6% (459 mm) and 35.2% (459 mm) of the dry season crop evapotranspiration for *Citrus sinensis* and *Yushinia alpina*, respectively. Combined application of B and DI significantly increased growth of both the species. New culms of *Y. alpina* were increased by applying both B and DI. The species differed significantly in height and diameter relative growth rate (RGR) and physiological responses. *C. sinensis* had higher height and diameter RGR than *Y. alpina*. Transpiration rate was significantly higher in *C. sinensis* than in *Y. alpina*, but vice versa in water use efficiency. Combined application of B and DI significantly enhanced the height and diameter RGR of the species in dry months through gas exchange enhancement. Both the species attained their maximum height growth rate at the end of the rainy seasons. Combined application of B and DI and DI alone significantly increased biomass of *Y. alpina*. Hence, combined application of B and DI is essential for successful establishment of *C. sinensis* and *Y. alpina* seedlings in farmlands of dryland areas.

CONTRIBUTION OF BRITISH AMERICAN TOBACCO (BAT) TO TREE PLANTING IN KENYA

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: Tobacco industry has been associated with improvement of livelihood as well as claims of degradation. A study in 2016 addressed the environmental impact of tobacco growing, paying special attention to tree planting and loss of vegetation in Kenya. The objective of the tree census was to evaluate the effect of afforestation programs by BAT tree planting project to its contracted farmers in Kenya that is Eastern, Western and Nyanza regions. The study targeted 517 farmers sampled from the total number of farmers estimated at 5500. Tree inventory, consultative and participatory survey approaches mainly targeting key informant interviews, documents reviews, questionnaires and focus group discussions were used. These targeted various levels of BAT customers/beneficiaries. Desk reviews on existing secondary data and documents were undertaken for study preparations, methodologies, benchmarking with other similar studies and to develop a comprehensive report. The study suggests three triggers that lead to vegetation loss associated with tobacco growing namely forest degradation and deforestation due to tobacco curing clearance for more growing land. The study noted that, although the global share of agricultural land used for tobacco growing is less than 1%, its impact on global deforestation is 2–4%, making a visible footprint for climate change. The key tree planting support that BAT gave to farmers and institutions was provision of free seedlings. In Western, the survival rate was higher for trees issued by BAT compared to trees sourced elsewhere, contrary to Eastern and Nyanza regions. The major reasons for mortality amongst tree seedlings include drought, poor season timing and pests attack, especially termites. The possible interventions for the challenges were watering trees during dry seasons and provision of pesticides/ termiticides. The company should supply tree seedlings in good time. Study recommended approaches to enhance tree cover initiatives that include increased tree nurseries for contract farmers, pest and disease monitoring, proper timing for tree planting and continued collaboration with key partners.

Key words: Tree census, tree planting, Participatory, tobacco growing, degradation, deforestation

Does intensive forest biomass harvest require nutrient compensation for sustainable biomass production?

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: The use of forest derived biofuels as an energy source has increased substantially during the last decades not least in Sweden. Whole-tree harvesting includes extraction of, except for stems, tops and branches used for energy purposes. This is a large-scale practice and recycling of the produced wood-ash is undertaken at some sites. There are only a few available field experiments with ash addition, especially when added in clear-cuts following whole tree harvesting. Therefore, to increase requested knowledge on how whole tree harvesting and ash recycling affect growth of Norway spruce (*Picea abies* L. Karst.) three field experiments were established to test the following hypotheses: (i) the growth is reduced after WTH, (ii) at fertile sites the growth is enhanced by ash addition, unaffected at medium-productive sites, and reduced at low-productive sites, (iii) the reduced growth by WTH is compensated for by ash addition at fertile sites only. The study includes monitoring of survival and tree growth measurements in the three field experiments located on sites of different fertility. The experimental design is treatments randomized within blocks (n = 5). At all sites the following treatments are included: (i) harvest of stems only, (ii) whole-tree harvest, (iii) harvest of stems only + 3 tonnes (dry matter) of self-hardened crushed biofuel ash, and (iv) whole-tree harvest + 3 tonnes (dry matter) of self-hardened crushed biofuel ash. Each study plot is sized 20 m × 20 m and included 64 seedlings at planting. The experiments were established between 2011 and 2015. Results on survival and growth over 8-10 growing seasons will be presented and the need for nutrient compensation after WTH will be discussed based on these results and the general knowledge on tree growth responses of WTH and different nutrient compensation regimes.

Does traditional agrisilvicultural systems benefit farmers? - A benefit-cost analysis of Grewia optiva on pea fields of northwest Himalayas

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: *Grewia optiva*, a multipurpose tree species, is widely preferred by farmers in traditional agroforestry systems in the northwest and central Himalayan regions of India. This species is retained deliberately by farmers on the farm bunds on account of its utility as fodder, fuel, fiber, and other purposes. The selection of intercrops depends mainly on edapho-climatic conditions of the area. The present study is aimed to assess the benefit-cost analysis of the *Grewia-based* traditional agrisilvicultural system in Chakrata tehsil of Dehradun district in the north-west Himalayan state of Uttarakhand during the winter season. We chose pea (*Pisum sativum*) as a representative rabi crop for the agricultural component of the study area as it is a major and most preferred crop of the region. The Two-stage random sampling was adopted for the selection of the primary sampling units, i.e., households. Villages were selected in the first stage and households in the second. At least 10% sampling intensity was maintained to randomly select the villages and a representative household survey was conducted following a pre-structured questionnaire in the selected villages. We calculated the benefit-to-cost ratio (B/C ratio) at a discounted rate of 7% for a period of 5 years by incorporating all the input and output costs associated with this tree-crop combination. A high 3.6 B/C ratio indicates multifold benefits gained from *Grewia-based* agri-silvicultural fields. The said benefits include the daily requirement of fodder and fuelwood during the lean winter season besides the main income generated from agricultural crops.

Driving Sustainable Economic Growth in Mountain Forest Communities through the Implementation of Charcoal Production Chains

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: Based on FAO data, most of the charcoal consumed in Europe is produced in non-European Union countries, particularly tropical regions. This reliance on imported charcoal raises concerns as it often contributes to illegal logging practices and forest degradation, posing significant environmental and sustainability challenges.

The use of local wood resources for charcoal production guarantees several benefits. Firstly, it reduces the dependence on imported charcoal from foreign countries, ensuring self-sufficiency and promoting local economic growth by generating additional income for forest owners and communities. Beyond its traditional use as a cooking fuel, charcoal has also several applications in industries such as metallurgy or pharmaceuticals.

Therefore, charcoal production and its distribution at the local level could represent an effective solution to reduce wood charcoal importation and at the same time add value to the local wood supply chain in the frame of the circular economy.

In this frame, a case study located in the north-eastern part of Italy has been analyzed considering: 1) wood harvesting efficiency, 2) potential availability of logging residues suitable for charcoal production; 3) charcoal production process efficiency; 4) charcoal quality compared to products already available in the market.

The study will present the consideration to implement a charcoal-production chain at a small-scale in terms of socioeconomic and environmental benefits.

Factors influencing adoption of energy conservation and production technologies for wood fuel resources in Makueni County, Kenya.

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: Abstract

In Kenyan, wood fuel is an important sector in the economy. Increased population, rapid urbanization, changes in lifestyles, high poverty levels and high cost of alternative fuels for cooking and heating have contributed to increased demand for wood energy. This has resulted in increased deforestation of public, private and community forests. Production and utilization of woodfuel resources is characterized by selective and unsustainable harvesting methods, overexploitation of preferred species and use of inefficient production and utilization technologies. A socio-economic survey undertaken in Makueni County to evaluate woodfuel resources, preferred, alternative fuels sources, and socio-economic factors influencing adoption of energy conservation and production technologies. The results revealed that energy mix and stacking is a replica of the national situation with fuelwood being the most preferred source of energy, followed by charcoal, kerosene, gas and crop residues respectively. Availability, cultural preferences, health and safety, cost of technology and sustainability of the fuel influenced choice. Decreasing indigenous trees on community forests and private farms, and increased planting of exotic trees for timber, fruits and aesthetic were the major factors contributing wood fuel scarcity. Availability of alternative fuels, scarcity of fuelwood, high cost of charcoal and convenience in use has influenced changes in types and quantities of energy used at household and institutions. There was a significant correlation between family sizes and energy consumption. Major challenges in obtaining fuelwood included: scarcity of firewood resources, long distance and time taken for collection, high cost of production, labor intensity, ban on charcoal production, inefficient production and climate change. Indigenous trees were the most preferred fuelwood sources though the tree are getting overexploitated. Acacia and Terminalia species were the most preferred. Adoption of energy conservation technologies was constrained by land and tree ownership, income level, education level, cultural values, lack of expertise, availability of alternative fuels and ignorance. The study concluded that bioenergy is a major source of cooking fuel for rural population. We recommend capacity building of community, groups and institutions on sustainable bioenergy production, utilization, environmental conservation and afforestation using indigenous species as way forward.

Keywords: bioenergy, technologies, energy sources, preferred species. Environment, biodiversity

Geographical variations of woodfuel supply and trade in northeastern Bangladesh: The question of sustainability

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: We surveyed woodfuel vendors in 112 markets within 30 km from the borders of Khadimnagar National Park (KNP subregion) and Lawachara National Park (LNP subregion), evaluating how two subregions differ in relation to market attributes (degree of urbanization, population density), environmental attributes (tree coverage, seasonality), vendor characteristics, and woodfuel sources utilized by the vendors. A total of 206 woodfuel vendors were interviewed, including 58 wholesalers, 22 mixed wholesalers, and 126 sawmills. Principal component analysis (PCA) was used to summarize the relationships between environmental factors and market attributes. Survey results revealed that 101 rural market vendors sold higher quantities of woodfuel compared to 94 semi-urban market vendors. In the KNP subregion, the average woodfuel sold across 74 markets was 243 ± 283 t/yr, while the LNP subregion saw 333 ± 316 t/yr of woodfuel sold across 38 markets. Sawmills in the two subregions had significantly greater woodfuel sales than the wholesalers and mixed wholesale vendors. There was a significant seasonal fluctuation in woodfuel sales, with lower sales during the wetter monsoon months (July-October) and higher sales in the winter months (November-February). Findings showed a positive correlation between the annual woodfuel sold in each market and market attributes, such as the surrounding population density. Non-forest sources, such as homestead forests, roadside plantations, tea estates, and sawmills supplied 73% of the total woodfuel sold. Moreover, the Multinomial logit model revealed significant effects of specific vendor attributes on the selection of utilized woodfuel sources ($p < 0.01$). Significant variations were observed in both the woodfuel selling price and vendor's net income between the two subregions. The findings highlight the importance of homestead forestry and roadside social forestry plantations in achieving sustainable woodfuel supply for Bangladesh's forest and energy sectors' sustainable development goals.

Governance of landscape approach applied to woodfuel value chains in Democratic Republic of Congo: Experiences from Yangambi landscape (North-eastern)

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: In the Democratic Republic of Congo (DRC), woodfuel is used by households as a primary source of domestic energy for cooking, with an increasing demand by urban centers. This situation calls for reconsideration of the balance between socio-economic and environmental outcomes of woodfuel value chains and potential of sustainable management.

Woodfuel production is often presented as one of the drivers of deforestation and forest degradation. However, this sector is part of more complex links and often a by-product of shifting cultivation practiced throughout the Congo Basin region. Previous efforts to formalise the woodfuel sector in the DRC have not sufficiently incorporated a landscape approach that considers these interlinkages with other uses and users in the supply chain. This paper shows how the landscape approach could be effectively applied to woodfuel value chains in order to contribute to biodiversity conservation and livelihood improvement for local communities. The analysis is based on a literature review and empirical data collected from producers, sellers and households in Yangambi landscape located in North-eastern in DRC.

Governance through the landscape approach helps to explore the formal and informal opportunities for the sustainability of woodfuel value chains linked to other livelihood activities.

In Yangambi landscape, this integrated approach through a participatory process resulted in bases for sustainable socio-ecological systems of woodfuel production (agroforestry, improved carbonisation techniques and valorisation of wood waste) and consumption (promotion of using improved stoves) based on local context.

Key words: Landscape approach, woodfuel value chain, Yangambi landscape.

Supporting Transitions to Sustainable Woodfuels in sub-Saharan Africa with New Tools and Novel Policies

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: Roughly 2.4 billion people in Global South rely on wood, charcoal, and other biomass as their primary source of energy. These fuels are typically burned in open fires or simple devices and are associated with a range of development challenges including profound health impacts, forest degradation, climate-forcing emissions, and gender inequities. Some regions are transitioning from woodfuels to cleaner options like cooking gas or electricity, which have fewer negative impacts. However, in the absence of major investments and shifts in policy, hundreds of millions of families will use biomass for years to come. Indeed, the WHO estimates that the woodfuel-dependent population in sub-Saharan Africa will **increase by 400 million people** in the next two decades.

Many countries in sub-Saharan Africa are trying to address these challenges by introducing new policies and seeking investment that would initiate or accelerate a transition away from traditional woodfuels. Indeed, thirty-eight countries in the region have included provisions in their Nationally Determined Contributions (NDCs) to the UN Framework Convention on Climate Change seeking to either make woodfuel consumption more sustainable, reduce woodfuel dependence, or eliminate it entirely. However, achieving those targets will be incredibly challenging. There are very few examples of successful woodfuel transitions in the region and the investments made in the sector have been woefully inadequate.

In this panel presentation, we will discuss recent efforts to promote sustainable woodfuels and introduce alternative sources of household energy in sub-Saharan Africa. Our presentation will examine both analytic tools and policies. The analytic tools we introduce are computer-based models that help us understand the nature and magnitude of the impacts that unsustainable woodfuel consumption has on the environment and society including forest degradation, greenhouse gas emissions, and health risks. Quantifying these impacts is critical to understand the full costs and benefits of transitions and to catalyze the necessary investment. The policies we examine have either been introduced or are under development and are intended to shift countries to more sustainable energy pathways. Specifically, we are advising the government of Uganda to develop a new Clean Cooking Strategy and cut woodfuel demand in half by 2025.

Sustainability of woody biomass feedstock for bioenergy sector in China- A case study of Guangxi

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: Guangxi is a forest resource rich province, with 62.2% of the land covered by forests. Half of it used for timber production, of which 10% are certified under FSC or PEFC. Guangxi supplies more than 40% of China's domestic timber. Guangxi's forest-based industries are amongst the largest in China, characterized by high level of integration, reliance on regional wood supply and interdependence between different value chains. It contrasts with other Chinese forest industry clusters that rely on imported raw material.

The study aims to evaluate the availability, sustainability and traceability of woody biomass feedstock for bioenergy. We mapped out value chains, identified sectors that supply woody biomass residue (WBR) and sectors which compete for WBR with bioenergy generation. Sustainability, and traceability of the WBR for bioenergy sectors are evaluated based on FSC FM and CoC standards.

Harvesting, sawmilling and plywood industries generate WBR that feed into the production of fiberboard, particleboard, wood pellet and biomass power generation. Given the large plywood production capacity, processing residue from plywood constitute the main source of WBR. A smaller portion comes from sawmilling industry. Harvesting residue, due to high cost of labor and transportation, is utilized at low rate. Large production capacity of fiberboard and particleboard compete fiercely for WBR with wood pellet and biomass power generation industries. The sustainability of WBR is largely ensured by theSFM principles and criteria which are embedded in China's recently revised forest law. Another layer of sustainability comes from WBR that are generated from FSC and PEFC certified supply chains. The main sustainability risks include over and false utilization of fertilizer and herbicide, worker safety and rights of immigrant workers. Traceability of WBR poses the biggest challenge because of high consolidation of sawmilling and plywood production industries.

Guangxi provincial government highly recognizes the contribution of forest-based industries to local economic development. Policies are in place to further catalyze the development of forest-based industries. Bioenergy industry as an integral part of the local bioeconomy and a sector that utilizes residues of mechanical wood producing industries have a key role to play in driving sustainability and traceability in the sector.

Sustainable Wood Fuel Production for Dendroenergy Generation – Challenges and Learnings Through Economic and Environmental Dimensions

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: The demand for energy particularly the renewable energy is gaining potential attraction among the developed and developing nations. Among the renewable energy resources, the significance of biomass energy generation is very well witnessed due to its role in decentralized energy generation, rural employment coupled with its role in carbon sequestration. Hence, studies were conducted in the state of Tamil Nadu, India to assess the status and opportunities of dendroenergy generation coupled with suitable research interventions to sustain the availability of biomass resources. The study considered the actual potential and demand of wood to meet the raw material requirement of various biomass industries coupled with policy directions on blending biomass in coal powered plants. This besides, the current availability of biomass has been reviewed and presented with the challenges and constraints which detracts the attraction of biomass energy generation. The paper also indicated the potential and viable opportunities to establish commercial and sustainable dendroenergy plantations through technological and organizational interventions. The development and deployment of High Yielding Short Rotation (HYSR) clones (100 tonnes/ha in 2-3 years) with improved thermo-chemical properties (Calorific value ranging between 3800 and 4500 Kcal), site-specific dendroenergy models (HDEP), value addition technology viz., wood chips (<10 mm, 20-40 mm), briquettes (70 mm & 90 mm) and pellets are the technological interventions which attracted dendroenergy generation. The establishment of suitable linkages among various stakeholders from the entire Production to Consumption System (PCS) in a consortium approach is proved to be very lucrative and attractive both for the growers and consuming industries. In a holistic analysis, the current paper describes the potential options for sustainable wood production through Forestry and Agroforestry options towards generating clean and green energy.

The Potential of Efficient Charcoal Production and Briquetting in Improving Livelihoods and Combating Climate Change

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: Unsustainable woodfuel production in fragile ecosystems is responsible for increasing deforestation and widening woodfuel supply-demand deficit. This is threatening the livelihood of communities while accelerating climate change. This study aimed at validating and upscaling efficient charcoal production and provision of briquettes for sustainability and improved livelihoods. The study determined efficiency and productivity of kilns, quality of charcoal and briquettes, greenhouse gas emissions, and profitability of efficient charcoaling and briquetting. The study was conducted using stems and withies from Prosopis, maize cobs, rice husks and bagasse. Pyrolysis technologies validated were traditional earth mound (baseline), improved earth mound, portable metal, top-lid up-draft box, modified drum and cylindrical husk Carbonizer. The kilns and accessories were fabricated and validated with community interest groups (CIGs). Key informant interviews and laboratory tests were conducted. Emission factors were obtained from published literature. Results indicated that portable metal kiln had the highest efficiency (35.3%) with annual profitability increase of 19.6% in relation to baseline kilns. Charcoal from improved traditional earth mound recorded the highest fixed carbon (77.5%) and least ash content (3.1%). Traditional earth mound kiln recorded higher average monthly CO_2 (1.3 tons) and CO (0.3 tons) emissions compared to other kilns. Briquetting technologies showed conversion efficiency above 25% on feedstocks tested. Briquettes from bagasse carbonized using modified drum kiln and mixed with gum arabic recorded the least ash content (9.1%) whilst briquettes from Prosopis withies carbonized using the same kiln and mixed with gum arabic recorded the highest fixed carbon content (67.4%) and calorific value (25.4 MJ kg^{-1}). It was estimated that a CIG producing briquettes using bagasse via a motorized machine could make the highest monthly profits (US$ 477), with the potential to make 5.1 tons of charcoal equivalent fuel monthly. Therefore, efficient charcoaling and briquetting can improve people's livelihood and combat climate change.

“Before, when we were poor…” - how a market driven afforestation changed trajectories in socio-economic and environmental resilience in Ethiopia

S2.3 Sustainable Woodfuel Production in Sub-Saharan Africa - Social, Economic and Environmental Dimensions

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Abstract: A rapid market driven land-use change from agriculture to forestry is occurring in the Amhara region in Ethiopia. Farmers have introduced an agro-forestry system with production of charcoal from fast growing *Acacia mearnsii* in a 4 to 6 year rotation, with high economic returns and impacts on landscape ecosystem features. The *Acacia* is intercropped with teff and grass during the first and second year of the rotation. This system largely replaced traditional annual cropping systems. Between 2002 and 2017 the area proportion of traditionally managed cropland reduced from 67% to 36% in the Fagita Lekoma district while the *Acacia* plantations went from less than 1% to 38% (25 000 ha in 2017). The value chain of the charcoal creates significant economic activity. Based on trade statistics from the district office we estimated annual export of charcoal in the order of 5.3 million bags yr^{-1} of charcoal (July 2018 – June 2019). This charcoal represents a market value in Addis Ababa of 450 million Birr (15 million USD). This has led to monetary income along the value chain including farmers, charcoal makers, local labourers, seedling producers, brokers and transporters. The seedling producing activities are substantial. Just to replant the harvested *Acacia* stands, in the order of 100 million seedlings/yr needs to be raised only in the Fagita Lekoma district. The income generated from the value chain is unequally distributed between men and women with higher pay for activities dominated by men. Wealth indicators indicate rapid improvement in household income for many families. The plantations has led to a significant increase in carbon sequestration, mainly attributed to the increase in *Acacia* above and below ground biomass while soil carbon has not increased. There has been an evident increase in the canopy cover of adjacent natural forests since the onset of the plantations, which we interpret to be a result of reduced collection of fuel wood and reduced free grazing. Studies on the effect on the water balance indicate higher infiltration rate in the stands than in the adjacent cropland which can explain farmers’ observations of reduced erosion due to the *Acacia* plantations.

S2.4 Unlocking the bioeconomy for nontimber forest products

Comparative transcriptome analysis of high temperature stress response in Mitragyna speciosa (Rubiaceae)

S2.4 Unlocking the bioeconomy for nontimber forest products

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Abstract: Plants have primary and secondary metabolisms, whereby primary metabolism produces metabolites essential for plant growth cum development, and secondary metabolism produces compounds involved in plant defence system. Throughout human history, plant secondary metabolites have been a treasure throve of therapeutic agents in treating diseases, alleviating symptoms and for pain relief. Many prospective plants for drug discovery are yet to be discovered from the forest. Kratom (*Mitragyna speciosa*) is a unique psychotropic tropical plant of the Rubiaceae family. It has been used as a traditional remedy to treat various ailments as well as a stimulant to boost energy. It has many medicinal properties, owing to its opioid-like, analgesic, and antitussive effects. As studies have shown that high temperature increases the production of secondary metabolites in some plants, we hypothesised that high temperature stress would increase the mitragynine content in Kratom leaf. Mitragynine is the major alkaloid of Kratom, an important pharmacologically active compound besides 7-hydroxymitragynine. The high-temperature treatment of *M. speciosa* plants was conducted in a growth chamber. Results from the phytochemical analysis of the control and treated leaf samples supported the hypothesis, in that the mitragynine content quantified was significantly higher in treated samples. Subsequently, RNA sequencing was conducted for the control and treated samples using Illumina platform. The sequences were assembled using a reference genome that generated 72,885 transcripts of 70,406 known genes and 2,479 novel genes. From the comparative transcriptome analysis, a total of 16,003 differentially expressed genes were identified, of which 6,894 were up-regulated and 9,109 down-regulated. A total of five genes related to the MG biosynthesis pathway were successfully validated by RT-qPCR.

Diversity and Importance Value Index (IVI) of Tree species with Non-Timber Forest Products attachment in Niassa Special Reserve, Mozambique.

S2.4 Unlocking the bioeconomy for nontimber forest products

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Abstract: Assessment of Tree species composition and structure was carried out in Niassa Special Reserve, Mozambique. Data on anatomy, botany, physiology and flowering/fruiting phenology of the various tree species used as source of Non- Timber Forest Products (NTFPs) was collected through community meetings, literature from local, regional and national sources, and key informant interviews. Key informant interviews were conducted with Wildlife Conservation Society (WCS) officials, traditional healers, and local leaders to help in identifying the different places where these tree species were being harvested. ,Two Linear transects having 500m long each per community/village were laid. Along each transect five composite plots of $2500m^2$ were established where data on tree species with NTFPs Attachment was collected. The distance between two different transect was determined after producing the village maps by the community members. Identification of different tree species with NTFPs attachment along each transect was based on visual assessment of physiognomic and ecological characteristics. The main parameters taken in account were dominant tree species, indicator species, tree density, height, and degree of disturbance. A total inventory of the different NTFPs Tree species was done from all the plots within each transect. A total of 56 different tree species and 25 families were identified. The family of *Fabaceae* had the highest number of species (17). Tree species were measured and the data was used to calculate Relative Abundance, Relative Dominance, and Relative Frequency. Their results were used to derive the Important Value Index (IVI) which determined the dominant tree species of the entire area under study. *Diplorhynchus condylocarpon* (29,03) had the most Importance Value Index followed by *Julbernadia globiflora* (26,82), *Burkea africana* (25,75), *Terminalia sericea* (22,42) and *Combretum apiculantum* (16,99). The tree species were harvested from the Leaves, Roots, Back, Fruits, seeds, and flowers and were harvested for Medicine, Firewood, Traditional/Cultural Attachment, Forage, Poles, Ropes, Honey production, Fishing, Food, Crafts and making canoes. The Niassa Special Reserve management should design programmes that will create awareness to people around and within the Reserve to realise the need of conserving the flora and fauna species most especially those with several uses but with low diversity.

Does income from environmental products have potential to eradicate poverty among forest-dependent communities? The case of Ophiocordyceps sinensis.

S2.4 Unlocking the bioeconomy for nontimber forest products

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Abstract: This paper examines whether the income from caterpillar fungus trade helps local communities to move out of poverty. Considering *Pupal* pasture and associated local communities from *Dhorpatan* Hunting Reserve as a case study, we applied socio-ecological system's perspective to examine the research question. We surveyed 223 caterpillar fungus collectors during May-June season of 2019 using a survey instrument. Findings suggest that the collectors earned on average USD 3,090 PPP from fungus collection in a season, which is about 80% of the household income. Average expenditure to collect fungus is about USD 736 PPP. This suggests that earnings from caterpillar fungus collection substantially contribute to reduce income poverty among the community of Eastern *Maikot* – who are the primary collector of fungus at Pupal pasture. If resource is managed sustainably, this income could be sustained in the long run which could potentially alleviate the poverty among forest dependent communities of Maikot.

Fostering transition pathways towards the sustainable integration of non-timber forest products to a bioeconomy: learning from the case of baobab

S2.4 Unlocking the bioeconomy for nontimber forest products

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Abstract: Many non-timber forest products (NTFPs) have great potential for higher-value processing and commercialisation, fostering more sustainable land-use practices and contributing positively to livelihoods. This is especially relevant for (semi-)arid regions, where many priority NTFPs are located. Their sustainable integration into a bioeconomy can offer a viable alternative to prevailing (agricultural) practices in such regions, which are already severely threatened by today's global challenges such as climate change or biodiversity loss. Frequently, however, the collection, processing, and trade of NTFPs remains on a small scale, creating only limited benefits. Thus, this paper aims to contribute to a better understanding on how such change could occur, e.g. how possible transition pathways could be framed, how NTFP value chains be mainstreamed into the economy, and associated challenges tackled; topics, which so far have only been insufficiently assessed. Besides drawing on conceptual underpinnings highlighting the necessity of a holistic, systems approach to aid transformation processes, we would like to illustrate how such a transition can occur in practice, by exploring the case of the baobab (*Adansonia digitata* L) tree in (semi-) arid regions of sub-Sahara Africa. The value chains of this species have already advanced quite substantially towards a stronger bioeconomy integration via the creation of a variety of innovative bio-based products, considering principles of cascading use. Baobab products are nowadays commercialised in different sectors and markets, from regional to international. This offers substantial lessons to be learnt for promoting an increased NTFP integration into the bioeconomy more generally, e.g. in terms of value chain structure and functioning, policy and institutional changes required, or the role of research. Drawing on these lessons, we aim to illustrate a holistic and participatory research and development approach which may help foster similar transition processes for other priority NTFPs in (semi-)arid regions.

How emerging non-timber forest products markets transform gender division of labour? Learnings from açaí (Euterpe oleracea) in the Amazon

S2.4 Unlocking the bioeconomy for nontimber forest products

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Abstract: The economy based on non-timber forest products (NTFPs) often relies on informal actors and activities, based on specific logics and worldviews. While the effects of these new markets on traditional societies and lifestyles have been studied, gender is rarely addressed. However, authors have shown that the inclusion of traditional products in markets, including NTFPs, tends to dispossess women of resources and of their activities, making the poorest fringe of the world's population even more vulnerable. We hypothesise that by understanding the changing roles of women and men in the markets for one NTFP, açaí, we can explain how, and under what conditions, women manage to be part in the supply chain and thus become economic stakeholders in their own right. The method is based on monographic studies conducted between 2014 and 2019 in the states of Pará and Amapá (Brasil), and in French Guiana, in different marketing contexts: home sales, short circuits, export. Practices surrounding the harvesting, processing and consumption were described and supplemented by historical interviews on traditional practices and know-how, as a reference time preceding the marketing of açaí.

Our results show that fruit-gathering was not a gendered activity, but was carried out by young people regardless of their sex, or on specific occasions when people were going out into the forest (hunting for instance). The urbanisation of lifestyles, combined with the loss of links with the forest, seems to have accelerated the process of masculinisation of fruit-gathering. Processing used to be carried out by women - although not exclusively; it is now the preserve of men in Brazil, including in micro-processing units. In French Guiana, while the açai economy is still invisible, processing is dominated by women, including for large volumes. Permanent control of processing, for commercial purposes, is systematically accompanied by financial independence (enabling the purchase of equipments). Our study also shows that the gendered specialisation of gathering can be accompanied, conversely, by the permanence or appearance of new forms of young men precariousness. These results may contribute to unlock the bioeconomy for non timber forest products.

Linking ecosystem, food systems and community for sustainable governance

S2.4 Unlocking the bioeconomy for nontimber forest products

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Abstract: With the development of agroforestry and urbanization, ecosystems, food systems, and communities are interacting more and more actively, especially in areas with high forest coverage. The global pandemic, reduction in biodiversity, and lack of resilience of food systems have alerted that countries should make efforts to establish a global governance framework with integrated ecosystems, food systems, and local communities. This research constructs a systematic framework to analyze the connections and interlinkages between the ecosystem, food systems, and local communities, and then conducts a qualitative study of the discourse coalition and actions of different stakeholders in the breeding and farmed wildlife industry of China using discourse analysis and actor-oriented approach. It finds that discourse and actions have had drastic turns in the pre-, early, and post-COVID-19 era. Government and stakeholders of the ecosystem and consumers in food systems tended to form discourse coalition in terms of disease control, ecosystem protection, and food safety, yet producers, processors, and other stakeholders in the food systems involuntarily joined discourse coalition and reroute actions initially as their economic conditions and livelihood were heavily affected. However, local communities and food systems have the self-repairing capacity in the long-term by “up to down” and “down to up” discourse architecture and grass-root collective actions after disruption and chaos occurred. Discourses regarding livelihood, poverty alleviation, and breeding wildlife for traditional Chinese medicine and economic growth of rural communities are found to be significantly weakening in the early COVID-19 era, yet distorted discourses and actions that isolate the connections between ecosystem, food systems, and communities have been gradually amended in the post-COVID-19 era. Social media, governments, and residents in the local communities play a key role in discourse coalition and emendation, yet social media, and online public opinions to some degree distort discourse and actions. It also finds that communities in the forestry areas are a core node that integrates farmed wildlife industry into the ecosystem, food system, and community network. This research reflects on achieving sustainable development by putting systematic, integrated, and inclusive policies and approaches to governing the ecosystems, food systems, and community at the core.

Non-timber forest products and the European bioeconomy: status and transition pathways

S2.4 Unlocking the bioeconomy for nontimber forest products

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Abstract: In Europe, Non-Timber Forest Products (NTFPs) are important for forest recreation, rural income, cultural heritage, and as industrial commodities. Although widely collected and consumed across the continent, national statistical and scientific data are limited. Combined with short and underexplored value-chains, the cross-sectoral nature of the legislative framework, and complex institutional arrangements, NTFPs remain on the fringes of European forest policy and management practices. The bioeconomy inherently implies strong reliance on natural resources, and ignoring NTFPs would impede the bioeconomic transition. Based on the literature, we review (i) the current knowledge on NTFPs collection, consumption, and trade in Europe, (ii) the institutional and legislative structures governing their use, and (iii) discuss how to realise their market and bioeconomy potential. We found (i) their value comparable to the value of annual roundwood removals, (ii) that in Western Europe they are primarily connected to forest recreation and in Eastern Europe to household consumption and income generation, and (iii) that complex and restrictive legislation frequently drives the commercialisation of NTFPs towards informal markets. We present legislative, economic, and information-based recommendations on integrating NTFPs into the bioeconomy. A priority should be strengthening of formal markets and developing value-added products.

The anatomy of a sustainable Himalayan bioeconomy

S2.4 Unlocking the bioeconomy for nontimber forest products

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Abstract: An enormous global bioeconomy is built on environmental products – plant, fungus, lichen, and animal products from managed and unmanaged habitats – harvested and sold by poor people in lower-income countries. This environmental income prevents harvesters from sinking deeper into poverty while also presenting a rare opportunity to increase the welfare of some of the poorest people in the world. Yes, connecting pro-poor economic growth and sustainable renewable resources in lower-income countries receives little attention, e.g. the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) conceptual framework connecting nature and people does not emphasise such linkages. The emerging bioeconomic theory and literature provide a structured point of departure to address this shortcoming. This presentation presents the anatomy of a sustainable Himalayan bioeconomy, using the example of commercial medicinal plants from Nepal. This case is particularly interesting due to its (i) scale, encompassing 300 traded species harvested for tubers, bark, leaves, etc., with an annual trade value of tens of millions of USD, (ii) dynamics, with the domestic processing industry evolving from 20 to 300 companies in the past two decades, annually processing thousands of tonnes of raw materials, (iii) absolute importance, as Nepal's most valuable export commodity even if it remains unrecorded in official statistics, and (iv) complexity, spanning from resource base management to demand drivers. Findings are based on a unique panel dataset covering 1997-98, 2014-15, and 2021-22, involving quantitative and qualitative interviews with hundreds of harvesters, traders, wholesalers, and processors. This data document the products' economic importance to rural households and national development and identify sustainable development pathways within a bioeconomic framework. What happened to many whale, fish, and timber species need not happen to medicinal plants or other groups of species. This speak focuses on how to get it right.

Transitioning to an inclusive forest-based bioeconomy.

S2.4 Unlocking the bioeconomy for nontimber forest products

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Abstract: The bioeconomy is rapidly evolving to become the economic strategy to address the global challenges – climate change, poverty, biodiversity loss - of the 21st century. In general, the essence of bioeconomic strategies has been using biomass to reduce the need for fossil fuels. Nontimber forest products are absent from early iterations of the bioeconomy model, even though more than ¼ of the world's population directly consume products from forests other than wood, and many of those people live in abject poverty. The more than 50000 plant species used for products other than wood add much to the forest biodiversity of the world, yet few of them are managed for sustainable production. Many nontimber forest products have long histories of contributing to nations' economies, yet are not accounted for in bioeconomies. So why are these products and the people that harvest and consume them not included in bioeconomies? What will it take to include them in progressive bioeconomy strategies? We address these questions. Fundamentally, the global bioeconomy community needs to move rapidly beyond thinking of this strategy as a way to increase efficiencies of wood uses to address major global challenges, and embrace the many other products and services from forest biodiversity that can contribute to these aspirations. A truly integrated forest-based bioeconomy represents a way to reconsider and redefine forestry and the forest products industry to increase the value of these natural resources for greater biodiversity conservation to benefit a larger portion of society. Transition pathways for inclusive forest-based bioeconomies are not easily determined. They will require changing priorities that reflect motivations of sectors that have not been considered part of the forest products industry. Cultural values and informal market economies are essential elements of successful pathways. New and novel economic, social and biophysical research and technology opportunities abound in support of the transition to an all-inclusive forest-based bioeconomy.

S2.5 Scaling up the exchange between forest science and business

S3.1 Assisted migration for adapting forests to climate change

Accounting for phenotypic plasticity and local adaptation in species distribution models to support prescriptions on assisted migration

S3.1 Assisted migration for adapting forests to climate change

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Abstract: The most common tool to predict future changes in species range are occurrence-based species distribution models. However, these models often underestimate the potential future habitat, as they do not account for phenotypic plasticity and local adaptation. These highly important processes in the response of tree populations to climate change are considered in trait-based models combining reaction norms of quantitative trait variation as a function of past climate experienced at seed source origin to which populations are genetically adapted, and simultaneously as a function of current climate experienced at the planting site to which they show plastic responses.
We make use of extensive provenance trial series of Norway spruce and European beech to model future height growth potential and compare these predictions with classic species distribution models. For Norway spruce, both the occurrence-based and the growth-based model show a significant retreat towards northern latitudes and higher elevations (-55 % and -43 % by 2080). However, thanks to the species particularly high phenotypic plasticity, the decline is delayed. Increasing summer heat coupled with decreasing water availability limits performance, while a prolonged frost-free period enables an increase within the remaining area. Signals of local adaptation along climatic gradients are low, as they are masked by a strong influence of latitude. The latter reflects population differentiation for the Baltics, but does not capture the high phenotypic variation associated with heterogeneity in Central European mountain ranges and postglacial migration history. The model is used to provide recommendations for optimal provenance selection under future climate. In essence, seed transfer cannot mitigate the projected range decline of Norway spruce, but it can help to exploit potential opportunities for better growth associated with warmer climate conditions. A comparable model for European beech is currently under development and results will be presented.

Assessing Carbon Storage and Habitat Characteristics in Jeju's Semi-Mangrove Ecosystems, South Korea

S3.1 Assisted migration for adapting forests to climate change

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Abstract: A research team was first tasked with finding a solution to the need for more creative ways to contribute to natural carbon capture and storage solutions to meet South Korea's national climate change objectives of reaching net zero by 2050. It was through this and the unique properties of Korea's southern islands that true mangroves and mangrove associates (semi-mangroves) were suggested as possible candidates that could promise high carbon absorption rates, and adaptability to continue to provide ecosystem services through climate change. Some pre-existing native habitats of semi-mangrove species (e.g., Hibiscus hamabo, Paliurus ramosissimus) on Jeju Island had already demonstrated comparatively higher carbon absorption abilities than other broadleaf species as measured by photosynthesis rates and soil carbon storage performance. This study investigates the distribution of carbon storage and the characteristics of semi-mangrove habitats based on the Lidar 3D imaging. This includes also evaluating their carbon uptake capabilities in order to forecast projections on the carbon storage and carbon absorption performance of selected species. This study is an opportunity to contribute further knowledge towards global carbon reduction and climate change mitigation objectives, especially given the high concentration of highly vulnerable or at-risk populations in the Asia-Pacific.

Assisted migration needs of northern red oak (Quercus rubra)

S3.1 Assisted migration for adapting forests to climate change
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Abstract: Intensifying climate change exacerbates droughts, heatwaves, and extreme weather events, endangering global forest health and biodiversity. Assisted migration is increasingly recognized as a management strategy for safeguarding forest species. But simply moving tree populations towards expected future mean annual temperatures does not account for increased extreme weather events nor incorporate trees' phenotypic plasticity.

In 2019, we planted a replicated provenance trial with 19 populations and 118 open-pollinated families of northern red oak (*Quercus rubra*) spanning 10°C mean annual temperature (MAT 4.1°C - 14.2°C). The provenance trial sites are located near the northern seed collection limit (Ford Center and Forest, MAT 4.4°C) and at a central location (W.K. Kellogg Experimental Forest, MAT 8.8°C). To assess the performance of populations within and beyond their natural distribution, we measured annual growth, tree and leaf morphology, leaf and root physiology, foliar metabolites, pest and pathogen damage, plant phenology, and frost damage. We assessed phenotypic plasticity by comparing measured traits at both sites within families as well as traits measured on the same trees over time.

Initially, warmer, southern populations outperformed northern populations in above-ground biomass accumulation at the northern site. Unseasonable cold events in fall 2020 and spring 2021 caused extensive tree dieback in southern populations. Northern populations had higher photosynthetic capacity and chlorophyll A levels; southern populations had lower optimal quantum efficiency. Traits related to physiology showed some phenotypic plasticity, allowing trees to adapt to varying environments. At the central site, trees from northern populations did not perform as well as central or southern populations.

These results indicate that moving trees against the direction of climate change harms tree performance and that assisted migration north may soon become necessary. While extreme weather events had minimal effect on populations shifted a few degrees Celsius north, trees from much warmer seed sources suffered during unseasonal frost events since their phenology was not adapted to the longer northern winters. Northern seed sources exhibited conservative growth strategies, while southern populations adopted acquisitive strategies that often led to bush-like growth after multiple rounds of frost damage to the leading shoot.

Assisted migration of European beech populations - options and limitations

S3.1 Assisted migration for adapting forests to climate change

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Abstract: European beech (*Fagus sylvatica* L.), the major native decidous tree species in Central Europe is known to be drought sensitive. In particular, the reoccurrence of two extreme drought events in 2003 and 2018–2020 in Central Europe, in a time span shorter than 20 years, caused severe deterioration and decline of tree crowns as well as growth reductions. This loss of vigor might persist as legacy effects, including lagged post-drought responses. These may hamper tree recovery, due to carbon depletion through reduced photosynthesis as well as hydraulic dysfunction, which, if persistent over time, can lead to mortality. In particular, on sites with low soil water storage capacity (SWC) beech trees run into the risk of lethal hydraulic failure if climate change aggravates drought and heat extremes; in Germany, the centre of beech native range, one third of today's beech forest area grow on drought-exposed sites with less than 90 mm soil water storage capacity within 1 meter soil depth. Assisted Migration (AM) may provide a solution towards more adaptive forests with beech, moving seed sources or populations of European beech to a location not accessible by natural dispersal. This is aimed at introducing better drought-adapted or adaptive beech genotypes and thus improving the resilience of forests. The high variation of beech populations within its recent native range in sensitivty to drought and cavitation enables adaptation options using AM, in particular using marginal population from the drought-induced range edges. However, phenotypic and epigenetic plasticity of beech and in-situ adaptation processes may also provide successful adaptation options. Based on own and compiled study results we discuss the options and limitations of AM versus in-situ adaptation of European beech in Central Europe and further needed steps to manage future forests with dominant or admixed European beech.

Assisted migration: a climate-adaptive and rehabilitation tool for degraded forests

S3.1 Assisted migration for adapting forests to climate change

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Abstract: Rehabilitation of degraded forests can mitigate the effects of global change through enhanced carbon sequestration. It can also improve the forests adaptive capacity by promoting resilience to disturbances through functional diversity. In this project, we assessed assisted migration, the deliberate displacement of tree species or populations to locations with suitable future climate conditions, as both adaptive and rehabilitation tool in degraded mixedwood forest.

We assessed seedling survival and growth of 9 species through abiotic (e.g. microclimate) and biotic (e.g. browsing, competing vegetation) filters in mixedwood plantings established 120 km northwest of Quebec City (Canada) in sub-boreal mixedwood natural stands high graded by diameter-limit cutting. The factorial experimental design comprised canopy cover (clearcut vs partial cut), cervid exclusion (excluded vs non-excluded) and competing vegetation (removed vs non-removed) treatments. In 2018, we planted species expected to have unfavorable (*Picea glauca, Picea rubens, Thuya occidentalis),* and favorable *(Pinus strobus, Pinus resinosa, Acer saccharum)* future habitat conditions, and species with potential new habitat in the area *(Quercus rubra, Prunus serotina, Carya ovata*). Seedlings were grown from seeds of locations associated to three climate analogues: current climate, projected climates for mid-century and end of century.

Cumulative basal diameter growth of all species, except for *Acer saccharum,* was larger in open conditions than under partial cover after 3 growing seasons. The understory vegetation control treatment by mechanical release benefited *Pinus* and *Picea* species, although the effect was only significant within the clearcuts for *Picea* species. Planting under partial cover contributed to acclimate southern species such as *Quercus rubra*, which suffered frost damage during the Spring 2020 and 2021, mostly in clearcuts. Overall, 3-yr species survival varied from 78% (*Carya ovata*) to 93% (*Picea glauca*). Survival tended to be lower for the end of century analogues of southern species such as *Acer saccharum* and *Prunus serotina*, but remained relatively high (beyond 75%), hinting that an assisted migration approach based on climate analogues can be potentially viable for restoring forests altered by past inappropriate cutting practices.

Desired REgeneration through Assisted Migration (DREAM): implementing a research framework for climate-adaptive silviculture.

S3.1 Assisted migration for adapting forests to climate change

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Abstract: Assisted migration (AM) is a climate-adaptation strategy that may ensure that forests established today are adapted to expected future climate conditions. Although many pilot AM efforts are underway, managers lack 1) access to decision-support tools to guide choices of seed sources for species and/or genotypes, 2) confidence in the ecophysiological tolerances of putatively future-adapted stock and 3) the silvicultural strategies necessary to regenerate future-adapted species in an assisted migration context. These shortcomings represent a critical problem because establishment of potentially poorly-adapted selections and/or inappropriate silvicultural strategies creates major risk to management time and financial resources.

The Desired REgeneration through Assisted Migration (DREAM) framework is an international collaboration that uses basic and applied research to reduce these uncertainties and derive climate-informed planting approaches. DREAM is self-reinforcing in that each step in the process informs and strengthens subsequent phases. Namely, it sources seed in a climatically informed manner, experimentally tests this sourced stock to probe for physiological maladaptation under controlled settings, grows the stock in the field under a range of silvicultural scenarios, and finally forecasts long-term outcomes using models parameterized from the controlled- and field-tests. Through these steps, the DREAM approach specifically addresses knowledge gaps necessary to successfully plan and execute assisted migration plantings.

Here, we describe the DREAM framework illustrate aspects and challenges of its implementation drawing from two experimental sites: one in Québec, Canada and one in Wisconsin, USA. Moreover, we present data from our suite of syntheses, lab, and field trials to accentuate how

operationalizing FAM effectively will require more than matching species or populations with expected future climates. Rather, it will require a deeper understanding of the context-dependencies at the outplanting site including, current climatic conditions, plant-soil feedbacks, and herbivory that may ultimately regulate establishment success.

Does earlier bud break in drought adapted tree species and provenances lead to a competitive advantage?

S3.1 Assisted migration for adapting forests to climate change

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Abstract: Rapid increase of temperature and dryness leads to novel climate in Central Europe. Experiments that test the performance of multiple native and non-native species under future climate as well as across different soil types are rare. To address this gap, the Polytunnel Greenhouse Experiment was set-up as an interdisciplinary research platform in autumn 2021. The experiment is located in three extant forest communities on the Swiss Plateau and simulates novel forests with future tree species, including native silver fir, European beech and sessile oak, and non-native Atlas cedar, Douglas fir and Turkey oak, each from four different seed sources (at least one from warmer/drier climate). The 4-yr-old seedlings grow in a climate that is warmer and drier than the current climate on the Swiss Plateau. We will model the growth performance of individual tree species and provenances in relation to their leaf-out phenology, climate (current climate, warming in the absence of drought, warming in the presence of drought), and soil type. Higher temperatures have advanced leaf out by 9–18 days in the first two years, depending on species and seed provenance. This increase in growing season length might lead to higher growth rates, while drought is expected to negatively impact growth and survival. Consequently, the combination of warming x drought will exacerbate trade-offs between fast seedling growth to compete with surrounding vegetation and slow resource use to resist drought. How native and assisted non-native tree species respond to these trade-offs in a heterogenous landscape is largely unknown. Our results will indicate how assisted migration of more drought and heat adapted provenances or tree species will change the competitive outcome between species in a future climate.

Does provenance matter? Surprising lessons learnt from two drought experiments in common gardens of two common shrub species in Belgium

S3.1 Assisted migration for adapting forests to climate change

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Abstract: Assisted migration is a much-debated topic in forest-adaptation to climate change. Most of the research, however, is focussing on commercial tree species, and little attention is given to shrubs.

In this study, we tested two shrub species in two common garden experiments.

In the first experiment, we twice withheld water from rooted cuttings of three provenances (Italian, local Belgian, and Swedish) of *Frangula alnus* in summer. Counter-intuitively, the Italian provenance displayed earlier symptoms and stronger effects of water limitation than the others. A higher transpiration was suggested based on larger shoot growth, larger leaves and higher stomatal density. In the second experiment (same genotypes, other ramets), we studied reproductive traits. The local Belgian provenance produced more ripened berries than the Italian and Swedish provenances, both in water-limited as in control plants. The next spring, the germination percentage of the stones from the water restricted mother plants was significantly higher than the controls for all three provenances. The timing of seedling emergence reflected the timing of bud burst of the mother plants, including a counter-gradient effect for the Swedish provenance, corroborating the suggestion that seedling emergence and leaf phenology may have a common genetic basis.

We also studied the responses to a summer water withholding, followed by rewatering, in a common garden (local Belgian and Pyrenean provenance) of *Cornus sanguineum*. We showed that the timing of autumnal leaf senescence was earlier than the controls for plants that displayed no to little leaf desiccation due to the experienced drought. On the contrary, plants suffering from heavy to total leaf desiccation resprouted after the drought and displayed a delayed leaf senescence. No shift in timing of leaf senescence was observed for plants with intermediate leaf desiccation, suggesting two different post-drought recovery strategies (acclimation vs damage repair), depending on the severity of the drought stress, that cancel each other for plants with intermediate symptoms. Results suggest that the first strategy was activated earlier in the Pyrenean provenance, whereas no difference in timing was detected for the second strategy.

In all, assisted migration from southern to western Europe might not always follow the expected patterns.

Enhancing resilience and adaptation of native European beech and sessile oak forests to climate change: assisted migration in practice

S3.1 Assisted migration for adapting forests to climate change

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Abstract: Climate change exerts impacts on forest growth, productivity, tree vitality, and species composition at both global and local scales. Due to limited natural migration capacity and local adaptation caused by the warming climate, some species will face significant loss of habitats and decreased distribution. In light of these concerns, the science-based and practice-oriented bilateral project REIN-Forest ATHU150 focused on two dominant deciduous forest tree species, *Quercus petraea* and *Fagus sylvatica*, in the Austrian-Hungarian border region. The project aimed to maintain the present forest cover, preserve biodiversity, and safeguard future economic benefits by selecting suitable, resilient, and potentially adapted provenances (seed sources). In each country, three provenance trials ranging from 1.2 to 2 hectares were established to assess, monitor and validate the benefits of these provenances compared to local ones. The future climate-adapted provenances were selected for the RCP 8.5 climate change scenario using previously developed model-based information on the current and future prospects of these forests in the study area and forest decision support systems: Forest Vulnerability and Seed Transfer Tool and SusSelect (SUSTREE project). During the establishment of the six provenance trials, forest reproductive material (FRM) from ten local and fifteen adapted to the future climate seed stands were planted, originating from seven different countries. In the winter of 2022, one site in each country was afforested with local and adapted sessile oak provenances, another with local and adapted European beech provenances, and the third site with a combination of local European beech and adapted sessile oak provenances, considering the predicted loss of beech dominance in the future. In the next fifteen years, the performance of the different FRMs will be evaluated by monitoring parameters such as survival, phenology, abiotic and biotic damage, quality and growth. Genetic monitoring may also be assessed to compare and validate the concept of assisted migration with future climate-adapted provenances alongside the transfer system recommendations. This presentation aims to share the practical experiences acquired during the establishment of the trials, highlight challenges and obstacles encountered during the import of FRM, and present first results on survival rates between the two groups of FRM.

Models and Motivation for Sustainable Mangrove Management in Ban Tha Bo Ko Mangrove Forest, Nakhon Si Thammarat Province, Thailand.

S3.1 Assisted migration for adapting forests to climate change

Sutida Maneeanakekul[1]
[1] Sutida Maneeanakekul

Abstract: The aims of this study were 1) to determine the appropriate model for Ban Tha Bo Ko Mangrove Forest Management with community participation. 2) to create appropriate motivations to encourage communities living in Ban Tha Bo Ko Mangrove Forest participated in sustainable management of mangrove forests and 3) to publicize and return information on sustainable management of mangrove forests under climate change and incentive measures to participate in appropriate mangrove forest preservation in study area.

The secondary data collections, site surveys, focus group discussions, and interviews were used to collect and analyze data on current patterns of mangrove utilization and management of communities living in Mangrove Forest. Incentive measures needed by the community to enable participation in the preservation and sustainable management of mangrove forests to support the REDD PLUS mechanism encountered in the management of each area by key informant groups, namely representatives from people living in the area involved in the utilization and management of Ban Tha Bo Ko Mangrove Forest, as well as evaluating opinions from using a questionnaire on community representatives and relevant officials about measures and guidelines to create incentives for sustainable management of mangrove forests.

The results shown that the important forms of proper mangrove forests management are mangrove planting activities, aquatic animal release activities, cooperation in preventing illegal fishing, jointly solving garbage problems, and protection against deforestation.The relevant agencies should set up appropriate incentive measures in four aspects: regulations and agreements, financial, social, and incentive support including assigning agencies /related agencies that should be responsible to carry out concrete work. The opinions of the local participants were evaluated at 5 levels on the measures and guidelines for motivating sustainable management of mangrove forests according to the REDD+ Mechanism in all 4 aspects: regulations and agreement, financial, social, and incentive support with 35 respondents.

Practitioner-focused, soil-sensitive decision support for assisted migration of tree species

S3.1 Assisted migration for adapting forests to climate change

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Abstract: Accounting for climate change in reforestation practices has the potential to be one of the most efficacious adaptation strategies for maintaining future forest ecosystem services. There is a rich literature projecting spatial shifts in climatic suitability for tree species and strong scientific evidence for the necessity of assisted migration. However, there has been limited translation of this research into operational reforestation, due in part to mismatches to the information needs of practitioners. To address this need, we have developed a practitioner-focused climate change informed tree species selection (CCISS) framework to support reforestation decisions in British Columbia (BC). CCISS projects the climate change redistribution of bioclimate units from the multi-scaled Biogeoclimatic Ecosystem Classification (BEC) system with machine-learning for an ensemble of modelled future climates. It leverages the reforestation knowledge from BEC to make site-specific species projections of reforestation feasibility with climate change uncertainty metrics. We present 21st-century feasibility projections for a comprehensive set of tree species native to western North America. Some general trends are evident: augmentation of the portfolio of feasible species in sub-boreal regions due to the rapid expansion of feasibility for temperate species; attrition at low elevations in southern BC due to declines in the feasibility of native species with little compensation by non-native species; and turnover at mid-elevations as declining feasibility for subalpine species is compensated by uphill expansion of climatic feasibility for submontane species. Edaphic (soil) factors are important; feasibility declines are higher on relatively dry sites than on wetter sites for most species. Our analysis emphasizes that changes in feasibility are species-specific, spatially variable, and influenced by edaphic site factors. In addition to our modeling results, we will present our recent work on integrating modeled results with observational evidence from assisted migration trials. By employing the multi-scaled BEC system that currently informs operational reforestation, CCISS translates research into actionable assisted migration guidance for practitioners.

Searching for drought-resistant genetic variants in Quercus cerris for future Austrian climate

S3.1 Assisted migration for adapting forests to climate change

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Abstract: In the current context of global change, forest ecosystems are among the most endangered.

The main objectives of our study are (1) to identify the genetic variants associated with drought stress resistance across *Quercus cerris* natural distribution, and (2) to screen the Austrian populations for such genetic variation. We plan on a phenotype-genotype association analysis of tree-ring width on dry years as a proxy for drought resistance, by means of ca 90 K SNPs detected with Single Primer Enrichment Technology (SPET). The first step of this analysis is to find regions in the current distribution of *Q. cerris* where the climate is comparable to predicted future conditions in Austria (IPCC climatic scenario RCP8.5). We established partnerships with research institutions in 14 countries, providing 40 locations of interest. In addition, we included 6,348 locations distributed evenly over the natural range of *Q. cerris* into our dataset. To represent Austria, we selected 34 locations where *Q. cerris* has high probability of presence in 2095 according to RCP8.5. Mean annual temperature, continentality, summer temperature, total annual precipitation and accumulated growing degree days are among the most important climatic variables for *Q. cerris*. The CHELSA dataset delivers data observations from 1981-2010 as well as predictions for RCP8.5 in the timeframe 2071-2100. We retrieved the observed variables for the locations of interest and the predicted variables for the 34 Austrian locations. Using the Elbow method, we established k=4 as the optimal number of clusters for this dataset. Interestingly, using Ward's clustering algorithm with Euclidean distance, we observed that 3 of these clusters were represented in Austria. In sum, we report a meaningful approach to select relevant sampling locations to investigate the genetic variants underlying drought resistance in climatic regions similar to the future of Austria, bringing us one step closer to ensuring forest ecosystems sustainability.

Selection experiments of southern origins of Pedunculated oak (Quercus robur) and development of related planting technology

S3.1 Assisted migration for adapting forests to climate change

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Abstract: The effects of climate change, which is increasingly affecting our time, also have a significant impact on the health of European oak stands. On the one hand, the decrease and shift in the amount of annual precipitation, and on the other hand, summer heat waves make it difficult for young oak trees to survive. In addition to abiotic effects, the role of biotic pests is becoming more and more important. The Oak lace bug (Corythucha arcuata) has been causing more and more damage to oak stands, especially to the acorn crop, in recent years. During our research, we are investigating container planting of healthy oak acorns from southern climates. During planting, we place the acorns in different directions, as this can also have a significant effect on the root structure. We also examine the effect of different nutrient media and nutrient solutions on growth. The purpose of the tests is, on the one hand, to determine the growth and survival rate of acorns from different climates, and on the other hand, to create stronger seedlings compared to traditional forestry planting methods. Seedlings grown from acorns from southern climates are expected to adapt better to the rapidly changing climate, research is aimed at creating climate-resistant propagating material and at the development of planting technology.

Survival and growth of Acacia senegal (L.) Wild. (Senegalia senegal (L.) Britton) provenances depend on the rainfall at the site of origin

S3.1 Assisted migration for adapting forests to climate change

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Abstract: Context: Several studies have shown important differences in adaptive properties among provenances (origins) of African savanna tree species, but there is a lack of studies on how these differences are expressed in different environments and age and to what extent they reflect local adaptation.

Aims: This study investigates the survival and growth of trees from 15 African *Acacia senegal* (*Senegalia senegal* (L.) Britton) provenances tested in two environments and relates the differences among provenances to the climate at their site of origin and tree age.

Methods: The study is based on 14 years growth in a common garden trial at two sites (Bambey and Dahra, Senegal) that differ in water availability, followed up by later assessment after 23 years at one of the sites.

Results: The variation among provenances in survival, height, and diameter was significant, and differences could be partly explained by the climate at their site of origin. In general, provenances from dry sites survived better at both sites. However, we observed genotype-by-environmental interactions where provenances from dry sites on average performed relatively poorer in height and diameter at the wettest site (Bambey) compared to the drier site (Dahra), while the opposite was the case for provenances from wetter sites.

Conclusion: The results support that divergent selection creates and maintains local adaptation of *Acacia senegal* provenances in relation to growth (height and diameter) and survival in areas with different water availability. This has important implications for choice of appropriate planting material for tree planting and for conservation of genetic variation among natural populations, but also for prediction of the effects of climate change.

Three-North Shelterbelt Program

S3.1 Assisted migration for adapting forests to climate change

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Abstract: The Three-North Shelterbelt Program (TNSP) is one of the world's largest afforestation projects, which involves in over 42.40% of China's total land area. The project has implemented over 40 years and the statistical data showing an increased forest area of 3014 ha (13.57% forest coverage), and many studies have assessed the ecological, economic and social benefits of this project. However, most of these studies are based on the statistical forest area released by the government and it is still unclear how much forest actually exists and what the spatiotemporal forest recovery pattern is in the TNSP region. This is partially because the harsh environmental condition in this region has caused the death of large area of planted trees right after planting. The existing geospatial land use and cover products failed to reflect the actual recovered forest area in the TNSP region due to various reasons. Based on time-series Landsat satellite images, LandTrendr change detection algorithm, machine-learning method and dense sampling plots, our study developed an integrative method to detect the spatiotemporal forest recovery patterns in the TNSP region during 1990-2022. The detected results were further evaluated against sampling plot data, inventory data and other geospatial land use and cover datasets using the metrics of overall accuracy (OA), Kappa coefficient, regression coefficient and Root Mean Square Error (RMSE). In addition, the forest growth status was also monitored and assessed based on the generated various vegetation indices. Our study not only provides a high-precision and resolution forest recovery dataset, but also assesses the forest health status under climate change, which could further help more accurately evaluate the long-term advantages or disadvantages of the implementation of TNSP.

Tree species choice tool supporting climate-smart forest management

S3.1 Assisted migration for adapting forests to climate change

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Abstract: *Context*

In response to climate change, tree species tend to migrate to more suitable climate zones. However, the current speed of climate change is generally too fast, which may result in local loss of species and related ecosystem services. Alternatively, assisted migration can be implemented, defined as human-facilitated species migration to regions with more suitable environmental conditions. This study focuses on enhancing forest resilience to climate change, using the principles of **"resilience trait-based assisted migration"**, which seeks to maximize functional diversity and redundancy through assisted migration. In this context, a tree species selection tool for Flanders, the northern region of Belgium is developed.

Methodology

A list of relevant native and non-native tree species is created, using national forest inventories and (inter)national studies on tree species distributions, followed by three evaluation steps:

1. Climate suitability: species are selected and ranked based on their suitability for present and future regional climatic conditions. Species distribution models are simulated for future climate scenarios, using the CHELSA dataset for IPCC climatic scenarios, and its BIOCLIM+ variables.
2. Risk assessment: potential risks linked to species introduction are considered. Species with unacceptable potential risks related to their introduction, are excluded. This exclusion stage can consider risks of drought, invasiveness, etc.
3. Feasibility: a wide variety of functional traits and ecosystem services derived from freely accessible databases are added to the tool to allow further species ranking and selection for restoration projects.

During this project, the methodology and results of this study are systematically discussed with an expert panel comprising experts in climate, nature conservation, and forestry. Field experience is included through interviews with experienced practitioners.

Results

This project results in a tool, consisting of a database with tree species that are ranked based on their potential to thrive in Flanders under a wide range of future climatic scenarios, as well as several functional traits, potential risks, and ecosystem services. This database can be used by the government as a decision support tool for policymaking, and in forestry and nature restoration for

the selection of tree species for plantation, based on desired traits and climate resilience.

Funding: Klimaatbomenproject ANB, Flemish Community.

Using assisted migration to design and adapt the next generation Scots pine seed orchards in Sweden to future climate conditions

S3.1 Assisted migration for adapting forests to climate change

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Abstract: Climate adaptation is an important challenge for future forests with rapidly altering growing conditions that may cause tree maladaptation leading to reduced growth, increased risk of damages and mortality. One way of addressing this issue is to select genetically improved seedlings and deploy them so that their high performance can be fully exploited. To enable that, Skogforsk has developed a decision support tool, Planter's guide, for Scots pine that ranks all contemporary and productive seed orchards according to the predicted volume production over a rotation. The latter is calculated from transfer effect models for survival at the establishment phase in the current climate, and growth at mid-rotation in a future climate, allowing for assisted migration.

Contemporary seed orchards span from 1g to 1.5g, whereas 2g seed orchards are currently being planned and established. However, 2g seed orchards established today will start to produce seedlings after 15-20 years and have an expected life span of 30 years. This means that the seedlings produced in such orchards will face a warmer climate at establishment and a substantially warmer climate at mid-rotation (30-50 years after planting). Not considering this, we risk designing the 2g seed orchards so that they will be maladapted to their intended seed zone when in full production.

We have used the Planter's guide model platform to analyze the performance of different 2g seed orchards designs in a pilot study that includes a Swedish forest company, SCA. We used their planned regeneration sites for the period 2050-2090 and maximized the yearly annual growth over all sites given a set of fictive 2g seed orchards with different designs. If we were to establish the 2g seed orchards with the same clonal composition as the current orchards, it would result in a substantial maladaptation of the optimal deployment area compared to the intended seed zone. Thus, a selection of clones from milder, more southern, conditions provided a better match to the intended seed zone. Furthermore, seed orchard design with high selection effort on survival in harsh conditions were less competitive compared to seed orchard design with more focus on growth.

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

A history-based critique on the global forest restoration project

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

Wil De Jong

Abstract: Restoring tree and forest cover is hailed as options to solve climate chang, biodiversity conservation, and development challenges. Multiple supra-national initiatives have sprung up to achieve forest restoration in large areas, here referred to as the global forest restoration project. They pursue ambitious targets and have adopted discourses hailing multiple benefits, not the least to 'deprived' residents in locations where restoration is to happen. A look at forest restoration histories reveals that in the past, centres of economic and political hegemony promoted and engaged in forest restoration, but also adopted discourses that have parallels with those of the contemporary global forest restoration project, including benefits to climate, biodiversity and to local people. The parallels between historic and contemporary trans-national forest restoration interests, discourses and projects intrigue. My elaborations will identify similarities and differences between past and modern transnational forest restoration, and reflect on these, including on whose interests are being addressed and are negated.

An economic view on the costs and benefits of forest restoration

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: Debates on the benefits of forest restoration tend to neglect the disparities of costs and benefits across different restoration options, and variations across contexts. These variations should be at the center when considering restoration futures, potential benefits, and who pays the costs and reaps the benefits. Drawing on a review of available studies and data across six different restoration options, we provide key findings and knowledge gaps regarding economic and financial costs and benefits of forest restoration. We show that while financial costs and benefits vary widely across and within forest restoration options, almost all forest restoration options are financially attractive. Natural regeneration options are the least costly options, followed by tree plantations in monocultures. While agroforestry systems are most costly and require higher upfront investments, comparatively they yield higher economic and ecological benefits depending on the agroforestry system. We observe significant variations in costs within similar forest restoration options suggesting that several contextual factors, including biophysical and political economic conditions, may explain some of this variability. In addition, economic cost-benefit analysis suggests that benefits outweigh the costs, particularly under longer restoration time horizons, and when looking at a wider range of benefits. Finally, we argue that there are several tradeoffs associated with forest restoration, mainly regarding the financial, socioeconomic, and environmental benefits, which also have a temporal dimension since benefits accrue over different timeframes, and many may only accrue in the long run.

Forest restoration governance: institutions, interests, ideas and their interlinked logics

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: High expectations have been raised that Forest Landscape Restoration (FLR) will provide an answer to climate change and biodiversity loss and support human wellbeing. Numerous local to global FLR initiatives have evolved over the past decades if not centuries, engaging a diverse set of actors and employing or encountering diverse logics and arguments related to (re)planting trees. We analyse these (de)legitimizing narratives of FLR (win-win, implementation, critique) and the underlying institutions and interests in which their discursive power rests. Based on the 3Is (institutional path dependency, interests and ideas), we identify and critically discuss three key distinct logics that to varying degrees drive FLR policy and practice today : (i) the global sustainability logic: planting trees to meet international challenges, (ii) the community logic: restoring or creating forests for local livelihoods and fostering empowerment, and (iii) the production logic: forest plantations and bioeconomy. We conclude that if the inherent historical power structures in FLR design and implementation are not recognized and addressed, then the currently dominant FLR logics—with a focus on global sustainability and production arguments—are likely to produce many "win-lose" or "lose-lose" projects.

Forest restoration strategies, ecosystem service delivery and trade-offs at site and landscape level in Ethiopia

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: Deforestation and forest degradation are becoming a global concern especially under current climatic changes and human population growth trends. Forest landscape restoration however, offers an opportunity to ameliorate impacts, end poverty, build climate resilience and enhance biodiversity. For this to happen, there is need to evaluate the context-specific success and failure factors in order to enable adaptive management. For many restoration projects worldwide, it is shown that there is a lack of knowledge and capacities for local forest restoration implementation, for example with regards to suitable seed sources and plant material, establishment techniques, as well as long-term tending of the restored forests. Furthermore, the goals and importance of ecosystem services differ among stakeholders leading to trade-offs and possible governance conflicts. We compare contributions of passive and active approaches, and evaluate perception of actors on societal benefits from restoration.

We conducted a rigorous assessment of biophysical and socioeconomic factors affecting restoration in Ethiopia as part of the FLESRA project. Forest and soil inventory of active and passive restoration sites, and identification of contextual factors was done. Data from 1,519 plots representing 7 forest stand types, 145 key informants and 371 farmer interviews across Oromia and Southern Nations regions was collected. Analyses of this data is expected to help to derive recommendations for best practices, and develop suitable tools for successful implementation and management of restoration.

Preliminary results show that management and soil properties play a key role in the performance of restoration especially among the active strategies. Active restoration strategies perform better especially in timber production and biomass, while passive restoration strategies are better in terms of plant diversity improvement at site level. At landscape scale, active restoration approaches contribute greatly to overall observed plant diversity. Also, among the strategies, timber and fuel are the most ranked direct services, while carbon absorption and erosion control are the most perceived indirect services. Surprisingly, actors do not perceive biodiversity as important across strategies.

Results suggest the importance of adoption of a mixture of passive and active restoration approaches in landscapes for multiple benefits, implementation of proper management and increased actor participation in restoration.

Introducing the IUFRO-WFSE book: Restoring forests and trees for sustainable development - Policies, practices, impacts and ways forward

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: This presentation presents the IUFRO-WFSE project's new book "Restoring forests and trees for sustainable development - Policies, practices, impacts and ways forward" and the process for developing it. The book provides a comprehensive overview of forest and forest landscape restoration and the different understandings, drivers, goals, and related commitments, approaches, and achievements. It presents the current state of knowledge and range of ideas regarding interacting social, economic, political, and ecological aspects of restoring forests and trees. The book focuses on the linkages between forest restoration, biodiversity, and ecosystem services, and addresses forest restoration from the point of view of socioeconomic development, justice, equity, and governance considerations. It provides science-based information for developing sustainable restoration policies and programs, guiding the planning and implementation of restoration efforts in different contexts, and developing pathways and approaches to mitigate the social, cultural, economic, and environmental risks associated with restoration.

Land use Landcover responses to Forest Landscape Restoration interventions: A case of Malawi

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: This paper analyses the impact of land use and land cover changes (LULC) on forest landscape restoration targets in Malawi, a country facing challenges such as deforestation, soil erosion, and declining forest resources exacerbated by population expansion. Understanding the relationship between land-use changes and their impact on forest landscape restoration targets is crucial in addressing challenges such as deforestation and declining forest resources in Malawi. The most practical method for monitoring forest change over large areas is using remotely sensed data. For operators and other practitioners looking to monitor land use land cover change (LULC) using free and open access data and maps becomes practical and inexpensive. However, achieving accurate monitoring remains challenging, especially in Africa where there is limited access to resources for ground truthing data. To assess LULC since the Bonn pledge in Malawi, we estimated tree cover gain/loss using Sentinel-2 data from ESRI's living atlas. We estimated tree cover gain and loss for the period 2017-2022 to ascertain whether Forest Landscape Restoration (FLR) Targets are being met. We then completed accuracy assessments and area estimation using reference data obtained from the Nation Forest Monitoring Unit who use a cluster stratified random sampling method to collect National Forest Inventory (NFI) point data. We used a confusion matrix to graphically summarizes the occurrence of individual classes being correctly identified and the occurrence of individual classes being misclassified. The confusion matrices for extracted Sentinel-2 2020 annual map when compared against NFI validation data for the same year (2020) depicted huge discrepancies. The results indicated that in LULC estimation, Sentinel-2 played a limited role in discerning land use classes correctly; the rangeland class achieved highly different results to the other classes as it fell within the description of three other land use classes (Shrubland, grassland and cropland) based on the land use schema of Malawi. The three land use classes are critical and have significant implications because continuous monitoring and validation efforts are essential to assess negative trends promptly and implement necessary interventions, ensuring that restoration targets are met.

LANDSCAPE RESTORATION FOR LOCAL DEVELOPMENT: HOW TO MAKE FLR WORK FOR FOOD SECURITY, LIVELIHOODS AND WELL-BEING OF LOCAL COMMUNITIES

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: Forest landscape restoration (FLR) is increasingly recognized as a people-centred approach to restore millions of hectares of degraded forested and agrarian landscapes by 2030. It holds promise as a solution to address global socio-environmental challenges, including environmental degradation and climate change. However, the current focus on environmental and ecological outcomes, despite acknowledging the importance of achieving both ecological and social outcomes in FLR, limits the potential of FLR to provide a wide range of ecosystem services for socio-ecological benefits. This situation highlights the ongoing challenges and trade-offs in balancing local social needs with global goals.

In order to avoid compromising global goals while meeting local needs, it is crucial to prioritize social equity in the design and implementation of FLR interventions. This chapter aims to draw attention to the significance of social equity in FLR processes on the ground. By exploring three key questions, we can preemptively address the equity implications of neglecting local social and human well-being in FLR interventions.

Firstly, we examine the potential of FLR to benefit local livelihoods and well-being. Secondly, we analyze the current challenges and trade-offs associated with integrating restoration efforts with local livelihoods and well-being. Lastly, we explore pathways towards collaborative management and identify ways to increase the benefits and co-benefits of FLR interventions for local development and livelihoods.

By addressing these questions, we provide recommendations to better incorporate local development and livelihoods into FLR processes and outcomes. This will help ensure that FLR interventions contribute to the well-being and sustainable development of local communities.

Participatory restoration planning in Abancay – Apurímac Model Forest, Perú

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: Model Forests (MF) are multi-stakeholder landscape governance processes. The Abancay-Apurímac MF (AAMF), located in the Apurímac region, Southern Andes of Peru, covers 80,030 hectares, with biodiverse high Andean ecosystems of forests, scrublands, wetlands, grasslands, “puna”, forest plantations, and agricultural mosaic. It is affected by expansion of the urban and agricultural frontier, and bad productive practices. The recent intensification of climate change with higher temperatures and incidence of droughts increased agricultural vulnerability and the incidence of forest fires. The Apurímac Region has a Restoration Strategy (2018), which identified 12,836 priority hectares to be restored within the scope of the AAMF.

We participatory facilitated a compreahensive Action Plan, for the implementation of the Strategy. 51 people participated in a sequence of workshops, interviews and surveys. We began with a stakeholders mapping and restoration initiatives. Subsequently, an online collaborative spatial analysis was carried out, using the Google Earth tool, as well as an analysis of human-cultural, physical-natural, economic-financial and sociopolitical resources and gaps. Finally, a set of actions for landscape restoration was proposed, prioritized, and validated.

Among the results are: 1) identification of 1,280 hectares to be restored in addition to those identified in 2018; 2) list of promising ecological and productive restoration practices, including: agroecology, community based conservation, and ecological restoration for the recovery of hidrological ecosystem services; and 3) the determination of 14 actions for landscape restoration, categorized in: good governance (GOB), capacity building (CAP), technical actions (TEC) and financial management (FIN). Political advocacy, territorial planning, capacity building and preparation of technical files by sector are key to unlock political and financial limitations. The next steps are the scheduling of activities and inter-institutional commitments.

Reforestation potential assessment to determine the suitability of degraded land for proactive large-scale nature-based reforestation.

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: Large areas of degraded land are vulnerable to further degradation and desertification because of overexploitation and climate change. The rate at which these areas reforest by natural regeneration is often too slow e.g. due to lack of seed sources, overgrazing, fire, and drought. However, significant parts of these degraded areas are potentially suitable for proactive reforestation by seeding or planting trees, thereby preventing further loss of vegetation and soil erosion. Nature-based reforestation is vital to establish forests with adaptive capacity to adjust to future circumstances and allow forest succession. Whilst large-scale reforestation is required for the supply of multiple forest ecosystem services for cost effectivenes and to meet stakeholder's demands.

We developed a tool that allows to assess:

1) the Goldilocks zone within which the land is neither too degraded or too vulnerable to future degradation so that a forest is an unfeasible goal, nor that active reforestation is unnecessary because of ample natural regeneration ('degradedness'),

2) the Forest Management Approaches (FMAs) that could be applied in the area, targeting different forest ecosystem services thus expressing the degree of nature-based reforestation of the FMA considered ('naturalness') and,

3) the spatial extent that allows combining FMAs thereby meeting multiple stakeholder demands ('scale').

The suitability of an area of degraded land for large-scale nature-based reforestation is first assessed at a 3-point decision scale for its Degradedness, Naturalness, and Scale. If the area falls within the acceptable range of these indicators, the assessment produces the following results:

- the Degradedness assessment provides potential reforestation targets expressed as a species pool and set of functional traits of the forest,
- the Naturalness assessment provides an overview of potential FMAs, given the constaints provided by Degradedness. We follow the approach developed by Dunkler et al. (2012) who characterize FMAs as Passive (Unmanaged forest nature reserve), Low (Close-to-nature forestry), Medium (Combined objective forestry), High (Intensive even-aged forestry), and Intensive (Short rotation forestry),
- the Scale assessment finally provides the distribution of FMAs over the area as the outcome of cost assessment and stakeholder demands.

We’ll present a case study applying the reforestation potential tool in a stakeholder consultation process.

Supporting land manager decision making for natural colonisation as an effective strategy for expanding forest cover and biodiversity recovery

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: There is a global drive to increase forest cover to protect biodiversity and help combat climate change. Tree planting is widely used to restore forest cover, but there is growing interest in using natural colonisation. However, predicting the outcome of natural colonisation is challenging as it is a highly variable process and evidence is sparse, especially in temperate landscapes. In the UK the responsibility for achieving national targets will fall mostly to private landowners and managers who own the majority of available land, and have been responsible for the most recent tree cover increase (e.g., across the UK, 97% of new trees were planted on privately-owned land in 2019). We present three years (2021-24) of empirical socio-ecological research using mixed methods (semi-structured interviews, site visits, and deliberative workshops) with c.150 land managers and advisors in different ecological and land use contexts and sites across the UK. We show that the perceived risks and opportunities associated with natural colonisation are linked with three broad identity types, with each identity type rating the bundle of risks and opportunities for restoration and biodiversity differently. Rather than a polarisation between ‘tree planters’ versus those using natural processes emerging, our research demonstrates the majority of land managers, across identities, appreciate a blend of active and passive approaches to meet their own objectives. Many also realise that hybrid approaches (i.e. applied nucleation) may actually assist natural processes, and reduce the risks of unexpected or unwanted species assemblages. “Story lines” and narratives associated with natural colonisation influence land managers decision making, but are not fully evidenced by ecological research. Critical analysis reveals that: i. the use of language which reflects identity types, ii. guidance and tools which demonstrate likely outcomes and risks, iii. financial support that reduces perceived risks, are all fundamental to encouraging uptake of natural colonisation and applied nucleation. We end by drawing important lessons and principals, from ways in which this research is being integrated into on-going policy development processes in the UK. We show how these are useful for other regions using natural colonisation for expanding resilient forest cover and biodiversity recovery.

The role of forests in land-based mitigation: reconciling different approaches, capacities and interests

S3.2 Restoring forests and trees: Balancing goals, interests and trade-offs

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Abstract: The recently completed Sixth Assessment Cycle of the Intergovernmental Panel on Climate Change (IPCC) suggests that it will be extremely challenging to meet the goal of limiting the global average tempterature increase to 1.5C or even 2C under many scenarios. The lack of progress in reducing GHG emissions across most sectors has led to expectations that a significant level of negative emissions will be needed, through land-based, ocean-based or industrial systems that insure net carbon removal from the atmosphere. Forests are envisioned to play a critical role among land-based mitigation strategies, not only because of their high capacity for carbon sequestration but also because of the many other benefits that forests provide, including biodiversity, air quality improvement, water quality regulation, ecosystem health, and social and cultural benefits. Although there can be co-benefits and even synergies between climate mitigation and other sustainability goals, there may also be trade-offs. The significant differences in both the biophysical and socio-economic context for forest management across different world regions - as well as across different means of management and governance - results in a fairly complex decision-making field for local, national and global stakeholders. These stakeholders also have quite different capacities and different priorities or interests.

We discuss here the results of a multi-year project of land use modeling, institutional analysis and stakeholder engagement on land-based mitigation across four world regions - East Africa, Southeast Asia, Latin America (Amazonas countries) and the Nordic countries. We had a particular focus on the central role of afforestation, reforestation and forest management in land-based mitigation portfolios, including differing approaches and priorities, and different implications for climate ambitions. We also considered the relation between local, national and regional perspectives and especially the opportunities for regional engagement to enhance climate ambition and co-benefits through scaling up and replication from national to regional levels. We present conclusions or recommendations on how competing interests might be reconciled and climate ambitions better articulated through an improved understanding of how enhanced capacities and means of implementation can be harnessed at regional as well as national level to better exploit co-benefits and synergies in achieving the aims of the Paris Agreement.

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

Addressing national forest monitoring R&D gaps through the Global Forest Observations Initiative

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: Effective monitoring of tropical forests plays a vital role in understanding their health, dynamics, and the ecosystem services they provide. With their critical contribution to climate change mitigation, there is a growing need to support national forest monitoring, particularly within the framework of Reducing Emissions from Deforestation and Forest Degradation (REDD+) and voluntary carbon markets, as outlined in Article 6 of the Paris Agreement. While countries are making progress in enhancing their forest monitoring capacities, significant technical gaps persist in their national forest monitoring systems.

The Global Forest Observations Initiative (GFOI) is a collaborative partnership involving international organizations, governments, and research institutions, with the primary objective of strengthening national forest monitoring capabilities through the provision of technical assistance, tools, and knowledge-sharing platforms. The GFOI R&D community has recently made substantial efforts to address research gaps related to national forest monitoring. Here we will highlight the latest advancements achieved by the research community in relation to the five GFOI R&D priorities: regrowth and degradation monitoring, biomass estimation, deforestation alerts, land use and greenhouse gas (GHG) monitoring, and uncertainty analysis. We will emphasize the key research initiatives undertaken by the GFOI R&D community, leveraging the increased availability of Earth Observation (EO) based data and derived products. Additionally, we will demonstrate context-specific applications of these new data sources to enhance national forest monitoring systems. Furthermore, we encourage researchers, practitioners, and interested parties to engage in future discussions and collaborations on these research priorities.

Cases of China-Europe cooperation in planted forest management and adaptation to climate change in Guangxi, China

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: The societal expectations from forests have changed fundamentally, over the past few decades. It is well recognized that forests have a very wide range of ecological, economic and societal functions that can be broadly classified as supporting, provisioning, regulating and cultural. Increasingly societies, particularly those which are better off economically, demand more from forests than mere forest products, thus bringing about a huge challenge to the forest scientists and managers considering the multifunctional forest ecosystem management imposed on the practitioners.

Guangxi Zhuang Autonomous Region of China has the largest planted forest area and the largest timber output of China. In the last 15 years, I involved in two international cooperation projects supported by China's Ministry of Science and Technology, and carried out cooperative studies with European partners from University of Freiburg, Dresden University of Technology, INRA, and Austrian Research Centre for Forests – BFW. The topics included the carbon stability and forest management, tree species richness and ecosystem functions, and the effect of experimental warming on soil carbon fluxes.

Main points and highlights of the international cooperation included (i) concept and practice of multifunctional forestry in Chinese and European research regions; (ii) adaptive tree species mixed silviculture strategies and techniques for multifunction increases; (iii) tree species diversity and forest ecosystem functions enhancing; (iv) response of soil warming and throughfall decreasing on the forest ecosystem carbon sequestration.

Several suggestions for the further cooperation could be (i) Sharing advanced idea in the joint research platform and laboratory; (ii) reducing the risk of climate change impacting the plantation production and ecological functions; (iii) increasing the resilience and adaptive capacity of the forest ecosystem to changing environment.

Climate-driven variations in functional strategies of forest ecosystems across USA and Europe

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: Functional strategies play a crucial role regulating forest capacity to cope with water stress. However, current understanding on community-level functional strategies of forest ecosystems and how they vary with geographic patterns is limited. We combined eight functional traits (i.e., leaf nitrogen content, xylem conductivity, leaf area to sapwood area ratio, leaf mass area, xylem water potential at 50% loss of conductivity (P50), slope for the curve between P50-P88, leaf turgor loss point and wood density) with forest inventory data across temperate regions in the USA and Europe (n=12,332 grid cells aggregated at 0.5° resolution) to identify functional strategies with respect to water stress and to analyse their relationships with water and temperature gradients. Principal components analysis suggests that functional strategies at species-level can be captured at community-level. Acquisitive-conservative strategies loaded along the first dimension, while the water storage and isohydricity strategies loaded along the second dimension. Spatial patterns of community-level strategies showed more explanatory power with temperature than aridity, suggesting that interfaces with other aspects of plant strategy may be strongly influencing the strategy adopted to handle water stress. This was accompanied by an increase in the diversity of strategies with respect to water stress as aridity increased, with more mesic forests converging on a

relatively narrower region of strategy space. Our findings promote the understanding of forest responses to drought across temperate regions and provide a basis for improving the ability of ecosystem models to predict the patterns of tree mortality and forest biomass accumulation.

CRAAFT, a new international initiative on the adaptation of forests and agroforests to climate change

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: The CRAAFT initiative originated at INRAE's general management level, with the support of CIRAD, in France. A French working group of 10 members, later enlarged to 30 international experts from various regions of the world, drew up a concept note designed to present the context, objectives and approaches of the initiative.

This initiative is dedicated to forest and agroforests social-ecosystems. The project considers the trees as the foundation species of theses ecosystems, but add all other types of living things, plants and animals, as well as microorganisms, and human beings.

While during the first 20 years of climatic change its effects were not obviously harmful, or were even sometimes found to be beneficial, things then changed rapidly: forest started to respond with more and more frequent and severe declines and diebacks, observed in all types of climates and forests.

Therefore, critical questions are addressed now to scientists: to which extent the natural mechanisms of local adaptation can allow forests to recover from the extreme events, which are a direct or indirect consequence of climate change? How to help them to regain rapidly a stable viable state, i.e. to show resilience? How can they continue to provide all categories of ecosystem services, both market and non-market?

Among the things that severely limit our ability to answer these questions is the uncertainty that accompanies future climates prediction. Future climates are increasingly dependent on large-scale political decisions that are beyond the control of the scientific community. Another major difficulty is our ability to consider the complex interactions between the different variables that directly and indirectly affect forest evolution.

Initiatives trying to imagine and test adaptive management interventions that could increase the resilience of forests to extreme climate events are highly needed. They require involvement of social and economic actors, and the high level of challenges and threats calls for extensive international exchanges of knowledge, innovation and solutions, in order to increase the power and the significance of experimentation. CRAAFT is one of these international initiatives, taking on some of the most urgent and relevant research actions.

Effectiveness of partnerships and regional cooperation in addressing forestry challenges.

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: Forestry sector, faces numerous challenges such as deforestation, climate change, illegal logging, and habitat degradation. Addressing these challenges requires a collective effort that goes beyond individual capabilities. Partnerships and regional cooperation has been adopted globally as a tool that can enhance joint articulation and tackling of forestry challenges and issues.

Partnerships provide a platform for governments, non-governmental organizations, local communities, and businesses to collaborate, share knowledge and jointly seek/pool resources. A key advantage of partnerships and regional cooperation is exchange of knowledge and expertise. Regional cooperation allows stakeholders to share best practices, research findings, and innovative technologies. By learning from each other's experiences, partners can develop comprehensive strategies that take into account local contexts and global trends. Partnerships and regional cooperation also enhance the conservation of natural resources especially those shared across borders. By working together, stakeholders establish protected areas, promote reforestation initiatives, and implement sustainable harvesting practices. Sharing resources and expertise can help optimize the allocation of limited funds and ensure that conservation efforts are targeted and impactful. Moreover, collective action increases the influence and effectiveness of advocacy efforts, encouraging policymakers to prioritize sustainable forestry. Example illegal charcoal trade challenges cut across East Africa Countries and a regional cooperation approach has potential benefits in enhancing regulation and Trans-border trade. Another significant benefit of partnerships is their potential to support local communities. In many regions, forests are intricately linked to the livelihoods and cultural identities of rural communities. For Example more than 70% Sub Saharan Africa communities depend on wood and forests. Collaborative initiatives provide opportunities for these communities to participate in decision-

Above all Regional cooperation facilitate access to funding and investment opportunities. The pooling of resources and expertise increases the attractiveness of forestry projects to financiers and donors, leverage public-private partnerships, secure grants, and attract. Collaborative initiatives leverage public-private partnerships and attract private sector investments.

This paper will present 3 selected cases on regional cooperation that include the KEFRI social Forestry regional trainings on climate change among others to showcase effectiveness of partnerships and regional cooperation in addressing forestry challenges.

Keyword: Partnerahips and regional cooperation, forestry,

Enhancing the role of forests and trees in transformational adaptation to climate change

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: The Intergovernmental Panel on Climate Change (IPCC) *Sixth Assessment Report* calls for upscaling and disseminating tried and tested adaptation measures that are recognized for their high feasibility and synergies with mitigation and the Sustainable Development Goals (SDGs). One of these measures identified by the IPCC is "forest-based adaptation", an ensemble of climate actions that employ forests and trees in support of climate change adaptation and resilience, including sustainable forest management, forest conservation and restoration, reforestation, silvopastoral systems, trees on farms and trees in cities.

Forests and trees provide ecosystem services which minimize exposure, reduce vulnerabilities, and strengthen capacities, thus contributing to adaptation and resilience. However, these adaptation services depend on forests being resilient to climate change. As such, forests and trees can sustain society's efforts to adapt to climate change, yet they also require society's contributions to maintain their resilience.

Building upon previous work in the field, FAO has been working with partners to highlight the contributions of forests and trees to fulfilling country commitments for climate change adaptation and resilience building. The FAO technical paper *Forest-based adaptation: transformational adaptation through forests and trees (2022)* unpacks the concept of forest-based adaptation and describes policy spheres that could bolster the role of forests and trees in providing adaptation and resilience benefits. It introduces a set of ten principles for using forests and trees to promote transformational adaptation, which were developed with leading experts from the Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF) and other partners. It describes the policy implications of each principle and draws on examples from diverse forest ecosystems and management practices to illustrate their application in practice.

Building on this work, we have facilitated a series of global and regional dialogues with international researchers and practitioners, adaptation and forestry country representatives, and climate finance actors to bolster cross-sectoral collaborations around emerging priorities, including to: promote mitigation-adaptation synergies; integrate forests in cross-sectoral adaptation strategies; assess the resilience of forests and trees to climate change; monitor adaptation progress; and mobilize finance for adaptation. This presentation will highlight the results of this collective work and indicate ways forward.

Forest management and biodiversity conservation in a changing climate: consequences and the way forward

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: Understanding forests functioning and how forests respond to climate disturbances is a major challenge for any forestry research programme in the 21st century. We still lack a clear understanding of the complex interactions between the different components of forest systems, the role played by the different levels of biodiversity, and the behaviour of unbalanced systems.

The geographical scale of the dangers posed by climate change to agroforests and forests far exceeds national borders. Also, forests are social-ecosystems where humans and non-humans cohabit, generally with conflicts of interest affecting certain beneficiaries of ecosystem services, both human and non-human. As a consequence, there is an urgent need for large-scale transdisciplinary international projects taking into account socio-ecological contexts, to ensure that multiple values are well considered.

In this presentation, we outline the opinion defended by the CRAAFT project, a new international initiative on the adaptation of forests and agroforests to climate change. We support the idea that research projects aiming at better characterizing (1) the response of forests to climatic disturbances and (2) the interactions between the different components of forest systems at large geographical scales are urgently needed. We propose to explore transformative strategies[1] in addition to adaptation or incremental strategies, and to provide new scientific knowledge to help decision-makers avoid insufficient, unsuitable or unsustainable options for future forest management. In particular, we believe that the highly needed research on natural adaptation and its mechanisms must be multidisciplinary and combine human and social sciences with biology and ecology to lead to effective adaptive management.

During this conference, we will show how current knowledge can be used to suggest the most promising avenues for research, i.e. those that will help preserve biodiversity and ensure sustainable forest management in the face of ongoing climate change.

[1]A transformative strategy is designed to create transformative change, which involves a fundamental shift in the functioning and dynamics of forest-landscape systems.

Improving the Sustainable Management of the Brazilian Cerrado

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: The Brazilian Cerrado is a savanna of global importance that is severely threatened by agricultural expansion and forest conversion into intensively managed pastures. While autochthonous silvopastoral systems offer a more sustainable alternative, they are currently less financially profitable compared to the intensively managed systems.

Our research alliance is a German-Brazilian initiative to improve the sustainable management of the Cerrado through quantification and valorisation of ecosystem services provided by silvopastoral systems. One potential pathway to enhance profitability compared to other land uses is by monetizing these services through various means, such as product labels, certification, value-added processing of non-timber forest products, and carbon credits. By recognizing and assigning value to the ecosystem services, we can create economic incentives that promote the adoption and continued support of silvopastoral systems in the region.

We combine household-level primary data with data collected through a market survey, and secondary sources for econometric modelling on the determinants of silvopastoral system adoption in the Cerrado region. We assess the factors determining silvopastoral system adoption and management, and aim for an improvement of rural livelihoods and household nutrition. Concluding, we stress the importance of building the capacity of extension agents, scientific community, and local government to facilitate a more sustainable management of the Cerrado.

Jurisdictional REDD+: A Comprehensive Literature Review on Opportunities, Challenges, and Potential

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: REDD+ stands for Reducing Emissions from Deforestation and Forest Degradation, which encompasses all activities aimed at protecting forests from deforestation. Within the realm of REDD+, jurisdictional projects emerge as a distinctive approach. In comparison to project-level REDD+, jurisdictional-level REDD+ offers several advantages, including a reduced risk of inflated baselines and over-crediting, as well as the ability to address the issue of leakage. This paper aims to undertake a comprehensive literature review to provide an in-depth understanding of the current state of research on subnational REDD+, shedding light on both the opportunities and challenges associated with this approach. Specifically, we will emphasize the pivotal role played by local stakeholders in the successful implementation of subnational REDD+ initiatives. Moreover, we will underscore the significance of establishing robust governance structures and institutional frameworks, which serve as key pillars for the effective execution of subnational REDD+ programs. Additionally, the necessity of implementing efficient monitoring and verification systems will be emphasized, as they are critical for ensuring the credibility and efficacy of subnational REDD+ endeavors. Furthermore, this paper will explore the potential for scaling up subnational REDD+ initiatives to a national level, evaluating their capacity to contribute to the overarching goals outlined in the Paris Agreement. By elucidating the complexities and nuances surrounding subnational REDD+, this study will provide valuable insights for policymakers and practitioners engaged in climate change mitigation efforts.

Linking Fruit and Forest tree communities: the FRUITDIV European initiative

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: Crop wild relatives (CWR) are wild plant taxa closely related to a crop. They represent an important source of genetic diversity for the improvement of agronomic traits and they are still available as tree species within the European forests. In the context of the One Health Initiative, temperate fruit trees are essential for human nutrition and health, yet CWR resources have hitherto been underused. Moreover, fruit tree long lifespan and a current production dominated by a few cultivars make them particularly vulnerable to the effects of global changes. To address this challenge, the FRUITDIV project will monitor, characterize, use, and conserve the diversity of emblematic fruit tree CWR, with a particular emphasis on Malus, Pyrus and Prunus, by linking horticulturists, forestry officers and citizens.

To better characterize the genetic and phenotypic diversity of CWR fruit trees and identify favourable traits for future introgression into cultivars, FRUITDIV will use a combination of floristic, ethnogeography and population genomics on genebanks and historical European hotspots of diversity. We will then develop new multiomics-based breeding strategies that combine marker assisted introgression for traits of interest (e.g. resilience, resistance to pests and diseases, fruit quality) with pangenomic prediction and a reduction of CWR-associated genetic load.

In addition to breeding programs, FRUITDIV will also work with networks of farmers and associations to help characterize CWR progeny in various pedo-climatic conditions in Europe. An European-wide online platform that provides genotyping and phenotyping data for free will be implemented to promote the use of CWR genitors by breeders and farmers and help disseminate plant material of interest for various usages and cultivation systems.
Overall, the FRUITDIV multi-actor approach involving geneticists, forestry officers, germplasm curators, farmers and citizens, will foster the in- and ex-situ conservation of Fruit tree CWR and promote sustainable agricultural and forestry practices across Europe.

FRUITDIV is by essence inter-disciplinary, gathering experts in horticulture, forestry, ecology, genetics and population genetics, genomics, bioinformatics, mathematics and social sciences. It is made of 27 partners from 10 EU countries and 4 non-EU countries. The above 5 authors will represent the consortium at the IUFRO conference.

TF on monitoring global tree mortality: opportunities and challenges of internationalization of research on forest adaptation to climate change

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: Forests are threatened by climate change in many regions across the globe. During the last decades, increased tree mortality and forest decline in response to drought and heat have been observed in all forested biomes and documented on a global map. However, the underlying observations in forests are often carried out in proximity to research institutions and-or in countries with forest assessment programs, leaving many blank spots on the global mortality map. It thus remains uncertain whether such a map represents a consistent trend in forest condition, but this information is crucial for evaluating forest damage from and also forest adaptation to climate change.

International and interdisciplinary research is needed to fill this blank, by creating synergies between forestry agencies, research plot networks, remote sensing analysts and vegetation modellers on the one hand, and field experts like forest ecologists, ecophysiologists, entomologists and pathologists ont the other hand. The IUFRO task force on monitoring global tree mortality has been aiming to foster such interdisciplinary research internationalization.

In this talk I will present experiences of six years of networking activities to create such synergies, and I will highlight both opportunities and challenges that lie within internationalization of forest research activities. While not specifically mandated to address forest adaptation to climate change, experiences collected during the lifetime of the IUFRO task force on monitoring global tree mortality can be valuable to other futue internationalization initiatives.

TreesAdapt: a global partnership platform to leverage forests, trees and agroforestry solutions for cross-sectoral adaptation

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: Forests, tree commodities and agroforestry systems -as well as their value chains- are and will be strongly affected by climate change. Moreover, forests and trees are key to buffer impacts of climate change on agriculture and other sectors, including water, infrastructures, cities and on the most vulnerable populations.

Actions mobilising the potential of forests and trees for adaptation have multiple benefits, mitigating climate change, contributing to the achievement of the SDGs as well as contributing to biodiversity and land restoration agendas. Adaptation of and with forests and trees is increasingly mentioned in NDCs and NAPs. There is also an increasing demand for cross cutting, systemic adaptation. This requires both the capacity to synthetize and organize issues and options inside a sector and to relate to other sectors and to broad challenges at national level. This is particularly important for transformative adaptation that changes the fundamental attributes of a system to respond to climate change and its effects.

There is a demand for evidence and knowledge to ground design and selection of options, for methods, tools, technical support capacity building for implementation of adaptation measures of/with forests and trees. There is also a key need to design and develop an appropriate enabling environment and appropriate learning loops and communication.

It is to answer these demands and needs that CIFOR-ICRAF, building upon a strong and diversified body of knowledge and track record, has organized a coordinated answer in partnership, to leverage the roles of forests, trees and agroforestry for cross-sectoral adaptation: ***TreesAdapt.***

Adopting a concrete entry point, forests and trees, ***TreesAdapt*** is a transformative partnership platform that targets implementation on the ground of climate change adaptation solutions with forests, trees and agroforestry. It aims to constitute forests and trees as a binding object that can trigger intersectoral dialogues, facilitate the elaboration of a shared understanding of issues and the co-construction of locally-adapted solutions. ***TreesAdapt***, because of its cross-cutting nature, is also a great vehicule for introducing system thinking in broad adaptation planning.

The ***TreesAdapt*** platform and its advances will be presented, and ways to engage and to partner will be discussed.

Why forestry science should go (really) global? Needs and challenges to have a significant impact on knowledge, scientists and forests worldwide

S4.1 Building international initiatives to strengthen forest adaptation strategies in a changing climate

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Abstract: There is ample consensus about the interrelated global challenges faced by humanity, associated to a growing human population, pressing on natural resources, and climate change. Forests are in the center of those challenges, as recipients of the negative impacts of climate and land use changes, and as providers of key ecosystems services (food, fibers, energy, biodiversity, carbon sequestration, water regulation, etc.) to contribute with their solution. The world may be rather simplistically divided between what is called “the Global North” and the “Global South”, which refers mainly to the socio-economic development of the nations within them. High-income countries (mostly on the geographic North, except Australia or New Zealand) have a high per-capita (or total) consumption of natural resources and are responsible of most of the greenhouse gas emissions. The low-income countries (mostly in the geographic South) have low per-capita impacts but are those with the highest world deforestation rates nowadays (mostly to provide commodities to the North, which pays more for them than for the missing forests` services). However, there are not only socio-economic differences, but environmental ones, with different combinations of climatic drivers and soil types unique to each continent. Studies focused on new regions may expand the current fragmentary knowledge we have about how the forests function now and could function in the future. To fill the gaps in knowledge, forest science should go really global. But this demands a new ethic in data generation and sharing and in scientists´ exchange and participation to build a fair and balanced scientific framework. Pairs and colleagues from all over the world should be part of the debates and decisions within the scientific community, for instance by forming part of research nets and editorial and academic boards, and recipients of long-term funding for forest data generation and curation. However, beyond the efforts to build a better frame for forestry scientists and generate better forestry knowledge, the possibility of forest science to contribute to global solutions demands new dialogues outside our community and forms of knowledge construction. It is time for us, therefore, to be more fair, open and creative.

S4.2 Forest Policy and Justifying Role of Science in Tropical Countries. A High-Level Policy Panel Dialogue

Inclusive science to inform forest policy in the tropics

S4.2 Forest Policy and Justifying Role of Science in Tropical Countries. A High-Level Policy Panel Dialogue

Pablo Pacheco[1]
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Abstract: The tropics continue to show trends of growing land occupation, unequal access to public services, and persistent rural poverty. Much of the economic wealth generated from land, forest, and minerals' resources use and extraction is concentrated and poorly redistributed. The dominant pattern of economic development has prompted natural forest loss and degradation, contributing to carbon emissions and biodiversity loss. The resilience of forest ecosystems, people's livelihoods, and local economies is growingly under threat due to compounding and cascading climate disturbances. While climate science has alerted on climate change and its consequences, it has done from a biophysical and ecological perspective, and there are major gaps related to translating scientific findings to inform local responses, including indigenous and local knowledge to understand forests and social behavior changes and adaptation, and approaching solutions in more integrative ways by building on a more inclusive science. Until today, policy and practice in the tropics is informed by scientific paradigms, which guide mainstream conservation, sustainable management and land use approaches that struggle to embrace more plural and holistic perspectives of understanding. However, increasingly, there are efforts to co-produce knowledge aimed at better connecting global trends and local socio-ecological and climate dynamics, understanding the socio-diversity of local contexts, and co-designing options to advance collective actions. I will argue that for overcoming the climate challenges, in the face of the economic and governance challenges facing the tropics, a more integrative science is needed, that builds on plural explanatory perspectives including those of indigenous and local knowledge, a better understanding of the climate and socio-institutional linkages shaped by context, and a more comprehensive acknowledgement of the responses potential that considers explicitly the needs and aspirations of the tropics' multiple stakeholders.

Science policy interface and tropical forests

S4.2 Forest Policy and Justifying Role of Science in Tropical Countries. A High-Level Policy Panel Dialogue

Robert Nasi[1]

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Abstract: Researchers are increasingly being forced to consider how their research findings can result in tangible impacts thereby presenting a considerable challenge to those seeking to achieve those impacts as a consequence of policy changes. The policy change process is subject to a bewildering array of social, economic and political influences, and policy decisions are taken largely independently from the actions of scientists and research institutes. To assume that conducting research on policies relating to forests and disseminating the findings will lead to changes in the policies themselves is unrealistically naive and grossly overestimates the role of knowledge acquisition in policy change processes. A role exists nevertheless.

Through successful case studies from tropical countries, we will demonstrate the transformative potential of forest science in driving positive change. It will showcase examples of sustainable forestry practices, community-based initiatives, and innovative conservation strategies that have emerged from scientific research.

We hope to underscore the pivotal role of forest science in the conservation and sustainable use of tropical forests. By integrating scientific evidence, interdisciplinary collaboration, and inclusive approaches, it becomes possible to develop effective policies and practices that ensure the long-term health, resilience, and equitable benefits of tropical forests for present and future generations.

The Politics of Numbers in Global Forest Governance

S4.2 Forest Policy and Justifying Role of Science in Tropical Countries. A High-Level Policy Panel Dialogue

Maria Brockhaus[1]
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Abstract: Scientific information - and scientists - are assumed to play a key role in global forest governance based on the idea that rigorous scientific information can lead to more effective, efficient and equitable forest policy outcomes. Data and information are central to forest policy processes, in framing the policy problem, designing and implementing policy 'solutions', and evaluating impacts. Better data and information infrastructures are expected to lead to better policies and outcomes, for example, by enabling transparent decision making and enhancing capacity and accountability. Scientists are expected to engage in diverse policy processes and science policy interfaces (SPIs) aiming for scientifically informed policy in forest related policy arenas, which often involve a multitude of actors with conflicting values and interests. In this context, scientists and their evidence are supposed to be striving for credibility, relevance, and legitimacy of the produced evidence while navigating these complex, politicized webs of public policy making. Yet, the collection, selection, representation, framing and application of data are not merely technical and apolitical procedures. Data and information are socially constructed, and their interpretations are shaped by the contexts in which they emerge – an observation not very popular among scientists and decision makers alike - as it easily can be misread as an effort to undermine claims of the research community to speak 'truth'. Dominant beliefs in the transformative power of new data and technologies, cannot explain why, often, new information does not translate into policy change and desired action. Despite this dissonance, it seems that the theories of change underlying the design of forest policy SPIs continue to assume that knowledge is the missing piece for policy makers and private sector actors, and for entrepreneurs to do 'better' – and hence to move effectively (measurably) away from an unsustainable business as usual. Acknowledging 'power and politics of numbers' in our contemporary and often highly contested forest policy arenas, will be a very important step when producing and assessing evidence, and designing and assessing the impacts of SPIs. Who counts and what is counted, counts in forest policy and practice.

Uncertainties and trends in the forest policy framework in Sierra Leone: an overview of forest sustainability challenges in the post-independence era

S4.2 Forest Policy and Justifying Role of Science in Tropical Countries. A High-Level Policy Panel Dialogue

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Abstract: Sierra Leone is part of the Upper Guinean Forests with a climate that enhances great floral biodiversity. The relationship between forest exploitation and plantation forest decline is broadly assumed to be influenced by population growth, weak forest policies, legislatures, forest management and monitoring policies over the past century. The paper examines forests status and forest resources policy evolution since the pre-colonial era but pays particular attention to policies developed from 1988, in the post-colonial era, and the challenges facing their implementation. The paper highlights major challenges facing the healthy and sustainable growth of forest resources in Sierra Leone. The challenges range from the attachment of the Forestry Division to the Ministry of Agriculture, Forestry and Food Security (MAFFS), the overlap in ministerial mandates about forest protection, corrupt government officials, poverty, illegal logging, inadequate funding and staff, natural disaster and outdated forestry instruments. Natural factors such as climate change, drought, and landslides are considered among the issues affecting the sustainable expansion of forest resources in Sierra Leone. A flowchart of forest sustainability challenges in Sierra Leone was designed, and classified forest challenges into natural and man-made causes. The inability of the Forestry Division to become an independent body and the continued reliance of the Division on the 1988 Forestry Act to make informed decisions in the 21st century is serving as a major barrier in sustaining forests resources in Sierra Leone. Improving forest management in the country requires the collective efforts of both national and international forests protections entities and organizations. Sound forests conservation policies and adequate funding and staffing can strengthen the Forestry Division in enforcing its constitutional mandates. Adopting the best practices models from countries such as China, India and the USA will help towards the goal of managing forest resources sustainably for current and future generations.

S4.3 International Forest Governance: A Comprehensive Global Review

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

A peri-urban forest conserving challenges in West Africa

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Urban forests have played crucial role of urban centers in West Africa. However, the growing population and rapid urbanization occasioned by demographic switch from rural to urban society is outstripping the planning and carrying capacity of municipal authorities in West Africa. Thus, evaluating the governance and the dynamics of peri-urban forests is fundamental to guide management and conservation policies. This study aimed to analyze the spatio-temporal dynamics of the "*Forêt Régionale du Centre*" (FRC) in Burkina Faso. Focus group surveys with local populations and foresters, combined to Landsat satellite images analysis for a period of twenty years from the study site were used. The results show that the FRC undergoes increasing degradation of plant resources characterized by landscape modification. Local populations perceive the regression of the forest, which is classified as in high degraded state by 93% of informants with the disappearing of the 10 most useful trees species such as *Parkia biglobosa, Lannea microcarpa* and *Bombax constatum*. The main identified drivers included the forest governance in which all stakeholders blame each other, human activities, demographic explosion, and climate variability. The analysis of the satellite images confirmed the regressive dynamics of the FRC. In twenty years, about 50% of the vegetation area was lost at the expense of bare soils and illegal habitations. To save the FRC, forestry administrations have to consider it as a specific component in its own right, by involving local populations in it management and protection.

A regenerative approach to forestry

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Today, as the multiple planetary crises converge irrupting our daily life and threatening our existence, we are increasingly becoming aware of our interdependence with nature. A core cause of the unprecedented degradation of the planet lies in our inner perceptions as separated from nature. Yet, most of the current sustainable forest management efforts are dedicated to transforming the external world of forestry policies, economies, or ecosystems, overlooking the inside dimensions of individuals and their deep transformational potential. There is growing recognition that addressing the inner dimensions and integrating the values and perceptions underpinning human-forest connections is essential for pursuing permanent changes in the outer dimensions.

In this paper, we introduce a regenerative approach to forestry, advancing the current sustainable forest management practices by including the inner dimensions of individuals, values, and perceptions to enable a long-term co-evolution with forests. The regenerative approach to forestry is based on the concept that all systems, human and natural, are interlinked and can influence each other. This means that each forestry project or community should always be considered within the context it is part of and its impact on its proximity. We contribute to the empirical corpus of regenerative forestry evidence through a case study in Algezur, Portugal. We found three main aspects where a regenerative forestry approach could add value to sustainable forest management. First by unfolding the transformative potential of forests within their local contexts, second, by cultivating the capacity in individuals to perceive and embody a whole living systems perspective, and third by reestablishing the reciprocal contributions between forests' benefits to people and people´s benefits to forests.

Actor centered power mapping for mangrove protected area governance

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: The effective governance of mangrove-protected areas is crucial for the conservation and sustainable management of these valuable ecosystems. However, power dynamics among different actors within these governance systems often play a significant role in shaping decision-making processes and policy outcomes. The Sundarbans, the world largest single tract mangrove forest was chosen for the study. This study aims to develop an actor-cantered power mapping framework to analyze and understand power relations within mangrove-protected area governance. The proposed framework integrates elements from social network analysis, power theory, and stakeholder analysis to identify key actors, their relationships, and the distribution of power among them. By utilizing qualitative and quantitative data, including interviews, surveys, and policy document analysis, the study examines the formal and informal power structures that influence decision-making processes in mangrove-protected areas. By mapping power relations, the framework provides insights into the influence of actors on policy formulation, resource allocation, and implementation. The findings of the study contribute to a deeper understanding of power dynamics and their implications for mangrove-protected area governance. This study creates a complete policy actor network for the Sundarbans protected area governance using the snowball sampling technique. Bangladesh forest department appears as the most powerful actor however shipping ministry, Mongla port authority and BIWTC are also among the powerful actor in the wider intersectoral policy decision making process. The study also reveals that the policy outcome satisfies the interest of the Bangladesh forest department, but the action fails in the implementation steps as the core interests of other powerful actor from outside the forest sector are not in synergy with BFD's interest. The study also reveals that equal share of decision-making responsibilities was not achieved in the Sundarbans protected area governance as the forest users have little influence in determining the policy outcome.

Adaptation through planting fast-growing broadleaves among private forest owners in Sweden

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Forest damages are increasing and there is a need to adapt the forest to climate change, at the same time as forests need to deliver a range of ecosystem services. To meet upcoming challenges, many advocate for a diversification of forest management strategies and tree species. Fast-growing broadleaves (FGBs) adopted as part of forestry or agroforestry include hybrid and native species and may contribute to diversifying forests currently dominated by conifers. Yet, knowledge gaps remain regarding their economic viability, as well as impacts on biodiversity and recreational values. To ensure that climate adapted forestry is not creating new conflicts between stakeholder groups with different interests, and facilitate convergence with policy, we must understand reactions and decision-making processes of diverse stakeholder and rightsholder groups in different places.

Comparable to many other countries in Europe and the United States, a large share of the productive forest land in Sweden is owned by private forest owners (also called family forest owners), making them a key actor for climate adaption in forests. This study examines forest owners' adoption of FGBs with a specific interest for the role of place (social and ecological characteristics) and decision-making processes. Since adopting FGBs is only one way to diversify, this decision is contrasted with willingness to adapt in other ways (e.g., other broadleaves). Based on data from a large survey of a random sample of private forest owners in Sweden (n = 5000), this study explores how owners in different municipalities and regions, with varying climate conditions but also ownership structures and access to sawmills processing broadleaves, vary in their interest in FGBs. In addition, analyses cover to what extent decisions to adopt is motivated by problems associated with current management (including appraisals of future damages) versus the emotions and beliefs associated with FGBs specifically. By considering decision making processes in relation to place characteristics covering both the social and ecological dimensions, this study provides insights on the drivers and barriers of adaptation among forest owners. This knowledge is key for an understanding of how the forest will be adapted to climate change.

Addressing wildfire risk. A review of approaches to design decision and criteria spaces and support adaptive forest management planning

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Wildfires pose a challenge to forest management planning. The provision of a wide range of ecosystem services in contexts of global change requires often the conversion of forest types. Yet the impacts of these management options on that provision are not immediate. They rather take place over extended temporal horizons and may thus be affected by the occurrence of wildfires. In this context, addressing the wildfire challenge requires models and methods that may design effectively both the forest management planning decision and criteria spaces. This will be influential to estimate the impact of management options on the provision of ecosystem services and to analyze the tradeoffs among the latter. This presentation reviews and classifies models and methods according to the support provided to the design of decision and criteria spaces in forested landscapes. It further reviews and discusses approaches to facilitate the engagement of decision-makers and stakeholders in the exploration of the criteria space. The potential of models, methods and tools to address wildfire risk and support adaptive forest management planning is illustrated by an application to a forested landscape extending over 14 thousand ha and involving multiple decision makers and stakeholders.

Adopting robust actions in forest management planning in protected areas – insights from Slovakia

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: The rapid and turbulent changes in our world create significant uncertainties on myriad factors, which present themselves in many ways, such as the climate, market conditions, legal frameworks, and their impacts. Faced with an unpredictable and fast-changing world, maintaining and promoting sustainable forest management in Slovakia in the coming decades will be a challenging task. Therefore the forest sector needs to think and act strategically. Developing robust strategies that are relatively insensitive to future uncertainty is an attractive way. Yet, the application and adaptation of forest management to uncertainties under climate changes or other developments (e.g., ecological, societal, economic, and technological demands) have been addressed just now. If it should be integrated into forest management planning, the non-probabilistic approaches are necessary to explore the future in plausible scenarios. In other words, the scenarios are not prognoses. Thus, they do not try to forecast the most probable future development but create variants of possible plausible future development. An important area of application of scenarios is strategic planning, the basis of which are critical decisions taken under uncertainty. This could be applied to general forest management planning and protected areas. As national parks are considered a key to conserving forest ecosystems and biodiversity, stakeholders' participation in forest management planning may help to improve and mitigate environmental, economic, or social inequalities. So far, forest management planning has been rather a technical task to match capacity with goals and a political one to give experts the responsibility of developing the plan. As a result, the research project's goal is to present an alternative to current planning processes in finding robust (participatory set) actions for the future. These robust actions will be determined using an innovative approach in which various methods (e.g., stakeholder analysis combined with social network analysis, scenario analysis combined with multicriterial optimization) will be integrated. As the demand in national parks in Slovakia for alternative forest management increased after recent institutional changes, now more than ever, there is a call for robust (participatory set) actions in general and in protected areas in particular.

Allocation of tree species under climate change uncertainty: optimizing reforestation for resilience using Modern Portfolio Theory

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Modern Portfolio Theory (MPT) mathematics underpin modern financial strategies to optimize investment performance under market uncertainty. This approach can be applied to the challenge of accounting for climate change uncertainty in the choice of tree species and provenance for reforestation. We developed a climate change informed species selection (CCISS) analysis to forecast future trends in the suitability of tree species under a wide range of global climate model – carbon scenarios for the province of British Columbia, Canada, where 300 million seedlings are planted yearly. CCISS generates site condition specific tree species suitability trends in 20-year periods out 100 years and delivers an output that meshes with the decision-making framework used by reforestation professionals. A challenge with this analysis is that the modelled outcomes rarely produce clear agreement in species suitability ratings across the modelled futures and time periods. Instead, each climate future has a different tree species suitability profile for each plausible future reflecting the uncertainty in climate futures. For decision-makers this complicated outcome, while providing a useful perspective on climate change implications to current reforestation standards, is difficult to interpret, optimize, and fully incorporate into decisions.

To provide clearer guidance to practitioners, we apply the concepts of MPT to CCISS predictions to generate climate-change optimized species ratios areas for reforestation. We use modelled changes to species suitability as a proxy for tree stress and forest health risks, and modelled tree growth rates (based on site index by site condition) for returns. The MPT analysis generates a range of portfolio options, from one or two species mixes with maximum potential return (but higher risk) to more species diverse portfolios with higher resilience. This MPT output allows forest managers to choose a risk-return level they deem appropriate for management goals and identify the species portfolio that optimizes the balance between forest productivity and climate change resilience.

Ambiguity, value of information and forest rotation decision under storm risk: a theoretical model and an experimental test

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Natural hazards represent the major threat for forest worldwide, especially storm. However, due to the more or less pessimistic scenarios of future climate change, storm frequency is now ambiguous and only partially known (i.e., scenario ambiguity). Furthermore, within each scenario, the quantification of storm frequency is also ambiguous due to the differences in risk quantification by experts, creating a second level of ambiguity (i.e., frequency ambiguity). In such an ambiguous context, knowledge of the future climate through accurate information about this risk is fundamental and can be of significant value. In this paper, we question how ambiguity and ambiguity aversion affect forest management, in particular, optimal cutting age, using both a theoretical model and an experimental test. Using a classical Faustmann framework of forest rotation decisions, we compare theoretically three different situations: risk, scenario ambiguity and frequency ambiguity, also considering the preferences of the forest owner. We show that risk and risk aversion significantly reduce the optimal cutting age. We also show that both scenario and frequency ambiguities reinforce the effect of risk. Inversely, ambiguity aversion has no effect. The value of information that resolves scenario ambiguity is high, whereas it is null for frequency ambiguity. In addition, we test these theoretical results through experimental economics. We realize an online experiment with a population of private forest owners from Grand-Est Region in France. We quantify risk and ambiguity aversion through classical Multiple Price List methodology. We then ask the forest owners to indicate the optimal cutting age in the various scenario. The experiment will be carried out during March and the data analysed thereafter.

Application of Risk-Based Approach for Sustainable Forest Management Assessment in Ukraine

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: One of the most robust ways to implement sustainable forest management is through voluntary certification standards that encourage the best available practices in forestry and actively develop new areas such as anti-corruption policy, gender equality and ecosystem services. In this regard, comprehensive approaches to certification are changing and necessitate more open data on forest management to cover, which will reveal existing and potential conflicts.

The study that was conducted during 2021-2023 provides insights on how different categories of open data and targeted stakeholder engagement can be applied for a third-party evaluation of an organization's compliance with FSC standards. In addition, the results of the study identify the potential use of this data in the organization's self-assessment and due diligence procedures.

The developed tool is in alignment with the risk management system in accordance with ISO 31000:2018 and ISO 9001:2015. At the same time, this tool enhances the ability to identify risks at different management levels, analyze and evaluate them, and determine mitigation measures. In this case, the developed risk matrix is based on the most relevant issues (for example, commercialization of thinning and sanitary felling) of forest management identified by experts. The matrix includes risk factors, risk designation (low or specified risks), links to the FSC National Forest Stewardship Standard requirement, data sources and relevant comments. The specified risk leads to applying risk-adjusted audits by certification bodies, in particular, by engaging an expert, using remote sensing methods and technologies, increasing the sample for field visits to forest areas and the frequency of assessments.

The application of the proposed tool is based on consolidating various datasets - public summaries of FSC forest management reports, media analyses, and forest management data - to enhance the flow of information within forest management units. In 2022-2023, some of certification bodies operating in Ukraine tested proposed matrix and recommendations. It helped them identify critical assessment points in forest management, optimize evaluation procedures, and promote adaptation to modern challenges, aiding forest conflict prevention.

The study demonstrates that a risk-based approach can be applied to evaluating sustainable forest management under diverse socio-ecological expectations and unpredicted challenges.

Changes of Protected Areas Policies in China

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Protected areas policies in China has been changing for nearly 70 years and becoming increasingly complicated. A policy system led by the Regulations on Nature Reserves and complemented by other laws, regulations, outline plans has been established. After the State Council's institutional reform in 2018, the State Forestry and Grassland Administration is responsible for supervising and managing all types of protected areas, partly solving the overlapping management issue. However, during the policy implementation, there are still issues such as the unbalanced powers and responsibilities assignment, insufficient human capacity, and the lack of inspection. By using historical institutionalism, this paper examines the structure and historical changes of protected areas policies in China. It is found that: economic, ecological and international impacts have influenced the protected areas policies; policy changes could be found in policy issuing subjects, policy implementing subjects and policy objectives; the Central Environmental Protection Inspectorate is a key approach to promote the implementation of protected areas policy. This paper suggests to promote the revision of the Regulations on Nature Reserves and the enactment of the Law on Protected Areas, with a comprehensive consideration of economic, ecological and international factors. It is also necessary to enhance the capacity of management agencies to manage various protected areas by staff training and technology investment, so as to promote the change of policy implementation subjects; improve legislation related to environmental protection inspection, so that the inspection mechanism can be standardized and normalized.

Climate change induced risks for forestry and forest owners' willingness to join the voluntary carbon schemes

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Forest carbon sinks can play an important role in mitigating climate change globally. The voluntary carbon schemes are a promising policy tool for incentivizing forest owners for increasing the carbon sinks. The success of the voluntary scheme is, however, dependent on the forest owners' willingness to join the scheme. According to the earlier studies, forest owners are interested in increasing the carbon sink in their forest for monetary compensation, but long contract periods or other limiting contract features may reduce the interest substantially.

The attractiveness of carbon scheme depends on forest owner's monetary and nonmonetary preferences, but also on her/his risk attitude. While the scheme may increase the earnings from forestry, the changes in management may increase the risk of natural disturbances like wind damages and insect outbreaks. Since the increase in expected earnings is associated with increased risks, the forest owners' risk attitudes can influence the willingness to join the scheme.

In this study we examine the impact of the forest owners' risk attitudes and their other characteristics on their willingness to join the voluntary carbon schemes. We compare the impact of these factors on two different types of the compensation schemes: in the first one the forest owners are compensated for lengthening the rotation period and, in the second one the compensations are based on the amount of carbon sequestered into the forest. In the first compensation scheme, the forest owners know the amount of compensation they get for certain measures. In the latter scheme, forest owners can choose the measures to increase the amount of carbon in their forest, but the future compensation is not known for sure.

The survey data will be collected in June 2023. The electronic survey questionnaire will be sent to 10 000 forest owners randomly sampled from the Finnish Forest Centre's database. In the survey, we use both contingent valuation and choice experiment methods to evaluate the forest owners' willingness to accept compensation for the carbon scheme. The results of the survey will be presented in the conference.

Community Perception Towards the Major Drivers for Deforestation and Land Degradation of the Afro-alpine Ecosystem

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: The Choke Mountains have several endangered and endemic wildlife species and provide important ecosystem services. Despite their environmental importance, the Choke Mountains are found in dangerous conditions. This raised the need for an evaluation of the community's perception of deforestation and its major drivers and suggested possible solutions in the Choke Mountains of northwestern Ethiopia. For this purpose, household surveys, key informant interviews, and focus group discussions were used. A total sample of 102 informants was used for this survey. A purposive sampling technique was applied to select the participants for in-depth interviews and focus group discussions. Both qualitative and quantitative data analyses were used. Computation of descriptive statistics such as mean, percentages, frequency, tables, figures, and graphs was applied to organize, analyze and interpret the study. This study assessed smallholder agricultural land expansion, Fuel wood collection, population growth; encroachment, free grazing, high demand of construction wood, unplanned resettlement, unemployment, border conflict, lack of a strong forest protecting system, and drought were the serious causes of forest depletion reported by local communities. Loss of land productivity, Soil erosion, soil fertility decline, increasing wind velocity, rising temperature, and frequency of drought was the most perceived impacts of deforestation. Most of the farmers have a holistic understanding of forest cover change. Strengthening forest protection, improving soil and water conservation, enrichment planting, awareness creation, payment for ecosystem services, and zero grazing campaigns were mentioned as possible solutions to the current state of deforestation. Applications of Intervention measures, such as animal fattening, beekeeping, and fruit production can contribute to decreasing the deforestation causes and improve communities' livelihood. In addition, concerted efforts of conservation will ensure that the forests' ecosystems contribute to increased ecosystem services. The major drivers of deforestation should be addressed with government intervention to change dependency on forest resources, income sources of the people, and institutional set-up of the forestry sector. Overall, further reduction in anthropogenic pressure is urgent and crucial for the recovery of the afro-alpine vegetation and the interrelated endangered wildlife in the Choke Mountains.

Coping with disturbance impacts in European forests: implications for forest multifunctionality and adaptive strategies

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Forest disturbances are becoming a main driver of forest dynamics in Europe and further interactions with climate change are expected to intensify disturbance activity in the future. This will require forest managers to anticipate disturbance and climate change impacts and act to promote forest resilience and the maintenance of ecosystem services in the region. Still, uncertainties remain on the impacts and vulnerability of European forests towards multiple disturbance agents under changing climatic conditions. Here we address this issue and evaluate the implications of climate change to forest growth in European forests, considering the influence of future windstorm and insect outbreak events on forest dynamics and ecosystem services. To this end, we apply an enhanced version of the process-based model 3PGmix, coupled with windstorm and bark beetle disturbance modules, under multiple climate change scenarios. We assess disturbance and climate impacts on the provision of multiple ecosystem services, including wood production, carbon sequestration and biodiversity. Furthermore, we evaluate different management strategies to mitigate negative impacts of disturbance events, including changes in species and harvesting intensity. Our results show that climate change will have profound impacts on future forest dynamics in European forests. The direction of changes in forest productivity is context dependent, with majorly positive influence of climate on forest productivity in the boreal zone, while more negative impacts are expected in Mediterranean forests and in Eastern Europe. Furthermore, disturbances are expected to increase forest damage in the future, reaching close to 80 million m^3 per year by the end of the century. Forest management, however, can be leveraged to mitigate climate change and disturbance impacts, while considering the increasing focus and contribution of European forests to climate and biodiversity protection goals.

Determinants of Forestry Insurance Adoption among Private Forest Owners: A Choice Experiment Approach

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Forestry insurance adoption by private owners is crucial for mitigating the financial risks associated with climate change and other hazards. Climate change is expected to have significant impacts on forests, including more frequent and severe natural disasters such as wildfires, storms, and pest outbreaks. However, the adoption of forestry insurance by private owners can be low in some European countries due to factors such as perceived cost, lack of knowledge, and low perceived risk.

Within the framework of the European project *Eco2adapt*, this study uses a choice experiment methodology to understand the preferences of forest owners and investigate the decision-making factors that influence the adoption of forestry insurance coverage in the context of climate change. A survey was conducted with private forest owners in European countries, where participants were presented with hypothetical insurance scenarios. The results show that the factors that most influence private owners' adoption of forestry insurance are perceived risk, insurance coverage, and cost, as well as the potential impact of climate change on forest risks. The results also suggest that private owners are willing to pay a premium for comprehensive insurance coverage. These findings can inform the development of forestry insurance policies and marketing strategies that are better tailored to the needs and preferences of private forest owners and can help to promote more sustainable and resilient forest management practices in the face of climate change.

Economic consequences for Norway Spruce of storm damage in German forests under climate change

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Wind storms pose a significant threat to European forests and may increase in frequency under climate change (Mölter et al. 2016).

We investigate the future storm damage risk under changing climate in the forests within Germany, simulating their future development over 30 years with the forest growth model 3-PG Mix (Forrester & Tang, 2016) and comparing their potential storm damage risk using two storm damage risk prediction models, Forest Gales (Gardiner et al. 2000) and Lothar (Schmidt et al. 2010). Forest Gales is a mechanistic damage model, while Lothar is a statistical model, calibrated from storm-damaged forests after the Lothar storm in 1999. The simulations were run using RCP 8.5 climate data. Four management strategies were simulated: a "Business as usual" thinning regime and intense, light and no thinning interventions. The simulations were initialised from national forest inventory data. An economic analysis of the 30 years of forest growth was undertaken, where the net present value, value at risk (VaR) and conditional value at risk (CVaR) were calculated.
Using Lothar, storm risk probability closely mirrored the past damage distribution of the historical Lothar storm in Baden Württemberg, where the most severe risk is predicted in the westerly region of the state. In contrast, Forest Gales showed less localised damage and was more spread across the entire region. Differences in the damage predictions are attributed to the differences in the risk calculation. While both models consider current stand parameters (height and diameter), the statistical nature of the Lothar model means there is more weighting of the probability on previously damage areas and topographic exposure. In Forest Gales, however, damage probability is more related to stand attributes and wind climate.

In all cases, considering changed climate, an intensive thinning strategy was found to provide the most favourable results in the worst case, i.e. the VaR and CVaR was the highest under this strategy. This applied when wind storm damage was and was not considered.

Therefore, under the growth conditions posed by extreme climate change, in addition to predicted storm damage risk, extreme losses could be mitigated by a more intensive thinning strategy.

Faustmann Model Expansion under Policy Uncertainty

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Faustmann Model Expansion under Policy Uncertainty
Forestry policies have certain uncertainties which bring adverse expectations to farmers' harvesting. The Faustmann model focuses on the optimal rotation period for forest management, whereas the Faustmann model on uncertainty focuses on the exploration of market uncertainty, and policy uncertainty is less studied. We develop a new index of forest policy uncertainty (FPU) based on three certain newspapers and policies released on forestry department websites. We rely on natural language processing tools to help select policy-relevant terms. The obtained contents were classified according to three key phrases: uncertainty U, forestry F, and policy P using natural language processing tools, and the resulting forestry policy uncertainty index was used to extend the Faustmann model under policy uncertainty.

Keywords： Faustmann；Forestry policies; Uncertainty; Foresty Policy Uncertainty index; Natural language processing

Forest adaptation strategies to climate change under socio-, economic and ecological uncertainties - a case study from Serbia

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: In the German-Serbian bilateral research cooperation project ANKLIWA-DS, we showcase how we tackle to overcome major “science gaps” to develop and implement adaptation strategies to climate change focusing on beech and oak forest management. Deviating from business-as-usual forest management requires extensive knowledge and scientific data on several levels regarding species suitability, profitability and social demands etc. A combination of site mapping, dendrochronological field measurements, inventory data and the calibration of forest growth simulators is leading to maps of productivity and dynamic tree species distribution. Risk and uncertainties in productivity, tree species suitability and distribution are analysed applying scenarios of climate change. Economic evaluation and optimization of simulation outputs is conducted. Intensive communication with stakeholder accompanies the project aiming at a better understanding on demands, needs and possibilities on both sides. Policy instruments are developed for the governance and implementation of smart climate change strategies in Serbia based on multi-level stakeholder analyses, expert interviews and surveys ("Climate Smart Forestry"). After a thorough risk evaluation, developed action alternatives combined with adequate policy programs are assessed that not only provide ecologically feasible and economically efficient but also socially acceptable and thus “robust” adaptation strategies under climate change.

Harmonizing the Ecosystem Symphony: Exploring the role of vital Actors in Payment for Ecosystem Services and Navigating the Challenges Ahead

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Payment for Ecosystem Services (PES) has been identified as an important mechanism to close the gap between the demands of society and the service providers. PES is where buyers are beneficiaries paying for ecosystem services, sellers are land and resource managers ensuring service supply and intermediaries facilitate scheme implementation.

Despite the extensive implementation of PES cases worldwide, there remains a need for a more comprehensive understanding among
policy and decision-makers regarding the optimal design features of future PES initiatives that are more likely to achieve
successful outcomes. This study aims to provide a systematic understanding of the roles of different actors in the PES scheme, identifying the most enabling actors for a sustainable program, and examining the critical challenges encountered throughout the program process.

As a primary data source for this research, a database of 145 implemented cases from 46 different countries was compiled based on
2 sources of databases from the NOBEL and SINCERE projects and reviewing the lessons learned. The information was synthesized
according to specific case study actors' groups such as type of intermediary, buyer, and sellers. In-depth interviews were
conducted with selected cases, to derive a detailed picture of the project´s challenges and underlying motives.

The study highlights the significant impact of actors and their different roles in the PES schemes. Trusted intermediaries in 90
percent of the cases, mostly NGOs, actively participated throughout the project. Government and Business companies are involved in
40 percent of reviewed PES cases involving as buyers. Local communities and landowners emerged as the primary providers in 50
percent of the identified PES schemes. The main barriers identified are the lack of market information, participation avoidance, and mistrust.

In conclusion, enhancing the capacity of locally based intermediaries holds great promise in addressing the issue of mistrust
among rural communities. It can play a vital role in increasing program awareness. Moreover,

strengthening these networks is
essential for fostering alternative livelihoods that encourage greater participation. However, by collaborating with government
entities, the potential for success in PES initiatives can be significantly enhanced, paving the way for sustainable environmental conservation and community development.

How can ambiguity influence the optimal management of a forest? An approach with Multi-Model Markov Decision Processes

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: In a context of climate change, it becomes difficult for private forest owners to optimize their decisions for the management of their forest. Indeed, climate change is not predictable in a perfect way, and the risks of fire threats on forests, strongly linked to climate change, will also evolve. Forest owners must therefore act in a situation of ambiguity. In addition, private forest owners are very heterogeneous in terms of objectives, attitudes and behaviors in their forest management, but also in terms of perception and defiance to ambiguity. It is therefore essential, in any given framework, to take this heterogeneity into consideration. Providing recommendations to private forest owners that take into account their preferences regarding ambiguity is a fundamental societal challenge in the face of climate change. This study aims to provide some answers in this context of ambiguity in order to optimize forest owners' decisions and find optimal policies. We define a maximization approach to obtain optimal forest management policies considering ambiguity and ambiguity aversion in order to explicitly consider climate change and the various possible fire risks. We adopt an infinite-horizon stationary Multi-Model Markov Decision Processes (MMDP) framework to model this problem. The main contribution of this work is to design a MMDP model to evaluate forest management policies in an ambiguous context due to climate change, and to generate the forest management policies evaluated under several parameters of forest owner's ambiguity preferences, according to two decision criteria, the α-MEU model or the smooth ambiguity model.This enables the forest owners to develop insights into the economic forest management under climate change. The MMDP framework is applied to a non-industrial private forest owner located in southwestern France facing a fire risk. Ambiguity and ambiguity aversion amplifie the effects of risk aversion and further reduces the optimal cutting age.

How prevention, supression and restoration actions my help to design resistant and resilient forested landscapes? The Portuguese Living Lab example

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Managing forests has been demonstrated to be an efficient strategy for fragmenting fuels and reducing fire spread rates, severity, and extreme wildfire events (EWE). Landscape managers and policymakers are facing a significant challenge in shifting the paradigm to integrate prevention, suppression, and restoration activities into fire and forest management. The FIRE-RES project proposes to implement innovation actions:1) demonstrate the use of tools (e.g. fire behavior simulators) and techniques (e.g. optimization approaches) in order to obtain optimal landscape configuration and fire management policies to minimize expected losses from EWE. 2) Designing strategic networks of managed areas to improve suppression efforts thru the implementation of a multi-criteria decision analysis and mathematical optimization, to define how to allocate fuel breaks to mitigate the impact of large fires and facilitate suppression efforts. And 3) Designing post-fire restoration strategies, also implementing a spatial multi-criteria decision analysis system to define which areas within a large fire perimeter should be prioritized for restoration actions. The innovation actions will be implemented in Living Labs such as Greece, Catalonia, Chile, and Portugal. We will present some results from the implementation of this LL Portugal in the case study area, Vale do Sousa, Northwest Portugal.

How socio-demographic factors affect perceptions of the relevance of forest ecosystem services?

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: This paper assesses the priority of forest ecosystem services (FES) and defines a socio-demographic profile of people who consider particular services an essential function of forests. The research material consists of the results of a questionnaire survey conducted on 1402 citizens in Poland. Twelve different types of FSE were valued, to which respondents assigned a relative priority (Ps) on a five-point Likert scale. The significance of differences in the importance of individual FES was tested using analysis of variance, while a logistic regression model was used to profile visitors in terms of differences in perception of the particular ecosystem service. Regulatory functions were considered the most important (Ps 3.35-3.63), followed by cultural functions (3.09 - 3.23) and least important provision functions (1.72-2.97). The trend in societal demand towards FES during the last decade was upward. The most significant increase occurred concerning regulatory functions, the smallest in the case of provisions, except for the provision of animal products in relation to which demand decreased. Regulating functions are seen as very important by people with higher education, satisfied with financial status, and women. Cultural functions are most valued by those satisfied with their material status and older people over 40. Provision functions are perceived as very important primarily by rural residents, often with low material status, with the provision of animal products being more appreciated by men and the supply of mushrooms and berries by women. Identifying the links between the condition of forest ecosystems and socially useful functions plays an important role in the planning process for sustainable forest development and ecosystem services. Our results allow us to understand public expectations for forests and better manage public forests

Index insurance for coping with drought-induced risk of production losses in French forests

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Drought-induced risk of forest dieback is increasing due to climate change. Insurance can be a good option to compensate potential financial losses associated with forest production losses. On the one hand, forest insurance markets focus only for storm and/or fire risks. On the other hand, literature on index insurance against drought focused on the agricultural sector in developing countries. In this context, we developed an ex ante index-based insurance model to cope with drought-induced risk of forest dieback. We applied this model to beech and oak forests in France. We defined and then compared different indices from simple ones relying on rainfall indices to more complex ones relying on the functional modelling of forest sensitivity to water stress. After the calibration of the contract parameters, an insurance scheme was optimized and tested. We showed that optimal insurance contracts generate low gain of certain equivalent income, high compensation, and a high basis risk. The best contract was not proportional to the complexity of the index. There was no clear advantage to differentiate contracts based on species. Results highlighting the various perspectives of this first approach are discussed: in particular, contracts and indices are tested by simulating them for two climate change scenarios (RCP 4.5 and RCP 8.5) using three global climate forecasting models, in order to adapt insurance contracts to the context of increasing risk related to climate change.

Integrating wind disturbances into Forest planning: A stochastic programming approach

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Forest disturbances challenge our ability to carefully plan for sustainable use of forest resources. As forest disturbances are stochastic, we cannot plan for the disturbance at any specific time or location, but we can plan for the possibility of a disturbance. Thus, mitigating disturbance impacts requires the incorporation of the potential range of disturbance intensity and frequency when examining alternative plans for the forest.

This study uses stochastic programming to integrate wind intensity and wind event frequency into the forest planning process. A small coastal Finnish forest landscape of 286 ha was used to demonstrate the potential of the approach. We use the mechanistic HWind model to quantify the critical wind speed for tree felling and a Monte Carlo framework to develop wind intensity and frequency scenarios. A stochastic programming model was applied to maximizing the expected forest net present value or minimizing expected conditional value at risk to meet predefined harvest targets. To evaluate the impact of improperly identifying wind intensity and frequency, we compare the outcomes of planning for the assumed correct vs incorrect wind assumptions.

The results of this study highlight the importance integrating wind disturbances into planning for specific management objectives. When maximizing the net present value, the impacts of misidentifying wind intensity and frequency have a minor impact on the expected net present value. This is likely caused by harvesting trees rather quickly. Alternatively, when minimizing the expected conditional value at risk, incorrectly identifying wind intensity and frequency severely impacts on the ability to meet the required harvest targets and reduces the expected net present value.

Incorporating wind disturbances into the planning process is possible and can provide useful guidance on how forest managers can effectively manage the risk preferences of a specific forest owner. However, the utility of incorporating wind disturbances into the planning process depends on the specific planning problem.

Living with the "riparian forest engineers": social perception and management alternatives for Eurasian beavers in Central Italy

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Conflict between released Eurasian beavers *Castor fiber* and human activity may arise following forest ecosystem modifications. In our project, we aimed at assessing the social perception towards the presence of the Eurasian beaver in Central Italy through direct questionnaires for the local human population. Moreover, we identified the areas where beaver populations are most likely to arrive in the next future in Italy. We surveyed the human population through standard methods commonly used in social science. Our questionnaire was planned to measure whether and how citizens, fishermen, and farmers perceive the presence of the beaver was administered to 1114 respondents. All surveyed people have been and will be over 18 years old and able to fill the questionnaire autonomously, and they should agree to participate in this research. All on-site questionnaires were implemented on paper, were anonymous, and conducted through autocompletion to avoid potential influences by operators. To monitor potential range expansion, we developed spatially-cross-validated species distribution models to identify the areas with the highest suitability for the model species. Then, we used connectivity modeling to assess the possible expansion routes in Italy.

We recorded a comprehensive awareness of the presence of the beaver in the study area (92.3%) and a general high knowledge of issues related to the presence of the beaver (i.e., potential effects on forests). The majority of the population was in favor of reintroducing beavers, and only 1.2% was firmly against it. The majority of interviewed people was against the removal of beavers from Italy, whereas only 3.7% was in favor, as fearing impacts on riparian forests.

We found wide areas with high environmental suitability in central Italy and in foothill areas of northern Italy. The connectivity model showed a high potential for expansion from records of central Italy to surrounding areas, while records of northern Italy seem to be more isolated. Our results can help environmental managers to understand where to focus both future monitoring of beaver populations and actions to prevent and mitigate possible human-wildlife conflicts, which could arise from the expansion of an environmental engineer such as the Eurasian beaver.

multi-level remote sensing and Forest Insurance in Japan

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Forest owners and managers face various risks associated with meteorological phenomena such as strong winds, heavy rain and snowfall, drought, freezing, and flooding. Forest insurance is one of the ways to hedge against such risks. When a disaster strikes forests, the extent and severity of the damage must be assessed before insurance payments can be made. Multi-level remote sensing supports rapid, safe, and accurate surveys. Satellite remote sensing is useful to assess extensive forest damage. UAS remote sensing is suitable for precise surveys of forest damage. We will explain the advantages and disadvantages of platforms and sensors, and the combined use of diverse remote sensing through the case studies to assess catastrophic forest disturbance caused by typhoons.
In Japan, forest insurance is provided according to the Forest Insurance Law, which has existed for more than 80 years. Since 2019, the forest insurance center, which is responsible for forest insurance in Japan, has been using remote sensing technology to assess damages for insurance payments. Accurate disturbance data derived from remote sensing will assist in a comprehensive understanding of forest risk. In the context of the current state of forest insurance, we will discuss risk communication and its challenges in the forest sector in the changing world.

Multi-objective forest management – an ecological-economic optimization approach

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: How to meet economic objectives of timber harvesting while maintaining the functioning of diverse forest ecosystems? Answering this question requires ecological-economic models that can be easily applied and generalized for uneven-aged mixed-species forests. Here, we develop a dynamic ecological-economic optimization model, which integrates a state-of-the-art demographic forest model with a continuous cover forestry harvesting model to optimize efficient and sustainable timber harvesting. As a proof-of-concept, we apply the model to a beech-dominated forest in the Hainich, Germany, with the goal of optimizing multiple objectives such as timber yield and the biodiversity value of the forest. The ecological module is the Perfect Plasticity Approximation (PPA) demographic forest model that simulates forest dynamics based on individual tree growth and survival rates in the understory layer and the canopy layer, respectively, as well as recruitment rates. We used repeated forest inventory data from a 28-ha permanent forest plot to quantify these demographic rates and validated the predictions of the ecological module against the structure of old-growth beech forests in Europe. The economic module includes constant marginal harvesting costs and timber prices to maximize the net present value of timber profits, and can be constrained by the number of retained habitat trees (>70 cm diameter) as an indicator for the biodiversity value of the forest. The forest model delivered good predictions of the size distribution, basal area, and maximum diameter of old-growth beech forests. When only timber yield was maximized, trees were harvested when they reached 65 cm in diameter. This is similar to current management practices in beech forests. There is a trade-off between maximizing timber harvest and biodiversity value. Initially, with a small number of retained habitat trees, timber harvest decreased modestly, yet as the number of habitat trees increased, timber harvest decreased sharply. We established a generic ecological-economic modeling framework that reliably represents forest dynamics as well as optimal forest management. The framework can be extended to mixed-species forests and support forest management for diverse ecosystem services.

People and forests in local Cambodian communities: perspectives from community-based forest management

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: The important role of local communities in sustainable forest management has been increasingly acknowledged since the 1980s, as many studies indicated that community-based approach would promote self-organized governance in which the rules are devised and modified by the resource users and mutual monitoring is enforced (Ostrom, 1990; Agrawal and Ostrom, 2001; Pretty and Ward, 2001; Agrawal, 2003). This study seeks to identify challenges and opportunities of community-based forest management (CBFM) by focusing Cambodia, where 1) forest resources are critical assets for local people, owing to the fact that nearly 76% of people still rely on fuel wood and 8% rely on charcoal for daily cooking (National Institute of Statistics, 2014); and 2) forests were historically inhabited by small groups of hunters and gatherers as well as isolated farming communities (Poffenberger, 2013), and this type of livelihood is still predominant. In this studay, a case study method is applied with literature review and field research including participant observation, interviews with key stakeholders, and questionnaire survey for local communities. Results from two different cases in Chambok and in Kampot showed that environmental education effects to the local communities, and that promotion of self-organized governance, mutual monitoring and benefit sharing system by CBFM. It is also indicated that motivations for forest management are derived from local people's perception from real experiences such as increase of fish caught by mangrove reforestation. Although substantial positive aspects for local community were found in this study, large and small challenges were also identified as: massive logging concessions by industries are on-going, tourism development is threathning CBFM site, and illegal loggers breaking into community's protected forests even from neighboring villages or countries have been witnessed (Poffenberger 2013). Despite efforts in CBFM, these external and considerable factors are endangering the welfare of forest resources and local communities. Further research for addressing these external factors is also needed to contribute to real sustainable CBFM schemes.

Robust management strategies promoting ecological resilience and economic efficiency in a temperate forest under the risk of severe drought

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Robust decision-making in forestry seeks solutions that reduce the risk of environmental damage and economic losses, which matters for designing forest adaptation measures. Droughts have had severe consequences in temperate forests, such as reduced resilience, which forest owners do not notice for some time, exacerbating stress-related mortality. Moreover, adapting forests to the effects of dry conditions is an option that owners and managers had explored to deal with increasingly frequent drought events. Nevertheless, effective adaptation to expected droughts depends on e.g., the ability of managers to understand how dry conditions affect forest development, the costs of adaptive measures to regulate the affectation, and the attitudes of foresters toward the risk of the decision to adapt. In that sense, the use of process-based modeling approaches provides an evident solution to cost-efficiently support adaptive forest management, facilitating the consolidation of knowledge from the processes behind forest adaptation. In this research, we propose a novel methodology to identify robust drought adaptive strategies aimed to find suitable solutions that would continuously perform satisfactorily over a wide range of plausible scenarios. First, we used a process based-model with an ensemble of climate change scenarios to simulate managed forest dynamics. Second, we quantified the ecological resilience and financial return as net present value (NPV), applying business-as-usual (BAU) and alternative adaptation strategies to regenerate the overstorey layer (trees ≥ 30 cm dbh) of the forest (e.g., “active”, “reactive”, and “do-nothing”). Afterward, we analyzed robustness by searching for the strategy with minimum worst-case losses of ecological and economic signposts. Our analysis found a reduced forest drought resilience under BAU and “do-nothing” strategies, determining a high probability of economic failure (~ -49% and ~ -67% loss in NPV respectively). While, an early “active” strategy would increase the NPV (~ +10%), and a highly-intense “reactive” strategy would have minimal losses (~ -2%). Finally, we found that local conditions influence the signpost performance magnitude but do not vary the robust solution. We conclude that our methodology facilitates applying a robustness analysis in forestry, and drought adaptation should occur rather sooner than later, considering constant revision.

Social Concerns and Opportunities for Intensively Managed Tree Plantations: Learnings from The Forests Dialogue

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Over the past 23 years, The Forests Dialogue (TFD) has convened and facilitated numerous multi-stakeholder dialogues to explore best practices and challenges as well as the complex social landscape surrounding planted forests. Via the "Tree Plantations in the Landscape" (TPL) Initiative, TFD has most recently convened 1 scoping and 3 field dialogues, specifically in South Africa, Chile, New Zealand, and Brazil. In June 2023, TFD held its 5th TPL dialogue in Indonesia. The current TPL Initiative builds on extensive previous work under TFD's Initiative on "Intensively Managed Planted Forests" (IMPF) which took place between 2005-2008.

Social issues in particular have regularly risen to the top of participants' priorities to be addressed in dialogues. In response, TPL dialogues have explored socially related issues such as 1) approaches to enable good governance and inclusive development, 2) land tenure and community rights and 3) learnings from indigenous techniques and strategies. Dialogues have also covered other topics such as 1) the design and implementation of planted forests in the context of jurisdictional and landscape approaches, and 2) the diversification of the forms and species composition of planted forests among other issues. Learnings from each of the dialogues have been varied depending on geography and context but have coalesced around:

1. the importance of recognizing local communities' land and access rights,
2. the relevance of indigenous techniques and strategies,
3. successful local engagement processes and grievance mechanisms related to tree plantations,
4. sustainable intensification techniques,
5. nature-based solutions.

At the IUFRO Congress, TFD can offer either an individual speaker presentation or a panel event to discuss the knowledge gained through both the TPL and IMPF Initiatives, specifically drawing upon the latest learnings from the June 2023 dialogue in Indonesia. If a panel event is preferred, panelists will be drawn from dialogue organizers and participants to form a balanced group that encompasses a wide range of perspectives on critical social concerns related to planted forests.

Starting from forest stakeholders' perspectives to prevent non-adaptation: A participatory approach to foster the implementation of adaptive practices

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: The biggest risk brought by climate change may not be the lack of experimental feedback (what could happen? what could we do?) or of risk management policies (what should we do?), but the actual lack of adaptive change in forest management. Therefore, the goal of this study was to identify potential obstacles and levers to forest adaptation by directly addressing socio-economic hurdles and behavioral barriers.

Focusing on non-industrial private forest (NIPF) owners, we led a comparative analysis of two regions in Western Europe and Northern America, dominated by temperate forests. Building upon the "Actors, Resources, Dynamics and Interaction" framework, we conducted participatory, in-person and collective workshops with 46 foresters around a simple question: "how can we help NIPF owners in adapting to climate change?". Step by step, NIPF participants were asked to draw a diagram indicating the most important actors and resources for their adaptation, and how actors and resources interact. This resulted in network representations of participants' perspective on how to implement adaptation to climate change. As NIPF owners' behaviors proceed from complex relationships with other forest stakeholders, we replicated these workshops with forest advisors, public forest managers, elected officials in charge of municipal forests, members of environmental organizations, and representatives of the timber industry. The speeches, interactions, prioritization lists and diagrams allowed for a comparative analysis across categories and regions.

In this session, we will present five highlights of our analysis on non-adaptation and maladaptation risks: (1) the low risk of non-adaptation; (2) the shared understanding of balancing different forest uses and forest ES prioritization (ex: timber production vs. recreative uses); (3) the distribution of adaptive power among foresters (power to change practices by oneself, power over other stakeholders to restrict or foster behavioral changes, and empowerment); (4) the way local and national authorities try to develop adaptation policies accounting for behavioral, social and economic levers; and (5) the potential contribution of participants' differing strategies to the design of more inclusive and effective adaptation policies.

Strengthening Inter-sectoral Convergence in Ecological Mangrove Restoration of Abandoned Brackish-water Fishponds in the Philippines

S4.4 Socio-ecological conflicts in forest management: risks of (not) adapting?

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Abstract: Rehabilitation of abandoned brackish-water ponds in the Philippines is often problematic due to
uncoordinated institutional policies and conflicts in ownership. Ecological Mangrove Restoration (EMR), which puts a premium on restoring natural hydrology to restore abandoned fishponds, has been applied in several countries but is not fully practiced in the Philippines. This study was done to pioneer ecological mangrove restoration in the Philippines, identify gaps in the current institutional arrangement, and recommend the roles of key stakeholders in the implementation of EMR. The selection of abandoned brackish-water fishponds was coordinated with national government agencies such as the Department of Environment and Natural Resources (DENR) and the Bureau of Fisheries and Aquatic Resources (BFAR). Other sectors involved in the implementation of EMR include the Local Government Units, Academe and Research Institutions, People's Organization and local community members. The identification of the lead and cooperating agencies and their roles in each step of the EMR process were determined based on their mandates and technical capacities. Suggested modifications in the EMR process are presented such as sustainability mechanism options and the combination of natural regeneration with active planting for better applicability in the Philippine setting. The results are seen to contribute to policy recommendations to mainstream EMR in mangrove rehabilitation projects and initiatives.

S4.5 Session of Nordic-Baltic Ministers

S5.1 Forest Futures

Potential leakage of biodiversity risks under the EU Biodiversity Strategy 2030

S5.1 Forest Futures

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Abstract: The EU Biodiversity Strategy 2030 (EUBDS) aims to regain biodiversity through enhanced forest conservation and protection in the EU. Existing studies already suggest that this may lead to increased timber harvest in non-EU countries. The effects of such increased harvest and roundwood production on forest biodiversity elsewhere have not yet been evaluated. We aim to identify potential leakage of biodiversity risks as induced by the implementation of EUBDS. We set up a biodiversity indicator framework and quantify vulnerability with country-wise values for 26 biodiversity indicators, mainly from publicly available databases. For risk assessment, we weight single indicator values with country-wise modelled figures on changed timber production under EUBDS implementation. Nearly 80% of the indicators point to higher vulnerability in the affected non-EU countries. Roundwood production would be transferred to countries with, on average, lower governance quality, political awareness, forest coverage and biomass and with less sustainable forest management. These countries still have more natural habitat and intact forest landscapes, but higher risks of species extinction and lower shares of protected areas. Only a few indicators point to lower vulnerability and biodiversity risks outside the EU. We conclude that safeguards are needed to ensure that implementation of EUBDS does not cause harm to ecosystems elsewhere. In this regard, the EU regulation on deforestation free supply chains might have limited effects because it hardly considers the sustainable management of persisting and even expanding forests. But as long as forest management is less sustainable and as long as forest protection status is lower outside EU, sustained roundwood production in the EU is needed to avoid placing more pressure on more vulnerable ecosystems elsewhere. Decreasing species and habitat indicator values nevertheless call for conservation and protection schemes. Effective land use planning is needed to balance conservation schemes with roundwood production.

S5.2 Harnessing Effective Communication: Building a Bolder Narrative for Forestry and Forest Science

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

Application of indigenous knowledge in sustainable utilization and management of mangrove forest in Lamu County

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

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Abstract: Mangroves have played a long and important role in the history of human activity in the East
African coast and in particular Lamu, Kenya. Mangrove forests in Kenya cover about 61,271 ha, with 67% occurring in Lamu County. The various goods and services derived from mangroves support the livelihood of about 80% of Lamu County's mangrove-dependent communities. However, over-exploitation of wood products, high poverty levels, lack of alternative livelihood, minimal community involvement, and poor governance has enhanced the degradation of mangroves hindering sustainable forest management. This has led to a series of presidential bans imposed on the exploitation of mangrove forests. The latest ban in 2018 had adverse effects on the livelihoods of mangrove-dependent communities prompting the government to lift the ban in Lamu, a year later. The community asserted that they have been sustainably utilizing and managing the mangroves for ages applying indigenous technical knowledge and hence shouldn't be denied user rights.

Inadequate information to support the role of indigenous knowledge in sustainable use and management of mangroves to apprise government decision-making informed this study. The overall objective was to document indigenous knowledge-based practices associated with mangrove utilization and management for integration into conventional management strategies for sustainable management of mangrove resources in Lamu County. Household surveys, Key Informant Interviews, and Focus Group Discussions were used to collect data in five sites with high mangrove dependents namely: Ndau, Faza, Pate, Mkunumbi, and Amu. The results indicated that traditional knowledge and associated practices are widely applied in mangroves' utilization, conservation, and management. The community practices selective harvesting of mangroves using non-destructive hand tools. The community also promotes mentorship and knowledge transfer from the elderly to young mangrove cutters for sustainability. Mangrove harvesting is also conducted on a rotational basis guided by monsoon wind patterns. This system allows controlled harvesting, enhancing the growth and recovery of already harvested areas. These traditional knowledge-based practices have contributed to the sustainable utilization and management of mangrove resources in Lamu County. The study recommends the integration of indigenous knowledge-based conservation strategies into conventional mangrove management strategies to enhance conservation interventions.

Bànglày at gàba: The Role of Traditional Shifting Cultivation Practices in Forest Conservation among the Molbog people of Balabac, Palawan

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

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Abstract: Abstract

Shifting cultivation, commonly known as *kaingin* in the Philippines, is a traditional technique that consists of a crop cultivation phase that lasts for a year and involves clearing and burning primary or secondary forest, followed by a fallow phase. For centuries, indigenous communities have relied on this farming practice for subsistence. In the islands of Balabac, Palawan, the Molbog people have managed to continue practicing *Bànglày,* their own traditional swidden farming. With the country's policies prohibiting cutting in natural and residual forests, their freedom to practice their traditions and rituals are under threat. Using ethnographic methods such as in-depth interviews, participant observation, informal focus group discussions, and chaine operatoire with purposive sampling of informants, the researchers document the chain of operations in their practice of *Bànglày,* describe the conflict between this practice and current forestry-related policies, and situate the role of *Bànglày* in forest conservation within their ancestral domain. The findings of this study reveal that the rotation of the clearing, planting and resting period of *Bànglày* play a significant role in conserving their remaining forests. Contrary to the *incipient type* of shifting cultivation practiced by lowlanders and migrants in upland communities, the Molbog people still perform rituals before clearing the forest, a symbol of respect to every organism that will be affected by their activity. In spite of the exemption to the law for indigenous people in light of the Indigenous Peoples' Rights Act of 1997, policy implementers and indigenous leaders should be strategic in demarcating whether the current *Bànglày* practices contribute to the conservation of *gàba,* their forest.

Keywords: Shifting cultivation, traditional, forest conservation, indigenous peoples, indigenous knowledge

Evaluation of university forestry curriculum for job competencies and emerging job opportunities for forestry graduates in Nigeria

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

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Abstract: Current job markets seeks graduates who meet the desired specifications for an advertised role. However, the level to which forestry education imparts the required knowledge and skills to graduates is not well known. The study, therefore, employed an exploratory behavioural interview model to evaluate the post-forestry education of fifteen forestry graduates between 2010 -2016 across eight Nigerian universities. The study aims to determine if the forestry curriculum is sufficient to prepare graduates with skills to meet job requirements. The majority of the interviewed graduates were males, and they completed their bachelor's degrees when they were between the ages of 22 and 28 years. Most of the respondents did not choose to study forestry at the university. Competencies related to the forest field were sufficiently covered in the syllabi. However, forestry graduates in Nigeria did not gain adequate working experience from their academic studies. Consequently, getting a job, especially in forestry, often took longer years. We recommend properly revising the Nigeria forestry curriculum to develop entrepreneurship skills and prepare forestry graduates for broader employment opportunities. The forestry curriculum should also pay more attention to developing students' professional skills to meet emerging job opportunities.

Fungal Pathogens Affecting the Red Pod Terminalia Flowers, Fruits and Seeds in Drylands, Kenya

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

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Abstract: The Red Pod Terminalia (*Terminalia brownii Fresen*) is in the Combretaceae family, it's a multipurpose agroforestry tree species widely grown in Arid and Semi-Arid Lands (ASALs) of East Africa. However, it has been over-utilized and its products such timber, posts, curving wood and seedlings are not available in the required quantities. Poor seed germination is attributed to fungal and insect infestation during flowering and fruit development. The study investigated the effect of fungal pathogens on viability of *T. brownii* seed. This study was carried out in three sites representing distinct ecological regions in agrosilvopastoral systems where *T. brownii* trees are naturally distributed in drylands of Kenya. The study sites were Nduumoni, Kimose and Kendu Bay, in Kitui, Baringo and Homa Bay counties; which are next to existing research experimental plots under the Kenya Forestry Research Institutes (KEFRI). The study investigated incidences of fungal disease infection in flowers, fruits and seed during their growth. Flower buds, flowers, and immature and mature fruits were sampled for culturing from 30 trees selected randomly within 5.0 hectares per site. Samples of 100 flower-buds, flowers, immature and mature fruits and seeds were surface sterilised using 40% hydrogen peroxide for 2 minutes and rinsed with distilled water. These were plated on Malt Extract Agar (MEA) and incubated at 28±2ºC for seven days. Fungal colonies were evaluated and sub-cultured to obtain pure cultures, and pathogens were identified using morphological characteristics and PCR techniques. Statistical analyses were done using the Kruskal-Wallis and Bonferroni multiple comparison tests to determine the differences among the sites. Common fungal pathogens isolated were *Fusarium* spp (42-49%), *Alternaria* spp (29-33%), *Bostryosphaeria* spp (4-12%), *Cladosporium* spp (38%) and *Pestalotia* spp (7%). There were significant differences ($p<0.05$) in fungal infection between flower buds, flowers, immature, mature fruits and extracted seeds but not across sites. Flower buds had minor fungal diseases, thus indicating that infection took place during and after flowering. Fungal pathogens were isolated from flowers, fruits and seed, thus reducing seed viability across study sites and affecting field natural regeneration *T. brownii*. *Terminalia brownii* seed should be dressed with appropriate fungicides to promote their germination.

Manejo forestal comunitario en ecosistemas altoandinos ante el cambio climático: caso de comunidades en la cuenca de Apacheta Ritipata, Ayacucho, Perú

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

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Abstract: In recent years, farming communities around the world are playing an increasingly important role in managing forests, conserving ecosystems and preserving local traditional knowledge. In the Andes, since pre-Columbian times and as a product of community experience, Quechua peasant communities have a particular vision of the world, which is maintained to this day (Murra, 2004). This worldview, shaped by individual and community experience, shapes forest management strategies at the community level, ensuring food security, sustainability of local livelihoods, and resilience to climate change. The presentation seeks to generate knowledge about the way of managing natural resources based on technical and social aspects that the Quechua communities of Chuschi and Canchacancha, settled in the Apacheta-Ritipata and Chikllarazu basins in the Ayacucho Region, have been carrying out. The applied methodology is descriptive, qualitative and participatory. The local NGO CEDAP identifies community agroforestry systems, the use of water, rescue of customs, knowledge, techniques and traditional practices as key to the sustainable management of Andean resources. These practices also condition the organizational structure, power relations and collaboration schemes in the communities. When Peruvian state agencies are unaware or ignorant of such norms and practices, community social practices erode and conflicts arise. Finally, the findings suggest a model of sustainable forest management at the community level and local governance based on case studies of the Chuschi and Canchancha communities by monitoring organizational and cultural aspects in addition to ecological ones in the management of high Andean ecosystems through of sustainable community forest management.

Poor people in the community forestry landscape disproportionately burdened from crop raiding and livestock depredation

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

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Abstract: Community forestry has become a major innovation in forest management in low- and mid-developing countries, aiming at forest conservation and livelihood improvement for forest-dependent people. Forest conditions have improved as a result of community forestry, providing ecosystem services that benefit the whole world, such as carbon sequestration and biodiversity conservation. The improved forest conditions also enhanced the habitat quality for wild animals, which generated negative externalities. Little attention has been paid to the unexpected disproportionate burden put on the poor people by crop raiding and livestock depredation by wild animals coming from these improved habitats as a result of community forestry. This paper presents findings from a study in the Middle Hills of Nepal, where community forestry originated in the country on the impacts of crop raiding and livestock depredation on local people's livelihood. We found that a large proportion of the rural households in the community forest landscape suffered losses from crop raiding and livestock depredation. Moreover, the poor households lost a much larger share of wealth from these negative externalities than the better-off households. No effective mechanism exists for these households to seek compensation to offset the losses despite the valuable global ecosystem services these forests provide.

Social and knowledge diversity in forest education: vital for the world's forests

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

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Abstract: An assessment of forest education was made 2020-2022 for the first time in global scale considering the status of tertiary, vocational, and technical forest education and training. The assessment utilizing online survey had 2741 respondents, of which 38 percent were women and 11 percent identified themselves as racial and/or ethnic minorities. However, it is likely that the digital survey did not reach various relevant groups living without modern communication facilities.

While exceptional institutions existed in many regions, several global level deficits were found. Coverage of *forest services and cultural and social issues* was weak in the curricula of many programmes. Inclusion of traditional and Indigenous knowledge was frequently poor or absent. Gaps were found in enrolment at tertiary education levels with respect to diversity in gender, race/ethnicity, and other societal groups. Based on the assessment one of the main results was that forest education programmes were lacking *knowledge and social diversity*.

Recognition and inclusion of traditional and Indigenous forest-related knowledge were particularly poor or absent as reported by students, recent graduates, teachers, and professionals in most parts of the world. This deficit in *knowledge diversity* is resulting in forest professionals missing invaluable opportunities to learn from a variety of knowledge systems and from the unique capacities of traditional and Indigenous cultures around the world.

The assessment identified gaps in tertiary education enrolment. Many hesitate to enroll in forest education and training programs and experience difficulties in finding decent employment in forest-related fields. Some lack opportunities to access formal education. *Social diversity* shortfalls in programmes are resulting in sectoral underrepresentation and underservice in education, practice, and policy. Examples include under-recognition of forest economic activities that principally involve women, unsafe working environments for women, and lack of representation amongst state officials governing lands used by Indigenous Peoples.

If unaddressed, forest researchers, professionals, and workers will continue to lack distinct knowledge systems and inclusive representation. Improvements in forest-education-related research, monitoring, policy, curriculum, recruitment, and promotion are recommended. Without remedial action to build a representative, skilled and knowledgeable workforce, prospects for forests to meet local, national and global goals are at risk.

The Fire and the Forest other views from Abya Yala

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

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Abstract: Colombia and Peru have approximately half of native forests in the hands of Indigenous Peoples and Local Communities, these lands are important to safeguard biodiversity, for adapting and mitigation face to climate changed and for conservation of local knowledge (Monsalve, 2021)

The disconnection between human being and native forests is growing in our times. It should be noted that the distance between one and the other has not been physical (we have never depended on trees and forests as much as now).The disconnection is emotional and spiritual. We do not see them as the amazing organisms that enable our life on earth. Most people identify forests as an inexhaustible object or resource that provides us with material to satisfy our individual and collective needs. (Jara 2018)

The profound lack of interest that many individuals of our species show towards the extraordinary kingdom of trees has led us to place such complex organisms on the same level as plastic bags: on the shelf of the useful but inert.

Many indigenous communities from Colombia and Peru don’t have separation between ‘forests’ and ‘people’. However, this true is very hard to understand by forest scientists and policy makers. Other example is the concept and management of fire in indigenous communities lands, where fire is a spirit that can help as a tool for clean and build new forest spaces and new human bodies. This article is a reflexive and critical approach to understanding the present state of knowledge, its foundations, conditions, and practices related with fire into a forest indigenous territories in Colombia and Peru.

The knowledge about fire and forest territories under other perspectives, offers a unique opportunity to study and learn about the biophysical and social materialization of complex multidimensional relationships and processes in the identification, recognition and management of fire in forests and indigenous territories.

The perception, knowledge and spiritual management of fire for three ethnic groups in Colombia and Peru can help to understand and support information about ecological, cultural, and social values, traditional knowledge, and rights of Indigenous Peoples and Local Communities (IPLCs) in forest programs.

THE IMPORTANCE OF INDIGENOUS TECHNICAL KNOWLEDGE ON VARIOUS USES OF NATURAL FOREST PRODUCTS; CASE STUDY OF LOIMA HILLS, TURKANA COUNTY

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

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Abstract: Indigenous knowledge is the local knowledge - knowledge that is unique to a given culture or society. It is the basis for local-level decision in agriculture, health care, food preparation, education, natural resource management, and a host of their activities in rural communities. Many forest communities possess considerable knowledge of the natural resources they use. Such knowledge can potentially inform scientific approaches to management, either as a source of baseline data to fill information gaps or to provide alternative management approaches from which scientists and managers might learn. However, little attention has been given to the relevance of such knowledge for resource management. Traditional institutions are generally instrumental in natural resource management and rural development processes at large. A study was conducted in Loima forest in Turkana County to document practices indicating the use of local knowledge on various uses of natural forest products, document the link between traditional custodianship and use of natural products to enhance community livelihoods and to document the socio-economic factors influencing local practices, use of natural products and traditional institutions. The study used household questionnaires and Focus group discussions for data collection and a total of 150 respondents were interviewed for household questionnaires and 13 key informants for the FGDs. Results indicated that there were trees species and other forest products of importance to the community. These species were *Vachellia tortilis* pods used for food and fodder especially during dry seasons, *Salvadora persica* roots, leaves and fruits used as medicine, water coolant and food, *Aloe turkanensis* leaves used as medicine for stomach issues, the gum is used for Malaria treatment, *Cordia sinensis* was used in traditional wedding ceremonies, to make the traditional stool used by the men known as '*Ekicholon'* and *Zizyphus Mauritania* used for food and fodder, the twigs are also used to light fires. The community also has Ekwars which are pieces of land which have specific species protected for grazing during dry seasons and are normally found along the river banks. Data collected indicates that traditional knowledge plays a huge role in conservation and livelihood improvement among communities adjacent to forests.

The role of local institutions in sustainable forest landscape management

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

Agnes Sirima[1]
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Abstract: In recognizing the importance of indigenous groups and local communities in forest management, governments are shifting the forest tenure systems to local and indigenous communities. This relatively new innovative approach serves as an opportunity for sustainable forest initiatives and economic development for some of the marginalized communities. This paper examines the role of local indigenous institutions in the management of Community Forests. Qualitative study was carried out in Tanzania to ascertain the claim. A total of 46 individuals participated, out of these, 17 were females and 29 were males. Review of practical examples else where was drawn to enrich the selected case. Thematic analysis was conducted and several themes were generated during the analysis. Results indicate that Community Forests are managed under a complex set of power structure with several local institutions actively engaged in the management of forest resources. There are internal conflicts among institutions, each questioning the role of the other. However, local institutions still play a strong role in the community conservation efforts by creating awareness and building capacity among members. Local institution also ensure that users are identified and the benefits are shared among the right users. It is therefore important to build capacity of local institutions to enable them to effectively contribute to forest conservation and management.

What Makes Your Forest Unique?

S5.3 How to incorporate indigenous and local knowledge in forest education, back to the roots

Wening Idzatilangi[1]
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Abstract: What Makes Your Forest Unique? is a participative project from forestry students around the world to capture the diversity perception of forest valuation paradigm. It compiles case studies from the field about cultural issues, forest management history, local ecological knowledge, movements, and Free, Prior, and Informed Consent of IPCLs. We see that in regard to forest valuation, monetary mechanisms such as timber or carbon trade can't provide justice solutions to many stakeholders including Indigenous People and Local Communities (IPLCs). Current valuation mechanism suggests an unbalanced sharing benefit and interest between capitalist and the communities (Mathur et al, 2013; Saunders et al, 2002). It is because the communities lack appropriate recognition in regards of land tenurial, human capacities, and financial resources (Robinson et al, 2014). While current forest valuations are the interim and calculable solutions to conserve the forest, it also brings threats of reducing the respect of IPCLs existence even erasing their livelihood (Rights and Resources Initiative, 2009; Renwick et al, 2014). Hence, the connection of IPCLs with the forest or the land over generations creates local important knowledge such as agricultural practice, medicine, and the cycle of climate change (Salim et al, 2023). In the era where the data spread so fast, any kind of effort like research, advocacy, and policy making for encouraging IPCLs to achieve its inclusivity is advanced (Valijärvi and Kahn, 2023). Combining that privilege and providing a platform where young foresters can take part in the effort of preserving the work continuation can be an advance work. The result of this project is aligned with the effort of documenting the local ecological knowledge to make the forest management become more diverse and based on local needs (Rai and Mishra, 2023). It also hoped any cultural issue in the forest can get more attention not only about describing it in textbooks but also to advocate the values and be one of the development intervention plans to revive the IPCLs interventions in decision making activities (Wiersum, 1997).

S5.4 In practice of a gender equal and inclusive forestry sector

A Sector Wide Approach to Shifting the Workplace Culture to be More Welcoming to All People - A Case Study

S5.4 In practice of a gender equal and inclusive forestry sector

Kelly Cooper[1]

[1] Centre for Social Intelligence Inc.

Abstract: Starting in 2018, the Centre for Social Intelligence and the Canadian Institute of Forestry joined forces to lead the development of a sector wide national action plan that aimed to increase the number of women in senior executive roles and in technical positions in Canada's forest sector.

This public-private funded partnership brought together representatives from the public, private, not-for-profit, academia and Indigenous communities to unite their efforts toward this goal and to create a new shared vision for the sector – one where Canada has a diverse and inclusive workforce that provides the foundation for a thriving forest sector and healthy communities. The national action plan was broken down into three main pillars of work:

- Building the evidence base (gathering data on gender and diversity in Canada's forest sector workforce)
- Fostering an inclusive culture (through training materials)
- Repositioning the sector (through communications)

Now in its second phase, and due to the online interest during the pandemic, the focus of engagement has recently shifted from a national to a global audience and is now considered a *movement*. It provides the opportunity to:

- sign on to a "declaration of intent" (i.e. commitment)
- participate in training webinars
- provide practical online training modules and
- communication shareables that everyone can use.

Online training topics include:

1. Explains why forest companies and organizations need to take action on diversity and inclusion
2. How to be an effective ally
3. How to create an inclusive culture
4. How to overcome barriers and resistance to diversity and inclusion

Strength – Unity across the sector with a common message and mandate. Strong leadership.
Weakness – Need greater funding to make a greater impact.
Research – Could develop social indicators to allow organizations to track gender diversity data for labour market needs across the sector.
Next Step – Engage leaders in the forest sector globally. Have people sign up for training modules to allow greater knowledge and understanding on the reason why action should be taken and how to

go about it.

Come and learn how you can join this movement and contribute to making the forest sector a magnet for top talent.

Equal chances in forestry - making forestry more equal and inclusive

S5.4 In practice of a gender equal and inclusive forestry sector

Iza Pigan[1, 2]
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[2] National Forest Holding the State Forests

Abstract: The project founded by EEA and Norway Grants was realized in 2021-2022 by Women in Forest Association (Poland) together with Norway and Iceland partners. Main goal was to improve women's situation in forestry and draw attention to existing inequalities. The addressees were people associated with the forestry industry, in particular female employees and managers in the national Forest Holding the State Forests.
The project has been divided into four complementary areas:
1. Diagnosis and recognition - a research study of equal treatment in Polish forestry was carried out, with particular emphasis on the gender context. Over 4000 surveys were collected, with nearly 3900 completed by employees and close to 200 by HR departments. Respondents worked mainly in the State Forests, few answers came from national parks and forest departments.
2. Anti-discrimination education, addressed mainly to women - conducted as part of four editions of anti-discrimination workshops, attended by 60 women. The participants worked both in the State Forests and in other institutions. Additionally three conferences, dealing with the issue of equality activities in global forestry and in other institutions, in particular uniformed services, also had an educational value
3. International cooperation – study visits of female foresters in Norway and Iceland and revisit of partners in Poland, allowing to share experiences and know-how
4. Solutions: formulated as Good Practices Guideline - a study that is the sum of the experience gained during the project and long term activity including observations during study visits, conferences' discussions, networking and anti-discrimination workshops and recommendations resulting from the research part of the project. It is a short list of indications aimed at improving the situation of forestry workers in the area of equal treatment.
Additional part of the project was also development support for Women in Forest as an organization. It helped to improve strategic management and strengthen international links. Mutual cooperation and project synergy allowed to establish an umbrella organization connecting entities with a similar profile in other countries: Women in Forestry International.

Forstfrauen – an association for Women in Forestry

S5.4 In practice of a gender equal and inclusive forestry sector
Dagmar Karisch-Gierer[1, 2]
Elisabet Johann[1, 2]
[1] Forest Training Center Pichl (Project manager)
[2] Forstfrauen (Chairwoman)

Abstract: In the early 2000s, women in the very traditionally oriented Austrian forestry were very rarely active in the sector, be it as a forest owner or as an employee. Apart from (difficult to prove) professional disadvantages, the unique selling point "woman" and thus a special visibility based solely on gender was also associated. This visibility, which is not self-chosen, is sometimes perceived as a burden. Having a space where women are not "the only one" was the main reason for starting a network for women in forestry. Started in 2001 with 10 women the network soon started growing and in 2003 the association "Forstfrauen" ("Women in Forestry") was founded with 46 members.

Today (May 2023) "Forstfrauen" count approx. 150 members – in a small sector, in a small country. Why is the network successful? The short version: GAIN

- **G**oals: From the beginning, the goal was to network and strengthen women in forestry, i.e. a supportive approach. We wanted to make a difference for women and for forestry as a whole. This positive approach is appreciated both inside and outside.
- **A**ctivities: Networking takes place in a variety of ways – digitally (Newsletter, Website, LinkedIn), in presence, at events or on an individual level.
- **I**ntegration: "Forstfrauen" were increasingly perceived as part of the forest actorship, especially since the 2010s. Today "Forstfrauen" are represented in committees (e.g. PEFC), are partners in projects and are seen actively and specifically as an information hub, e.g. for media inquiries or job advertisements.
- **N**etwork & Members:
    - Since membership is not tied to relevant professional training, the members contribute a wide range of skills in addition to their professional background - from trainers for strategic communication to tax consultants.
    - Numerous members of the first hour have climbed the career ladder, others are at the beginning of their careers. Members in a wide variety of positions can get in touch with each other over short distances
    - Men were always invited to join the network – 6% of the members are men.

The challenge for the future is to keep our finger on the pulse - for people and forests.

Gender dimensions to climate resilience of cocoa farming systems in West Africa

S5.4 In practice of a gender equal and inclusive forestry sector

Elizabeth Asantewaa Obeng[1]
Christophe Kouame[2], **Mavis Akuffobea-Essilfie**[3], Julie Weah[4], Charles King[5], Aguilar Francisco[6]
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[2] World Agroforestry Center
[3] CSIR-Science and Technology Policy Research Institute
[4] Foundation for Good Governance and Democratic Initiatives
[5] Liberian Central Agricultural Research Institute
[6] Swedish University of Agricultural Sciences

Abstract: Through a meta-analysis of the scholarly and development literature we examine how the adoption of agronomic-oriented agroforestry practices, and gender-focus policy interventions can advance the sustainability of cocoa farming systems in West Africa. We explore the capacity of these interventions in advancing Sustainable Development Goals ‘5: Gender Equality’, ‘8: Decent Work and Economic Growth’, and ‘15: Life on Land’ and SDG specific targets. We point to the importance of combining regulatory approaches that can enhance *de jure* conditions (such as laws limiting female land ownership), and engaging in a participatory process to improve norms that might limit full female access to credit (effectively in a *de facto* conditions that discriminate against women). During our review we identified the challenge of gender-aware statistics as well the opportunity of tailoring extension programs that explicitly consider gender issues. We complement this work with the analysis of survey data collected across Cote d’Ivoire, Ghana and Liberia to assess how agroforestry practices can enhance climate resilience by eliciting farmer-level capacity to cope with drought. Results show how gender disparities arise although we point to the challenge of quantitatively determine gender-based causality. Our research highlights the value of qualitative and quantitative assessments in examining opportunities to enhance the climate resiliency of cocoa farming in West Africa through agronomic and gender-centered interventions.

Gender equality in practice and theory

S5.4 In practice of a gender equal and inclusive forestry sector

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[3] Sveriges lantbruksuniversitet, Sweden
[4] Université de Moncton, Canada
[5] University of Saskatchewan, Canada

Abstract: Since the Beijing Declaration in 1995, several international and national initiatives have sought to enhance women's participation in and experiences of working in male dominated sectors such as forestry. However, the framing of these initiatives differs depending on the overarching gender equality policies as well as the specific country or industry context. Typically, we are observing a shift from framing gender equality as a human rights issue to it being seen as a business advantage that enhances productivity and competitiveness. In such a framing, benefits to the workforce, organisations and society are emphasized over the benefits to women themselves, potentially leaving women vulnerable to future changes in economic conditions. Government and organisational policies typically reflect the dominant framing within that jurisdiction, in turn influencing programs and legislative measures that are used (or not used) to promote (or discourage) women's participation in these sectors. Distinct from such framing and policies, an increasing number of women-led networks and grass-roots initiatives are addressing the inequality of women and advocating and supporting the place of women in forestry.

Several theoretical approaches help us to understand the origins of gender inequality, as well as the ways in which it is maintained or challenged, including homosociality and inequality regimes. These concepts help us understand how individuals and complex organizational practices and processes create and maintain inequalities. Using theory to recognize the patterns and processes that apply to an organization allows us to question their legitimacy and supports realigning practices with the changing culture, policies, and norms of society.

The contributors to this panel have been promoting women's participation in forestry in the Global North (Sweden, Austria, USA and Canada) and the Global South (Indonesia). Their experiences with framing, policies, networks, and on-the ground initiatives helps us see how to move gender equality from theory to practice.

Gender justice through climate resilient green initiatives in Nepal

S5.4 In practice of a gender equal and inclusive forestry sector

Srijana Baral
Kanchan Lama[1]
[1] ForestAction Nepal

Abstract: The climate change associated risks and vulnerabilities have gender dimensions that increases inequalities and risks. In the current era, low carbon solutions are devised so as to mitigate climate change however; there is paucity of academic scholarships linking the potential synergies between women's economic empowerment and low-carbon transitions. This research is based on action research project that was designed and implemented to support the women to build social, economic and ecological resilience through forest-based solutions. Taking the case of two women entrepreneur groups- bio cup and plates the study analyses – i) how will the green jobs created enhance women's resilience; ii) how the nature based entrepreneurial solutions lead to ecological resilience, and iii) analyse how adoption of low carbon technology empowers women and gender justice in climate actions. 60 women entrepreneurs involved in were surveyed and four policy dialogues participated by 150 individuals were carried out to assess opportunities and challenges of forest based low carbon enterprises in economically empowering women. The results reveal that the target women groups are land-poor/landless who often get excluded from any land based economic activities consequently lack access to financial institutions. Engaging them in the small scale forest-based enterprises are accepted and welcomed by women for building climate resilience- social, economic, cultural and ecological resilience. It has been creating direct employment from collecting *Shorea robusta* (Sal) leaves, preparing *lapha**[1]*** preparation, operating machine and marketing their products. Use of bio-cups and plates economy is preferred over plastic economy having adverse impact on the women health. Moreover, use of low carbon technology has proven- efficient, reliable, time saving and easy to operate. Though the return from the forest based enterprises is moderate, these actions do not demand for detachment from their families. Hence, the use of low carbon technologies in the small-scale enterprises are economically and culturally appropriate to women groups as they rejoice their care economy while also contributing to the climate justice.[1] Lapha is the set of leaves arranged together to form be pressed to form the plate or bowl.

Joining forces and tackling problems: developing a national forum for gender equality in Swedish forest sector

S5.4 In practice of a gender equal and inclusive forestry sector

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[2] Swedish Forest Agency

Abstract: For more than a decade, gender equality has been of the agenda for the Swedish forest sector. Different types of actions and measures has been implemented on various levels. However, since the national gender equality strategy for the forest sector was launched in 2011, there has been an identified need for a forum for collaboration and coordination to support the work. In the beginning of 2022, as a response to this, the Swedish forest agency (SFA) initiated the Forest Sector´s Gender Equality Council in dialogue with the sector. Later the same year, a national forum was formed, which comprise of about 60 representatives, both gender equality experts and top management, from about 35 forest organizations (companies, forest owners associations, universitates etc.). The work is supported by the secretariat consistent of SFA and the Swedish University of Agricultural Sciences. Its aim is to contribute to the national Sweden's gender equality policy goals with the focus on three areas: education, working life and individual forest ownership. The work with these areas is developed by three working groups consists of 8-10 representatives from the council. The purpose of the council is to jointly develop both individual organizations' and the sector's overall gender equality work by e.g.:

- Identify and address common problems and challenge.
- Initiate strategic, long-term and integrated processes.
- Create a knowledge-based foundation for interventions and follow-up.

Providing a basis for a systemic and collective development of gender equality actions, on both sectorial and organizational level, constitute the main strength of the initiative, while the initiation by governmental agencies contributes to challenges in terms of creating active participation, sense of agency, ownership and responsibility of the council and its work. The high dependence on the participation and commitment of the represented organizations constitutes both a strength and challenges, while future expansions of activities and efforts of the council will require additional funding/resources.

Mainstreaming Gender within the Forest Stewardship Council (FSC) system

S5.4 In practice of a gender equal and inclusive forestry sector

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Abstract: After an extensive two-year process, FSC approved the "FSC Strategic Framework on Diversity and Gender" in 2022. This Framework serves as a roadmap for FSC, enabling it to navigate complexity, maintain focus, and align with ongoing strategic efforts to mainstream diversity and gender (D&G) within FSC by 2026. Four focus areas for activities are laid out: human rights and access to resources, tenure, and use; active participation and decision-making by all stakeholders, including all genders and all levels of seniority; the gender gap; and rights-based climate and biodiversity action.

The Framework recommends striving for the full recognition of the multifunctionality of forests driven by the active and equal participation of all actors, including those in forest education, resulting in gender transformative change. As part of the implementation efforts, a gender action plan will provide more concrete interventions considering different levers and time horizons. An important development will start in 2024 as the revision process for the "FSC Principles & Criteria for Forest Stewardship" (P&C) will commence. These P&C form the foundation of FSC's global forest management certification. Currently, gender issues are addressed through a specific criterion within principle 2, which pertains to the social and economic well-being of workers. Acknowledging that gender mainstreaming requires a broader scope and perspective, the strategic framework calls for the incorporation of gender considerations into the outcome-oriented revision of the P&C, as well as the ongoing processes for revising specific indicators (performance requirements) in national forest stewardship standards.

We will also show how and when gender and diversity specialists and researchers can engage in FSC processes to ensure that gender considerations are effectively integrated in the FSC system and implemented in FSC-certified forest operations.

Situation of Gender Equality in Community Forests of Nepal

S5.4 In practice of a gender equal and inclusive forestry sector

Mathura Khanal[1]

[1] Mahila Hit Samaj, Nepal

Abstract: Abstract

Community Forestry is one of the most popular participatory forest management practices in Nepal started in 1970 after realization of the people's participation in the sustainable development by the government of Nepal. Community forests are national forests handed over to the local user groups for protection, management and utilization according to the Forest Act, 1993. Since 1970, the handover process of the CF have been increasing in the hilly region as well as in Terai. In Nepal, around 34% of the country's National forests as community forests are managed by more than 22,000 community-forest user groups. Although it is said that CF is a participatory process, active participation of different groups of the community is still lacking. In particular, women's involvement in many aspects of CF is still lacking far behind. Many amendments have been made in forestry sector policies and strategies for gender equality and social inclusion but leadership by women and Dalits in CF management become very challenging. Current forest policy has made mandatory to hold one of the major key posts (Chairperson, Secretary and Treasurer) in the CF executive committee. Therefore, main position of CFUC is occupied by female members however; the task has been performed by male members of their family or other male members of the committee. However, female are the main participants in conservation and harvesting of the forest products. Elite domination is still remaining in most of the CF leadership and weak institutional development exist.

Keywords: Community Forestry, Gender equality, Civil society, Conservation, Dalits.

The Brazilian Forest Women Network: promoting gender equity in the forest sector

S5.4 In practice of a gender equal and inclusive forestry sector

Barbara Bomfim
Ana Flavia Neves Mendes Castro[1], Fernanda Rodrigues[1], Giovanna Marcolin[1], Maria Harumi Yoshioka[1], Mariana Schuchovski[1], Nathália Granato[1], Patricia Nazario[1]
[1] Rede Mulher Florestal (Brazilian Forest Women Network)

Abstract: Rede Mulher Florestal (the Brazilian Forest Women Network) is a non-governmental organization created in 2018 with the mission of promoting respect for diversity and equal opportunities for women in the forest sector by discussing gender. The organization currently has over 180 individual members from all five regions of Brazil, as well as from other countries, and 30 legal entity members that represent over 50,000 people employed in the forest sector. The organization's creation was inspired by the question of "Where are the women in the Brazilian Forest Sector?" Based on this questioning, Rede Mulher Florestal organized the Gender Panorama of the Forest Sector in 2019, a pioneering initiative aimed at researching, identifying, and disseminating forest sector data focused on gender. The Gender Panorama had its second edition in 2021, and the third is scheduled for 2023. Companies with expertise in paper and cellulose, log and sawn wood, panels, and laminated floors, among others, participated in the research. In all editions, we found that there was a predominantly male participation in almost all positions surveyed, with emphasis on executive positions, where female participation was 8.1% in 2019 and 15.9% in 2021. On the other hand, organizations have been seeking to implement policies aimed at reducing inequality. In 2019, 45.8% of organizations had a specific policy or declaration committing to non-discrimination and promoting gender equality, and in 2021, this percentage increased to 63.2%. These gender-focused data suggest that achieving gender equity is still a long process, but the creation and ongoing work of the Network are fundamental steps towards progress. Based on the data generated by the Gender Panorama of Rede Mulher Florestal, organizations in the forest sector have an opportunity to improve or expand their policies related to gender equity, enabling a future with more gender equity in the Brazilian forest sector.

The changes of women's role in the succession of private forest ownership in Japan: using life course theory

S5.4 In practice of a gender equal and inclusive forestry sector

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Abstract: In Japan, private forest owners own not only forests but also farmlands, residences, and various other assets, and their presence and actions have influenced each community. The basic premise of this generational succession is the existence of women who have spent much of their lives supporting their families and relatives through marriage, childbirth, and child rearing. However, their behavior, which have been important factors in the social relations in farming and mountain villages and in the inheritance of private forests, have changed dramatically after a certain generation. Particularly since the mid-2010s, there have been cases of men inheriting forests and aging single, single women taking over forests, and children who have moved to the cities selling their forests along with their houses and graves. For Japan's private forests, which are often located in mountainous areas, this situation poses a land conservation problem. This study aims to clarify the role of women in the inheritance of Japan's private forests and its changes, and to develop a vision for the future. Cohorts are identified using life course theory. A "life course matrix" will be created for each person born in each year of the 200-year period from the 1800s, the period of Japan's early forestry, and compared to historical events to construct a basic data set. The following two points will be considered: 1) In the case study, the last generation of direct family members, led by the head of the family and his wife, who worked in the forest, farmland, village events, and community work, was born in the 1920s and 1930s. 2) Their children (born between 1947 and 1949) were the first generation of 'Rinken Forest Group' to organize a women's club and actively lead the group's activities. 3) The combo of these two generations is distinguished by the women (born in 1964 and later) who have worked in civil service forestry since Japan's Equal Employment Opportunity Law (1986), and the members of the "Forestry Women's Association" (born in 1987-90s) in the 2010s. At each of these life stages, relationships with local communities are being renewed and constructed.

S5.5 Integration of gender and diversity perspectives in knowledge production

A critical assessment of recognitional justice in urban forestry knowledge production

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: Globally, cities are looking to their urban forests to improve climate resilience and liveability. Alongside this interest, there is an increasing focus on environmental justice in research and practice, with multiple cities incorporating equity provisions in their greening policies. Approaches typically reflect dominant discourses in urban forestry and environmental justice, namely the ecosystem services framework and distributive justice. And yet, urban forestry is motivated by and enacts diverse epistemologies, particularly at the grassroots scale. Recognition—respect for identities and cultural difference, and the ways in which agents, ideas, and cultures are valued in discourses, practices, and experiences—is a central and necessary component of environmental justice in urban forestry. However, it is understudied in research and poorly understood in practice.

To address this gap, we conducted a critical scoping review across academic literatures related to urban forestry. Our review (i) investigated the diverse ways in which relationships between human and non-human nature are expressed, and (ii) characterized these according to the Life Framework of Values to demonstrate how recognition of different epistemologies and associated environmental values occurs within the literature. Our results showed that most research advanced values related to 'living from' (the environment as a resource) and 'living in' (the environment as a place for recreation and other social activities) life frames, reflecting the dominance of ecosystem-services thinking. Research with a stronger ecological focus also commonly advanced the 'living with' frame (non-human nature as important others who coexist with humans). Less common within the literature was the 'living as' frame (the more-than-human as self, oneness, and kinship), which was most common in literatures from Indigenous and feminist scholarship, civic green space stewardship, and biocultural diversity.

Our findings show that recognitional injustice related to underrepresented epistemologies is commonplace within urban forestry literature. Urban forestry practices informed by existing research risk perpetuating environmental injustice by reproducing dominant discourses and 'only way' approaches. There is a clear need for urban forestry research to expand beyond ecosystem services and distributive justice to incorporate diverse and underrepresented perspectives. Such a move would support urban forestry practice that truly enables environmental justice and supports resilient, liveable cities.

Adaptive Collaborative Management and Gender in Forestry

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: This contribution will focus on a) the importance of incorporating the views, knowledge, and motivation of both community women and men into forestry research planning and conduct; and b) the necessity to implement a longer term approach like Adaptive Collaborative Management in order to do that. Specific emphases will include established (if variable) difficulties working with women, such as their

- lower literacy levels,
- less traditional power and authority,
- fewer available resources (money, land, rights),
- more domestic responsibilities, and
- more norms interfering with communication between women and outsiders,

on the part of women themselves; and avoidance of women by outsiders (related variably to

- fears about other people's suspicions of one's motivations [potentially sexual],
- unfair and unrealistic dismissal of women's relevance, or
- genuine dangers of working with women, in a few contexts).

This discussion will also touch on the importance of noting men's variable ideals about their own masculinity, which can be a potent force interfering with the empowerment of women – and resulting access to women's views, knowledge and motivations (in short, their potential contributions to forestry research and management).

The talk will also briefly introduce current work that builds on research done in the 1970s. This research examines what an American school was teaching children and youth during that era, and suggests the implications of those lessons for present-day adult scientists and policymakers in forestry research.

Anthropogenic climate change around forest ecosystems implications for gender equality

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: The article also discusses the gendered impacts of climate change on forest ecosystems. Climate change exacerbates existing gender inequalities and can increase women's workload and reduce their access to forest resources. The main objective of the study is to critically examine the relationship between gender equality, climate change, and sustainable development. Both secondary and primary data were employed, with a combination of qualitative and quantitative research methods. Household surveys were conducted to gather quantitative data on the impact of climate change, gender equality, and sustainable development in Kenya. The population target was 2,000 people in 47 counties, the respondents were 1, 470, and the period of the study was 2019 to 2022. Projected climate change poses a serious threat to gender equality and sustainable development; it acts as a threat multiplier for instability in some of the most volatile regions in Kenya; projected climate change adds to tensions even in stable regions. Climate change-related shifts in rainfall patterns and increased frequency of droughts have led to resource scarcity and competition, exacerbating existing social and economic vulnerabilities, especially on women Local authorities lack the resources, capacity, and coordination needed to effectively manage the impacts of climate change on gender equality. The study findings reveal that climate changes are led by human actions such as population pressure, political motives influencing occupation of the forest land, growth of subsistence agriculture, logging, charcoal making, and rural-urban development. To address the climate change threat to sustainable development and gender equality in Kenya, gender-sensitive adaptation strategies are needed. International support is critical to addressing the climate change threat to gender equality in Kenya. While dealing with climate change issues, national policies are guided by taking into consideration addressing sustainable growth dimensions as a major threat to forest lands. The study concludes that the areas around the forests are experiencing rapid climate changes, including recurrent and persistent drought periods and rainfall variability. These changes in the local climate pose unprecedented implications for the sustainable development of the country and the region that depends on the forest complex.

Beyond Knowledge and Information: Addressing disjunctures in knowledge production and communication

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: Rights and control over forests are at the centre of conflictual relations all around

the world and have given rise to public debates that focus on biodiversity, sustainability and issues of democracy in relation to development and environmental governance. Political decentralization and the participation of local people in local development and management of resources that was on the agenda in the previous decades has given way to a rhetoric of the importance of new actors especially private interests. The need for knowledge and the free flow of information has been advocated as important to be able to meet the challenges for sustainable environmental management.

However, there are problems with the assumption that this would automatically lead

to better management. In my intervention, I advocate a different perspective and take up

three different and yet interrelated issues. Firstly, there are different kinds of knowledge

usually represented as most important by different groups of people. These are by no means

hermetically sealed but also need to be able to relate to each other for people to be able to

communicate on particular environmental issues. A second related issue is that the same body

of knowledge can look very different from different perspectives: knowledge for what and for

whom? Lastly and importantly, communication and deliberation about environmental

issues is not enough if we come from different structural positions. Using examples from my past research, I discuss how attempts at local management of forests brought up

these three issues poignantly from cases across the world. In part I will discuss how unequal (gender) relations made the idea of dialogue and discursive democracy limiting. Greater expert knowledge or greater information was not helpful for marginalized groups if it there was not at the same time a change in the structural basis of power relations.

Beyond notions of technicality: Forest science is need of plural conceptualizations of knowledges & practices

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: Forest science, in academic spaces, has largely been positioned as a technical science. This framing, while useful to build technical knowledge, also creates a narrow epistemological entry-point to better elucidate the larger social, political, financial, gendered playing field in which forests and people interact. Forest practice, on the other hand, remains plural, and shows a diversity of ways several social actors including women, marginalized groups, development practitioners generate and practice forest knowledge. Yet, these operate in distinct spaces, allowing lesser learning, reflection, and opportunities for integration. Using existing literature, case studies, and ethnographic reflection, I argue the need to connect these two spaces, and offer pathways to do so. These discussions are aimed to generate a better understanding of forest science and knowledge from diverse actors' perspectives and their relational connection to forests.

Changes in cyclist patterns in a State Park: a gender perspective

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: During global health crises like the COVID-19 pandemic, there has been a significant increase in the demand for natural spaces, leading to a growing interest in outdoor recreational activities such as cycling. However, despite this overall increase, gender disparities persist as a significant feature, related to access to protected areas. This study aimed to assess gender inequality in bicycle usage among men and women in the post-pandemic period (2021-2022) in the Juquery State Park, São Paulo, Brazil. Our database was Strava Metro, which compiles data from the sports application Strava, with information collected from January 2018 to December 2022, excluding the months of 2020 and 2021 when the park was closed. The results showed a significant increase, $t(29.47) = -5.63$, $p < 0.00001$, in the average per month in the number of post-pandemic cyclists ($M = 214.60$) compared to the pre-pandemic period of 2018-2019 ($M = 138.65$), as well as a gender disparity. In the pre-pandemic period, male cyclists accounted for over 90% of the total while the female proportion was less than 10%. In the post-pandemic period, the proportion of female cyclists increased, but gender inequality remained noticeable. The proportion of female cyclists reached a maximum of only about 23% of the total individuals. A chi-square test for proportions confirmed a significant change for this data, $X^2(1) = 91.921$, $p < 0.0001$. Conversely, the proportion of male cyclists decreased from 90.98% to 83.97% post-pandemic. Although the post-pandemic dataset showed a general increase in the number of cyclists and, mainly, in the proportion of female participants, the frequency of male and female individuals is far from similar. These findings highlight the persistent gender disparities in access to natural spaces and recreational activities, emphasizing the need for managers to consider the underlying issues behind this inequality and incorporate them into the planning of these areas. One of the hypotheses we will work on is related to the safety of cyclists, if the risks are real, or if they are imposed by gender. Furthermore, understanding the reasons that led to the increase in the number of female cyclists in the protected area studied is an important future development.

Drawing the Line in Gender Blind Land Restoration: Case studies from the Savanna Parklands of Ghana and Burkina Faso.

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: The parklands of northern Ghana and south central Burkina Faso comprise mosaic landscapes of forest and farmland. The tree systems at the interface between these two systems play a critical role in supporting smallholder livelihood systems and providing ecological restoration pathways to address degradation. Degraded landscapes attracts several restoration initiatives, often focused around vegetation increases, seeking to address increasing climate vulnerability to food security. Trees play an important role in meeting the livelihood needs of woman, particularly in critical food gap months when many households have exhausted farm supplies. Despite the prominence of trees in woman's livelihood systems, their access to tree products is often constrained by underlying gender norms that limit their access and agency in terms of how trees are managed across a landscape. This imbalance is often neglected in restoration initiatives resulting in inequitable outcomes for woman despite women's livelihood being directly tied to tree resources and tree products directly underpinning household livelihood security. This study used gendered participatory mapping of the forest-farm mosaic and household surveys to collect data on land use access and valuation for ecosystem services. Results show a heterogeneous parkland landscape with several complex land use access regimes restrictive to women. Land uses with the highest livelihood potential for woman were a low priority for restoration initiatives forcing woman to travel longer distances (at greater risk) to access tree products. Distinct gendered norms that have evolved these complex gendered access and control regimes gives men control over valuable which was shown to influence men and women's valuation of key provisioning ecosystem services in both countries. The paper outlines the case for rebalancing restoration intervention design and planning by explicitly engaging with the underlying gender norms that maintain access restrictions to enable more equitable (and effective) outcomes of land restoration.

Equal chances in forestry - case study

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: The project has been conducted in Poland by Women in Forestry Association together with partnering organizations from Norway and Iceland. Its aim was to fill the knowledge gap and prepare recommendations for good practices in gender equality.
The part of the project was to run a survey on gender equality making use of the Gender Index (GI) approach. GI approach was previously elaborated to evaluate gender differences
in work place. It was used in several organisations, also in forestry (in 2012). The current study makes it possible to find out changes over 10 years as regards women's and men's position in forestry. The CAWI survey has been run in the State Forests, main employer in Polish forestry, managing 75% of all the forest area.
Over 4 000 questionnaires were collected. The survey data have been analysed both in total (total GI) and domains distinguished (seven domain-specific gender indicators).
Since 2012 a visible increase of female employees in the State Forest has been observed up to nearly 30%. The share of women in decisive managerial positions remains very low (3%).
Despite some measures undertaken in the State Forests there are no significant changes for the better. Additionally, there is a strong regional diversity in the GI, which is difficult to explain considering a high unification of internal regulations of the State Forests.
The most gender inequality refers to protection against mobbing and harassment, while the access to training reveals the best gender equality indicator. The crude gender pay gap is relatively high (10%) while the adjusted pay gap is 2.7%. The wage difference between women and men results mainly from job segregation and retirement age by sex.
The main problem of management practices is unawareness and neglecting the area of gender inequalities.
Results of our study made it possible to formulate a broad range of recommendations, showing the most important measures to improve the situation.
They may be grouped as follows:
monitoring regarding women's share on different levels of the professional hierarchy and a gender pay gap
trainings for managers and employees
cohesive gender policies
supporting and promoting women

Five archetypes to discuss gender, gender roles and forest fires in the context of extractivism and climate change

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: In our collective imaginations, forest fires are still “male” issues. However, it is evident not only that women participate actively and diversely in the event of a fire, but that they are also present in daily work to prevent them, both in the past and in the current context of environmental and climate change. Based on the question "What different roles do women have in forest fires?", in this communication we will present our work in progress that critically analyses, on the one hand, the publications on the subject. On the other hand, we will present field observations of the role of women in contexts of forest extractivism based on tree plantations - their practices, knowledges, care and resistance - around forest fires in Spain, Sweden and Chile. The three territories are characterized by having undergone major environmental and territorial transformations and dispossessions based on the implementation of pine and eucalyptus forest plantations. Based on the material analyzed - press documents, interviews, participant observation, etc. - we argue that the presence of women around forest fires is repeatedly structured in roles that we synthesize as follows: "the strong", "the victim ", “the caretaker”, “the wise” and “the witch”. The analysis of these archetypes helps to consider the diversity of women's roles in relation to forest fires, so that the possibilities of just socio-ecological transformations are considered beyond the invisibility or the caricature of the role of women in contexts of extraction and environmental disaster.

Gender differentiated energy use choice in rural households: Evidence from the giant panda nature reserves in China

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: China's economic development faces tremendous pressure from energy constraints, energy conservation and emission reduction. Since rural energy consumption accounts for more than 30% of the total energy consumption and the strict implementation of the ecological-priority principle in nature reserves, focusing on energy use choices in rural China is crucial. Using field investigation of 943 samples in 17 giant panda nature reserves in Sichuan and Shaanxi provinces, this study uses the exogenous switching treatment effect regression to explore the behavioral difference in energy use among the gender of rural households. Results showed that household income and off-farm income ratio directly impact the energy use choices among all household types. Education level only affects energy use decisions in MHHs (male-headed households) and De facto FHHs (i.e., a household where the husband is away). Forest size and distance from home to forest significantly impact dirty energy use in De jure FHHs (i.e., a household run by a single, widowed, or divorced woman). By comparing the energy use choice among MHHs, De facto FHHs and De jure FHHs, it showed that De jure FHHs would have the highest probability of choosing dirty energy, and De facto FHHs would have the lowest. The significant treatment effects indicating that the energy use differences between MHHs, De facto FHHs and De jure FHHs could be explained by resource endowment and return differences of these household types. However, the unobserved institutional and structural challenges different household types face have less explanatory power. Hence, policy supports on skills training and daily life subsidies are expected especially for De jure FHHs to decrease their reliance on forest natural resources. In addition, improving environmental protection awareness and self-health recognition are still needed to increase the life quality of rural households in nature reserves.

The integration of gender dimension at research of environmental legal sources

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: Most qualified public policies related with Environmental Law were elaborated from the contributions made by expert researchers, from the public and private sector, and the whole community, by combining their scientific knowledge and their social institutional expertise to face the complexity of socio-ecological and legal systems. The discipline of Law has limited quantity of methodological tools, so it is important to implement and adapt other which are provided by Social Sciences to obtain solid scientific results. This will be applied at the analysis of legal sources such as regulations, jurisprudence, and doctrine. The methodological strategy of this proposal includes the gender dimension because legal and environmental issues tend to be designed with the assumption that a community is homogenous and has shared interests. Also, some studies about gendered nature of ecosystem services should be considered because they state that they are important for the elaboration and application of public policies and future legal sources. Some authors as K. Bartlett state that without prior consideration of the gender dimension, this can generate unintended trade-offs across sub-groups of individuals that hold variable preferences, opportunities, and constraints. Because of gendered roles, responsibilities and asymmetrical power relations in the household and community, interventions that alter access can differentially affect women. In this regard, it is relevant to consider the epistemological implications of feminist legal methods by examining the nature of the assertions they generate considering the following techniques: rational empiricism, epistemology and postmodernism, and the positioning. The methodological approach of our research projects should include a gender approach which have a relevant role in connection with the analysis and proposal of legal guidelines for future regulations and public policies, to assure that there will be an equal management and protection of forests performed by all citizens and that these legal texts make these aspects visible. In this regard, it is necessary to apply and adapt different feminists' theories which were designed for its application to Law and work jointly with specialists and combine it with other social techniques.

What is the evidence that gender affects access to and use of forest assets for food security? A tool for decision-making.

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: A systematic evidence evaluation was undertaken to test the hypothesis that there are wide gender disparities in access to and use of forests, and that better food security outcomes can be achieved for individuals and households when women have equal access to forests in communities that depend on forests for their livelihoods. Ten bibliographic databases and 22 websites of international development and conservation organisations were searched using keywords suggested by stakeholders. Other articles were found by emailing authors and organisations to send potentially relevant publications. 19,500 articles were retrieved from bibliographic databases and 1281 from other sources. After iterative screening, 77 studies were included: 41 focussed on Africa, 22 on Asia, 12 on Latin America, 2 were global. Most indicators of food security measured access to food, measured by total consumption, expenditure, or income. Studies showed that there was strong gender specialisation in roles associated with use of forests. Commercial access and utilisation of forests and forest products were dominated by men, whereas access for subsistence and household consumption was almost exclusively the task of women. The systematic evidence evaluation revealed critical gaps in the evidence base, including geographical representation in primary research and a range of study designs for evaluation of the review topics. Results of the systematic evidence evalaution were used to create an interactive evidence map, which can be used as a tool for decision-making and to focus further research.

“You’re not a “forester” – marginalized voices and unequal relations in professional forestry practice.

S5.5 Integration of gender and diversity perspectives in knowledge production

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Abstract: In Canada, the responsibility for professional forestry practice lies with professional foresters, who offer services related to the development, management, conservation, and sustainability of forested land. These services require extensive knowledge, training, and experience and thus to become a professional forester, individuals must follow a standardized career development process that combines education and practical experience. Professional foresters primarily work in government, industry, conservation authorities, or as private consultants in various roles in the field, management, or policy settings, both in rural and urban contexts. However, their gender and length of work in the field, specific location of their work, the roles they perform, and the values they prioritize can influence how they are perceived, welcomed, and accepted by their peers within the profession, as well as how their knowledge is valued. For instance, what happens when a forester's values regarding forest management conflict with the dominant approaches in the field? This research examines how the decisions of professional foresters to pursue different pathways within the forestry occupation impact their acceptance within the profession, the value placed on their knowledge, and impact on their overall health and well-being. The findings of this study suggest that efforts to promote and attract diverse individuals to the field of forestry should consider alternative practices of knowledge production, different values on forest management and the diversity of roles in the profession.

S5.6 Transforming and restoring forests for more resilient landscapes and societies

A sustainable forest future in the tropics means considering secondary forests as an alternative source for timber production

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Tropical forests are recognized for their exceptional biodiversity related to the provision of vital ecosystem services. They are also highly vulnerable and threatened, primarily by agricultural development. Tropical forests are disappearing at huge rates and old-growth forests now only account for 25% of all existing tropical forests.

In some tropical landscapes, growing deforestation and degradation of old-growth forests is paralleled by the increasing extent of secondary forest (SFs) that regenerates naturally on large areas of abandoned farmland. They represent a hope for sustainable forest future.

However, within tropical landscapes SFs are themselves extremely vulnerable to land use changes, but also natural and human-induced catastrophic events, such as fires. SFs have lost their capacity to provide a high level of goods and services, and are located in highly dynamic and human-pressured landscapes, where they interact with competitive productive landscapes.

Without appropriate silvicultural management to increase their economic value and restore their ecological functions, they often become degraded and are cleared for more short-term economically productive activities.

We hypothesize that the nowadays context of the increasing demand for tropical timber is an opportunity for SF conservation, through active and productive restoration for timber production in tropical SFs.

Promoting sustainable and diverse timber production -associated with other environmental services- in SFs is also a way to reduce logging pressure on the remaining intact primary tropical forests : this may be the most important reason to enhance active and productive restoration in tropical SFs.

In the suggested flash talk, based on results and knowledge of different studies gathered in the special issue "Active restoration of timber production and other ecosystem services in secondary and degraded forests" (Forest Ecology and Management), we show that timber species actually represent an unknown and important proportion of tree diversity and AGB within studied SFs plots in Central America and West Africa.

Future studies may address this key “global south” challenges of sustainable future for wood production in the tropics, working on active and productive restoration for timber production in SFs, but also on other coherent factors as appropriate logistical investment, local policies and incentives that enhance secondary forest regeneration.

Building a pathway for high quality FLR implementation across the globe: WWF´s regional initiatives.

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Promoting the implementation of high-quality Forest Landscape Restoration (FLR), accelerating implementation and upscaling it globally has been set as priority for WWF Forest Practice and its globally acting FLR community. The GPFLR, defines FLR as "a process that aims to regain ecological functionality and enhance human well-being in deforested or degraded landscapes" and has adopted six principles to guide implementation; complementary the UN Decade on Ecosystem Restoration has established 10 principles. Achieving high quality FLR requires a strong consideration and adherence to those principles, associated with well-designed strategies, careful implementation, effective monitoring and transparency, under and adaptive management approach. By adopting the Conservation Standards for the Practice of Conservation, WWF developed theory of changes under the adaptive management approach and trough a participatory process. Regional initiatives in Africa, Latin America and Southeast Asia are now structured in a coherent framework set under tree pillars: 1) enabling policy, governance and institutional frameworks; 2) promoting markets and finance mechanisms and 3) delivering Bonn challenges commitments on the ground at scale. The goals and objectives for each country and landscapes were them set under landscapes approaches process considering the local contexts and voices. The FLR in Africa Initiative engages 9 countries and is empowering and enabling national and regional governments to deliver their AFR100 commitments in a just way that promotes sustainable livelihoods for local people and biodiversity conservation. The Transformational Initiative on Forest and Landscape Restoration in Latin America is kickstarting the restoration of over 7 million hectares of degraded and deforested landscapes across 12 countries as a contribution to the Initiative 20x20. Along with the regional work in the Mekong region, WWF is being able to promote cross learning and exchange among the network and partners. For transparency WWF is building landscape collections in Restor. With partners WWF is promoting enabling conditions to accelerate implementation. The Trillion Tree gives us the opportunity to protect and restore, based on science and proven impact. With SER we are developing standards for restoration projects certification. And with IUCN, WRI, with the support from IKI we are launching the FLR Implementation Hub.

Citizen Science as a tool to promote mental well-being and connection with nature in a Brazilian Park

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Participatory approaches have proven essential in natural resource management worldwide, as they can reduce inequalities in decision-making and encourage public engagement in environmental issues. Citizen Science, a relatively unexplored avenue in protected areas, holds great potential for balancing priorities such as education, research, and social development. This exploratory study evaluated the impact of cultural ecosystem services on self-perceived mental well-being, connection to nature, and pro-environmental behaviors among volunteers participating in an environmental monitoring project in the Serra dos Órgãos National Park, Rio de Janeiro, Brazil. We employed a questionnaire with validated psychometric scales, including the Positive and Negative Affect Schedule (1988), Vitality Scale (1997), Nature Relatedness Scale (21-items, 2009), and Inclusion of Nature in Self (2001). The participant profile consisted of low-income undergraduate students and public servants from different age groups, with some people visiting a protected area for the first time. The results were promising, revealing differences in self-perceived well-being before and after participants engaged in observing nature. All scales exhibited positive variations in the median and mean between pre- and post-participation, however only the Negative Affect (PANAS), Nature Relatedness, and Inclusion of Nature in Self resulted in significant differences, with p-values below 0.05 in the Wilcoxon signed-rank test for small paired samples. While further research is needed to explore other aspects of human well-being in citizen science projects, this study provides valuable insights into the influence of this cultural ecosystem service and can guide future public policies and research endeavors.

Conserving grasslands for regenerating degraded forests in a semi-arid region

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: An experimental project on conserving and nurturing grasses in the Indian Savannah region is being undertaken in Gajraha, a small hamlet located 100 metres away from the buffer zone of Bandhavgarh Tiger Reserve in Madhya Pradesh. Prakruti Prerana Foundation, a non-profit organisation is working on conservation of forests and grasslands in a 30 acre non-arable area acquired from local villagers. An extensive survey of grasslands was conducted to identify and document a mix of 25 different species of grasses within a forest habit populated with Madhuca *longifolia,* Shorea *robusta,* Diospyros *melanoxylon,* Ficus *benghalensis,* Butea *monosperma,*and Syzygium *cumini* on the premises.

The method used for identification was collection of grass species and its subsequent cross checking with a report published by the state biodiversity board. This study tries to understand the impact of grasslands in helping forests regenerate without any human intervention as both native and invasive species of plants and grasses are present on site. Since the study on grasses is conducted on an experimental forest land, it revealed information on two major species- Aristida *adscensionis* and Cenchrus *ciliaris*. Their widespread distribution throughout the site indicates presence of sandy loamy soil. Typically, this soil has low level of micro nutrients which arrests the growth of plants and fosters grasslands. Out of the above two species, Aristida *adscensionis* thrives in sunlight and extreme heat since temperatures in the tropics reach close to 50 degree celsius in daytime. The other species, Cenchrus *ciliaris* grows in shade, being a pioneer species in this forest helps retain moisture content in soil. It is drought tolerant and extremely beneficial under irrigation in a semi-arid region.

The study revealed the potential commercial use of these grasses as good fodder value, as well as their role in creating grazelands. These grasses have helped restore the soil nutrition balance in the current site. Both species are used in re-vegetation of degraded lands and controlling soil erosion on slopes as well as in ethno-pharmacological studies.

Keywords: Indian Savannah grasslands, Aristida adscensionis, Cenchrus ciliaris, pioneer species, forest regeneration, semi- arid region

Decision making factors influencing land use transformation and its implication on forest landscape restoration in Ethiopia

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Macro level patterns are often a result of a strong influence of human decisions and behaviour at the micro level. To improve our understanding and the process of land use transformation, the abilities, objectives, and motivation of land use decision makers should be explicitly addressed. This research investigates the decision factors of Ethiopian smallholder farmers to transform their land use in the process of implementing Forest Landscape Restoration (FLR). A combination of systematic and random sampling was employed to select 228 households for a household survey. The decision to transform a landscape from one use to another is significantly associated with economic, environmental, social, and institutional decision factors. Economic, soil fertility, and policy are the main drivers of land use transformation occurring in the landscape. Most smallholder farmers changed their land use from cropland to woodlot intending higher economic profit whereby, few have reversed from Woodlot to cropland due to longer waiting period to harvest. The study reveals that crop and grazing have very high significance variation within the group of survivalist, subsistence oriented and market oriented smallholder farmers as compared to land allocation for woodlot and agroforestry. There is a high tendency of subsistence oriented farmers to convert from cropland to agroforestry and woodlot in pursuit of profit. Implementation of FLR in the study area and in similar landscapes where smallholder farmers are targeted to be involved should consider promoting economically rewarding tree species.

Deforestation, Forest Degradation, and Climate Change in Ethiopia: A Physical Recovery and Climate Change Mitigation and Adaptation Strategy

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Deforestation and forest degradation have been rampant in Ethiopia, posing major challenges to forests and the livelihoods of those who rely on them. The main causes are agricultural expansion; rising demand for construction materials, industrial use, fuel wood, and charcoal; a lack of forest protection and conservation policy; a weak forest administration system incapable of arresting the rapidly increasing rate of deforestation; a lack of effort to ensure community participation in forest protection and conservation and benefit-sharing; and failure to clearly delineate and enforce the boundaries of natural forest reserves. There are currently efforts being made by the government and local communities. Attempts to safeguard forests in the country include the establishment of protected and forest priority areas, as well as the protection of sacred forest sites and the introduction of new energy-efficient stoves. Another conservation initiative being implemented by the government is forest rehabilitation by afforestation, replanting, and area enclosures with participatory forest management methods. Long-term fluctuations in temperature, precipitation, wind, and other characteristics of the Earth's climate system are referred to as climate change. Climate change can be caused by natural or human-made events. Climate change is mostly caused by human activity such as the combustion of fossil fuels and the removal of forests. High-income countries are mostly responsible for greenhouse gas emissions, whereas low-income countries bear the brunt of climate change's harmful consequences. Because of their poverty and significant reliance on the environment for survival, developing countries are less capable of mitigating or adapting to changes. Climate change has a wide range of consequences for the environment, socioeconomic sectors, and linked industries, including water resources, agriculture and food security, human health, terrestrial ecosystems, and biodiversity. The Ethiopian government has previously implemented a number of policies, strategies, and programs aimed at improving adaptability and reducing climatic fluctuation and change. As a result, the goal of this review study is to look at deforestation and forest degradation in Ethiopia, as well as climate change and its mitigation and adaptation initiatives.

Exploring the Sustainable Development Solution of the 2019 Beijing International Horticultural Exposition that Will Never End

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Sustainable development is promoting and assisting urban sustainable development from the perspective of environment and resources. Due to the large size of the venue for the World Horticultural Exposition, the transformation and development model after the event has become an important issue of concern for domestic venues hosting the expo. On the one hand, due to the large area of the venue during the event, the current post event operation methods adopted by domestic expo include retaining and transforming it into a theme park, conducting secondary development and construction, and serving as urban park green space. The actual operation is almost a combination of multiple modes. On the other hand, unreasonable post event utilization cannot fully utilize the brand effect and potential value created by the expo, It is particularly important to achieve sustainable development after the World Horticultural Exposition.

Taking the following programmatic planning for sustainable use of the 2019 Beijing World Horticultural Exposition as an example, this paper expounds the solution of the 2019 Beijing World Horticultural Exposition, and positions the Beijing World Horticultural Garden Park as a ecotype park based on local adaptive plants to create a near natural landscape and achieve sustainable development. Always embodying the important idea of ecological civilization, we aim to create a professional and experiential plant garden complex that serves the public, and to build a new and vibrant horticultural theme center with a sense of social responsibility that integrates tourism, cultural and creative activities, science and education, and art. To achieve the sustainability of the mission and cultural vision, as well as the sustainability of the operational economy, in order to become a model for post exhibition operations.

Forest Adaptation and Restoraration under Global Change - status and perspectives

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Forests and forest landscapes fulfil multiple essential ecosystem services (ES). These include (i) provisioning services such as the provision of food, raw materials, freshwater and medicinal resources; (ii) regulating services such as carbon sequestration and storage for climate protection, regulation of the landscape water cycling and climate, moderation of extreme events and natural hazards; (iii) cultural services for recreation, mental and physical health, tourism, and aesthetic, cultural and spiritual experiences, as well as (iv) supporting services for preserving biodiversity. For rural populations, forests are often the basis for their social identity, livelihoods, and the local economy. Forest landscapes are social-ecological systems shaped by multiple influences and they play an outstanding role, contributing to all 17 Sustainable Development Goals (SDG). However, forest landscapes are under pressure with the loss of forest areas by conversion to other land uses and degradation of existing forests, and reduced biodiversity. An estimated 10 million hectares of forest area have been lost between 2015 and 2020 and an even larger amount is estimated to be degraded. Environmental and climate changes are rapidly altering the growth, survival, and regeneration conditions for forest ecosystems with direct and dramatic impacts on 3.2 billion people, in particular the most vulnerable. Tropical forests, for example, are home to over two-thirds of the Earth's terrestrial biodiversity and they are facing significant threats from human activities as well as climate change. With this, forests and forest landscapes may lose their characteristic structural and ecological features, and societies worldwide face diminishing levels of ecosystem services provided by forest landscapes. Thus, along with the preservation of intact forest landscapes, forest adaptation and restoration are needed to prevent the continued global loss of ecosystem services and biodiversity, so that forest landscapes can meet the ecological, economic, and societal challenges due to global change. In this presentation we provide an overview about the status of global activities on forest adaptation and restoration based on an online survey and other sources, and discuss the future perspectives of Forest Landscape Restoration (FLR) for various ES like climate protection, water cycling, biodiversity, and the provision of food and raw materials.

Impacts of Establishing Pilot National Parks on Local Residents' Sustainable Livelihoods and Their Coping Strategies in China

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: National Parks are a category of protected areas that emphasizes the sustainable use of park resources. In 2013, the Chinese administrative authorities announced the establishment of its own national park system to better protect the country's natural heritage and the integrity of its large ecosystems. Since 2015, ten pilot national parks have been designated to explore a pathway to implement the national park system better. Local communities are among the most critical stakeholders in establishing and managing a national park. Park management wouldn't be successful without the local residents' support and active involvement. Since national parks are positioned in China as protected areas with the highest priority to nature protection, their impacts on the local people, either inhabiting the park or living nearby, are unprecedented in the country. The park-people relationship is not a new topic in national park research; however, in the context of China's social, economic, and political framework, very little is known about the sustainable livelihood impacts of establishing a national park on the local residents and what strategies those residents should adapt to cope. In this study, the authors attempt to reveal the livelihood impacts of the national park creation in China on the local residents and their adaptation approaches by taking Northeast Tiger and Leopard National Park (NTLNP) as a case through a propensity score matching difference-in-differences model (PSM-DID model). The study results indicate that the establishment of NTLNP and its policies have significantly impacted the sustainable livelihoods of the local residents. The weakening effect of the establishment of the NTLNP on the sustainable livelihood of the local residents has a certain lag. The reason may lie in: (1)The local community has a weak self-development ability and has a high dependence on natural resources. (2) The Northeast Tiger and Leopard National Park is a comparatively dense area of wildlife population distribution. The overlapping of human and wildlife activities and the competition for resource utilization also directly or indirectly cause losses to the production and livelihood of the community residents inside and outside the protected areas.

Land Use and Land Cover Change along River Lumi Riparian Ecosystem in Kenya: Implications on forest ecosystems and Local Livelihoods

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Riparian forests minimize impacts of land degradation on stream ecosystems and provide direct and indirect benefits to people. However, these ecosystems are threatened by degradation and deforestation attributed to land use changes. River Lumi riparian ecosystem in Taita- Taveta County in Kenya has experienced rapid and extensive land use changes over the past three decades in response to economic, institutional and demographic factors. There is growing concern of riparian degradation attributed to land use change with far reaching implications on local livelihoods. A study was conducted to examine the patternsof land use and land cover change along River Lumi riparian ecosystem between 1987 and 2019. The aim of the study was to ascertain the impactsof land use and land cover change on the riparian forest and local livelihoods. Landsat images were used to assess land use and land cover change while socio-economic data was collected from 353 households in Njukini, Chala and Mboghoni located in the upper, middle and lower sections of River Lumi ecosystem respectively. Research evidence authenticated that the area under farmlands, settlement and water body increased by 20.5%, 112.1% and 2.3% respectively between 1987 and 2019 while area under forest patches, grazing land and riverine vegetation decreased by 52.7%, 3.0%, and 36.6% respectively. The increase in population in surrounding areas coupled with encroachment of the riparian areas for crop farming and livestock grazing resulted to loss of riparian forest patches/vegetation and associated biodiversity with negative implications on household livelihoods. The implication of these results is the need for land use regulations and management interventions at the County government level to arrest further encroachment of River Lumi riparian ecosystem and consequent loss of biodiversity and livelihoods.

PERFORMANCE OF BAMBOO TREES ALONG RIVER TANA FOR FLOOD RISK MITIGATION AND SOIL AND WATER CONSERVATION WITHIN GARISSA AND TANA RIVER COUNTIES IN KENYA

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Riparian lands provide suitable environment for human activities and livelihood sources. They support thousands of households by ensuring supplies of food and income through irrigation activities. However, with the ballooning human population and the negative impact of climate change, riparian lands have attracted more people resulting in over-exploitation of resources therein. In addition to the destruction of riparian vegetation, anthropogenic activities in these lands have led land degradation through river bank erosion and consequently flooding and pollution of water sources along the rivers. River Tana in Kenya has faced similar consequences with increased clearing of riparian vegetation for more agricultural land and charcoal burning, and obtaining building poles. As a result, the magnitude of the floods and the associated impacts have been increasing over the years. The recurrent flooding in River Tana has not only destabilized/deformed its banks but has also led to the loss of both human and livestock lives, loss of livelihood, destruction of property and infrastructure, water contamination, and disease outbreak in Garissa and Tana River Counties. In an attempt to mitigate flood risk as well as conserve soil and water, this project planted bamboo trees at erosion hotspots and areas of high, medium, and low flood risks along River Tana bank.

Basing on the flood risk hazard maps by Kenya Red Cross Society and National Drought Management Authority 3 experimental sites with high, medium, and low flood risk were selected in each of the counties. About 1500 bamboo seedlings were planted on 12 farms. A survival rate of 88% was recorded but with differentiated growth rate. The minimum and maximum height recorded in the first year were 0.2 and 4.9 meters respectively while number of shoots per tree between 1 and 12. The challenges encountered included lack of water for watering due to slight changes in the river course, destruction by livestock, *Prosopis juliflora invasion* as well as poor management by farmers. The project observed that the potential for controlling floods and bank erosion through the use of bamboo trees is feasible considering their survival and growth rate and positive attitude toward bamboo trees by farmers.

Socioecological Innovations in Landscape Restoration: Exploring Examples within the Brazilian Context

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Forest and Landscape Restoration (FLR) is a transformative process that reshapes land use dynamics to improve ecosystem services and overall well-being by influencing values, behaviours, and social relationships. It involves preserving and expanding areas that provide essential services such as water resource protection, biodiversity conservation, and sustainable agriculture. However, the success of FLR is influenced by complex power dynamics among competing land use interests, where institutions mediate access to resources, decision-making authority, and capital. This can lead to varying outcomes, potentially exacerbating social inequalities and environmental degradation. To address these challenges, participatory and adaptive management approaches led or supported by local communities are crucial and can foster Social Innovations (SI). SI represents the sharing of ideas, knowledge, and collective actions to address common challenges, with Socioecological Innovation (SEI) being the term used when these innovations also benefit nature. This paper examines three SEI cases within the framework of "Socially Innovative Forest and Landscape Restoration" (SIFLR): "Sawing Agroforestry" in Minas Gerais, "Sawing Sustainability," and "Actors of Forest Restoration in the Paraiba Valley" in São Paulo, Brazil. These initiatives, characterized by participatory and adaptive processes driven or supported by local communities, aim to address restoration challenges. Through collective actions, communities bring about tangible changes socially and ecologically by sharing ideas and knowledge. The study uses the SIFLR framework to explore how these initiatives have promoted social and ecological innovation. The framework acknowledges social, political, economic, and ecological interdependence in successful restoration and emphasizes collaboration among diverse stakeholders. The examples demonstrate that SEIs effectively promote sustainable restoration, benefiting local communities and the environment. These initiatives encourage stakeholder participation, enabling knowledge-sharing and consensus-building to address the complex challenges associated with FLR. Given the global urgency to prioritize landscape restoration, it is essential to promote the implementation of such initiatives to ensure social inclusion, equity, and environmental sustainability. Based on the findings, scaling up and supporting these innovative approaches is recommended, as they have the potential to play a vital role in building a resilient and healthy future.

Transitional forestry in New Zealand: re-evaluating the design and management of forest systems through the lens of forest purpose

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Forestry management worldwide has become increasingly effective at obtaining high timber yields from plantation forests. In New Zealand, focus on improving an increasingly successful and largely *Pinus radiata* plantation forestry model over the last 150 years has enabled the most productive timber forests in the temperate zone. In contrast to this success, the full range of forested landscapes across New Zealand, including native forests, are degraded by growing pressures from introduced pests, diseases, and a changing climate, placing considerable biological, social and economic value at risk. Government policies further incentivise reforestation and afforestation, but the social acceptability of some newly planted forests is now being challenged.

We present 'transitional forestry' as a solution. This new model design and management paradigm is appropriate to a range of forest types, including non-commercial forests. In our framework, all forest types are optimised as nature-based solutions and forest purpose is placed at the heart of decision making. We use New Zealand as a case study region, describing how a purpose-led transitional forestry model can deliver benefits across a range of forest types; from industrialised forest plantations to dedicated conservation forest reserves and a range of multiple-purpose, mixed-species forests in between. Transitional forestry is an ongoing multi-decade process of change from current 'business-as-usual' forest management to multiple future systems of forest management, embedded across a continuum of forest types. This incorporates ecological thinking to enhance efficiencies of timber production, improve overall forest landscape resilience, and reduce potential negative environmental impacts of commercial plantation forestry. The cultural acceptability and biodiversity value of both commercial and non-commercial forests is maximised.

Transitional forestry addresses emerging tensions between meeting forest climate mitigation and biodiversity targets, alongside accelerating demands for forest biomass feedstocks to meet near-term bioenergy and bioeconomy goals. As ambitious international policies set targets for global programmes of reforestation and afforestation using both native and exotic species, there is an increasing opportunity to make these forest transitions *via* integrated thinking that optimises the values of all forest types, while embracing the diversity of ways in which such targets can be reached.

Why restoring boreal forest landscapes for indigenous Sámi reindeer herding is important to fight effects of climate change on open alpine heathland

S5.6 Transforming and restoring forests for more resilient landscapes and societies

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Abstract: Treeless, alpine areas (and associated species) are in many regions threatened by warming climate as shrubs and trees are moving to higher elevations and latitudes, leading to continuous decrease of alpine habitat. This is also true for the Scandinavian mountains. However, it has been shown that grazing from reindeers can hamper "schrubification" and delay the advance of the treeline.

In northern Sweden there are about 250.000 semi-domesticated reindeers, owned and cared for by the indigenous Sámi people. Reindeer husbandry has a long tradition in Scandinavia but today the herders use modern technology to herd and guard the animals as they roam freely in the search for grazing areas and resting places. The reindeer herding communities (RHC) have exclusive right to use approximately half of the Swedish territory for reindeer grazing, irrespectively of land ownership. Reindeers are migratory and most reindeers in Scandinavia stays in the alpine mountains during summer and in the forested inland and coast during winter. During summer the reindeers eat mainly grass, herbs, and leaves and in the winter, they mainly eat lichens. The winter is the most critical period for the reindeers and thus the amount and access to lichens in the forests during winter is one major factor limiting the number reindeers that will graze the alpine areas in the summer. However, in the last 50 years the amount of ground lichens in the forests has decreased by as much as 70 %, primary due to intensive forestry, and the connectivity between good grazing areas and along the migration routes are continuously being more and more disrupted.

To strengthen the landscape connectivity for reindeers and to halt the loss/enhance (re)-growth of ground lichens, and in the long run protect the alpine habitats, the forests within the reindeer grazing areas need to be restored.

In Vindelälven-Juhttátahkka Unesco Biosphere reserve in northern Sweden, the RHC Ran and Gran are collaborating with both the Horizon 2020-project SUPERB and Rewilding Sweden to map and describe restoration needs, and to perform restoration actions. In this presentation we will talk about the proceeding of this initiative and the results so far.

S5.7 Leadership for Sustainability - Overcoming Challenges in Forest Research

S5.8 Power of youth in scaling multisectoral collaboration: The role of forests in achieving the vision for 2050

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

Antifungal Activity of Culture Filtrate from Endophytic Fungus Nectria balsamea E282 and Its Fractions against Raffaelea quercus-mongolicae

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Since 2004, oak wilt disease caused by *Raffaelea quercus-mongolicae* has been a threat to *Quercus mongolica* in Korea. Our previous study indicated that three endophytic fungal isolates from pine and oak trees, E089 *(Daldinia childiae)*, E282 *(Nectria balsamea)* and E409 *(Colletotrichum acutatum)* had antifungal activities against *R. quercus-mongolicae.* The objectives of this study were to optimize antifungal efficiency of these endophytic fungi and to assess antifungal activities of fractions isolated from culture filtrate. Mycelial growth of *R. quercus-mongolicae* on PDA medium containing culture filtrates was significantly affected by culture periods of endophytic fungi. Culture filtrates of E089, E282, and E409 obtained after three weeks' cultivation had higher mycelial growth inhibitions compared to those of 2 weeks' with inhibition rates of 82.2%, 100%, and 85.0%, respectively. Culture filtrates of these isolates also showed higher sporulation inhibitions on PDA medium containing 3-week culture filtrates with rates of 93.3%, 100%, and 92.1%, respectively. For spore germination of oak wilt fungus, only E409 had a lower inhibition rate on 3-week culture filtrate compared to that of 2 weeks' while the opposite occurred for E089 with an inhibition rate of 100% on 3-week culture filtrate. Especially, spore germination inhibition rates of E282 reached 100% in both culture period conditions. These results showed that E282 (*N. balsamea*) completely inhibited mycelial growth, sporulation, and spore germination of oak wilt fungus. The antifungal activities of its fractions against oak wilt fungus were significantly different. Of which, diethyl ether (Et_2O) fraction completely inhibited mycelial growth, sporulation of oak wilt fungus and had the strongest activity in inhibiting spore germination. Thus, this endophytic fungus could be developed as a potential biocontrol agent against *R. quercus-mongolicae*, the wilt pathogen of *Q. mongolica.*

Assesment of different methods for tolerance testing of Fraxinus excelsior genotypes towards Hymenoscyphus fraxineus

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: The ash dieback pathogen (*Hymenoscyphus fraxineus*) was first observed in Poland in 1992 and from then it developed to a severe threat for living ash trees in Europe. In many countries as Germany, Austria, France, England or Denmark research-programs were initiated to find common ash (Fraxinus excelsior) genotypes resistant to the ash dieback pathogen. Several methods for testing pathogen resistance of the ash genotypes were used. Here we investigated three different methods and compared them to field observations (crown defoliation). Stem infections, leaf infections (rachis infections) and germination rates of *H. fraxineus* spores on leaf malt agar were tested using 12 ash genotypes. Replicates were achieved by graftings. Stem infections provided the best correlation to the field observations. However, this method needs a long preparation time, and the duration of the experiment takes at least 3 months. The easiest and fastest method was that of the leaf (rachis) infections. It lasts one month and implies almost no preparation time. Although this method correlates less strongly to the field observations it correlates well with the stem infections. The spore germination on ash leaf agar method would be also fast, but the time synchronization between sporulation and leaf malt agar preparation makes the method very difficult to apply. Moreover, we observed no correlation to the stem infections. To get accurate results of the resistance of ash genotypes against ash dieback, stem infections seem to be still the best way.

Chestnut defense genes against the invasive gall maker Dryocosmus kuriphilus

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Several chestnut (*Castanea* sp.) genotypes resistant to the Asian gall maker *Dryocosmus kuriphilus* have been described. Studies of the defensive mechanism involved in this process revealed that the immune response of the resistant genotypes is mainly based on a hypersensitivity reaction (HR) to eggs or neonate larvae inside the tree buds, as well as on the early and precise abscission of the nascent galls from the expanding leaves. HR is an induced resistance response that appears in the area immediately adjacent to the egg mass within the tree bud visible as a necrotic lesion that prevents gall formation. HR is triggered by specific molecules responsible for activation of the defensive response and involves several steps: insect recognition, development of the oxidative burst, activation of defense genes and cell death. Abscission consists of a process of cell separation by which plants can shed some of their organs. Abscission of infested leaves, fruit or seeds is common and is considered especially effective against insects with poor motility such as gall makers. In the present work we identified defensive genes involved in this process by massive gene expression analysis. We performed RNAseq on different phenotypes and experimental conditions for highly sensitive and accurate evaluation. This technology allowed us to identify differentially expressed genes and enriched pathways related to the defensive response involving immune-related genes between sensitive and resistant plants. Candidate genes are being validated by qPCR on new plants according to their resistance status. The goal of this research is to improve the understanding of the mechanisms underlying the immune response in plants that may have practical implications for the improvement of tree resistance breeding for chestnut production.

Climate, host and geography are of similar importance in shaping insect and fungal communities of trees on a global scale

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Non-native pests, climate change, and their interactions are expected to disrupt the relationships between trees and the organisms associated with them, thereby impacting forest health. In order to comprehend and anticipate these changes, it is crucial to identify the factors that shape tree-associated communities. We collected and analysed insects and fungi obtained from dormant twigs of 155 tree species across 51 botanical gardens or arboreta in 32 countries on six continents.

Fungi were characterized by high-throughput sequencing. Insects were first reared and then sorted into taxonomic orders and feeding guilds. Herbivorous insects were then grouped into morphospecies and were identified using molecular and morphological approaches. By employing generalized dissimilarity models, we assessed the relative significance of various climatic, host-related, and geographic factors in driving dissimilarities among tree-associated communities. This dataset reveals the diversity of tree-associated taxa, as it contains 12,721 amplicon sequence variants and 208 herbivorous insect morphospecies, sampled across broad geographic and climatic gradients and for many tree species. Mean annual temperature, the phylogenetic distance between hosts, and the geographic distance between locations were the primary determinants of dissimilarities. The increasing influence of high temperatures on community differences suggests that climate change could directly and indirectly impact tree-associated organisms through shifts in host ranges. Furthermore, insect and fungal communities exhibited greater similarity among closely related hosts compared to distantly related hosts, implying that expansion of host ranges could facilitate the emergence of new pests. Additionally, dissimilarities among tree-associated communities increased with geographic distance, suggesting that human-mediated transportation could lead to the introduction of new pests. These study results underscore the importance of limiting the introduction and establishment of tree pests and enhancing the resilience of forest ecosystems in response to climate change.

Commodity imports and climatic filtering drive compositional variation in non-native insect establishments

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Invasions of non-native insects can have substantial impacts on agriculture, forestry, human health and biodiversity with considerable economic and environmental consequences. To better understand the causes of this process, it is important to quantify the relative importance of main drivers such as commodity imports vs climatic requirements. To evaluate the relative contributions of these factors in explaining global variation in numbers of non-native insect establishments in different world regions, we conducted direct ordination analyses considering temporal changes in family-level composition and changes in native range composition of established non-native species from 1881 to 2020, focusing on the six most data-rich world regions, North America, Chile, Europe, Australia, New Zealand, and Japan.

At the family level, there were overall temporal changes in the composition of non-native species assemblages, however, were dominated by scale insects prior to 1900 but then shifted to a more diverse set of species while North America exhibited relatively small compositional changes over the entire 140-year period. Changes in the composition of established species were partially driven both by imports and climatic factors, each explaining 8.4% and 5.0% of total variation, respectively. The analysis of native ranges of non-native species indicated that there was no conspicuous temporal variation. Established species in New Zealand were predominantly native to Australasia, and species in North America and Chile were mainly from Europe. Non-native assemblages in Europe, Japan and Australia mainly originated from the Nearctic, Indomalayan, Afrotropic, and Asian regions. Imports had the primary effect (27.0%) on the total variation in the native range composition, although climatic factors in the destination regions also had substantial effects (21.3%). Based on these results, we conclude that both commodity imports and climatic filtering act together as drivers of establishment success for non-native insects in all six regions.

Cross-scale drivers of Sirex noctilio outbreaks in its native and invasive ranges

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: *Sirex noctilio* is a woodwasp native to Europe that has been inadvertently introduced across the world and is a highly destructive pest in southern hemisphere pine plantations. *Sirex noctilio* was also detected in the northeastern USA in 2004 where it has become established but is not currently a major pest to native or plantation forests. However, concern exists over its potential expansion into the vast pine forests of the western and southern USA creating a need to understand how tree- to landscape-scale factors affect Sirex outbreaks to inform risk projections for pine species in the USA. A variety of demographic forces affect local, stand-level Sirex dynamics (e.g.,parasitism, reproduction) but across its intercontinental range, stand- to landscape-scale abundance of *S. noctilio* is consistently linked to the availability of suppressed trees – a consequence of high stocking levels linked to stand management objectives and market value of pine products and to abiotic conditions that affect tree growth and mortality. In this project we will evaluate multi-scale models describing interactions between *S. noctilio* and forests, from individual trees to forest stands to landscapes, to assess key determinants of *S. noctilio* outbreaks and tree mortality in northern versus southern hemispheres. This research will help support management of pine stands affected by *Sirex* and provide updated risk projections for key pine resources in the USA

Detection of a Rhizoctonia Fungus Associated with Vascular Streak Dieback of Ornamental Woody Plant Species in the United States.

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Ornamental nursery production in the United States is currently being challenged by a recently discovered dieback and vascular streaking disorder observed on at least 21 tree and shrub species across California, Florida, Indiana, North Carolina, Oklahoma, Tennessee, and Virginia. The host list includes several economically important North American native tree species including, but not limited to Eastern redbud (*Cercis canadensis*), red maple (*Acer rubrum*), and flowering dogwood *(Cornus florida*). This emerging disorder, named Vascular Streak Dieback (VSD), presents symptoms as plant decline, twig/limb dieback, and vascular system streaking that vary with host plant species. While pathogenicity testing is in progress to confirm the causal agent of VSD, an association with a *Rhizoctonia* fungus tentatively identified as *Ceratobasidium theobromae* sensu lato (syn. *Rhizoctonia theobromae*) has been proposed. The associated VSD fungus is challenging to isolate and grow in culture which complicates identification and assessment of plant pathogenicity. We plan to implement previously developed microsatellite-based methodology used for molecular detection of thousand cankers disease in walnuts, laurel wilt in avocado and sassafras, and oak wilt in oak trees. Our goal is to decrease confirmation time while providing a reliable and rapid detection method for VSD. DNA sequence analysis of a *Rhizoctonia* like isolate sampled from *C. canadensis* in Tennessee identified 985 candidate microsatellite markers and 570 primers were developed for 384, 91, and 95 di-, tri-, and tetra-nucleotide motifs, respectively. Microsatellite genetic markers will be developed and examined for allelic diversity and polymorphism within *C. theobromae* sensu lato and compared to closely and distantly related groups of *Rhizoctonia* fungi. The development of a TaqMan-based probe assay for identifying and detecting *C. theobromae* sensu lato from plant tissue that deploys improved microsatellite and specialized blue wavelength technology to increase cost effectiveness and fungal specificity will be discussed.

Developing an Integrated Pest Management system for the invasive insect, oystershell scale, in Populous tremuloides

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Oystershell scale (OSS; *Lepidosaphes ulmi*) is a regionally important and rapidly emerging invasive insect pest affecting aspen (*Populus tremuloides*) in the interior western United States. Aspen is considered a foundation species with disproportionately high ecological value in this region. Rapid climate change has likely facilitated the emergence of OSS as an agent of aspen mortality and a threat to aspen sustainability in the region. We are developing an Integrated Pest Management (IPM) system for OSS in aspen ecosystems using silviculture, insecticide, and prescribed fire. We will evaluate the efficacy of these treatments using a before-after-control-intervention experimental design, which includes pre- and post-treatment monitoring of treated units and untreated controls. Silvicultural treatments, which include clearfelling and sanitation thinning units, were first implemented in 2019, with additional units treated annually. Limited experimental use of the insecticide dinotefuran will occur in spring 2024, and prescribed fire will be included as resources and opportunities allow. We are also evaluating OSS life cycle timing, voltinism, and survival across elevational and latitudinal gradients. Through continued monitoring of permanent plots, OSS biology, natural enemies, insecticide movement, and non-target arthropods monitoring, we will develop the initial IPM system, which will be refined as new data are collected and interpreted and new sites are added. Through a formal outreach plan, we will develop products for land managers, forest health professionals, and other interested parties about OSS and the status of IPM development. This presentation will present results from our collaboration to date, including OSS geographic distribution, OSS-caused aspen mortality estimates, early results from the silvicultural treatments, and status of IPM system development.

DISTRIBUTION AND POPULATION DYNAMICS OF INVASIVE PESTS OF EUCALYPTS IN CENTRAL KENYA HIGHLANDS

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Eucalypts are native to Australia and are grown in many areas as exotics in the world. There is increasing understanding of spread and distribution of the invasive pests of Eucalyptus in Kenya's forestry systems, however there is paucity of information on their natural enemies, despite the economic loss they cause. A survey was carried out from 2018 to 2023 to determine the trends in population, distribution and parasitoids of invasive insect-pests of Eucalyptus, to implement biocontrol program. A transect cutting through counties in Central Highlands of Kenya was identified and eighty plots inform of woodlots, plantations and on-farm trees assessed for occurrence and infestation severity. In each plot, 50 trees of *E. grandis, E. camaldulensis, E. maculata, E. panculata* and clonal hybrids were individually assessed. Plant materials were collected from sample plots, reared in the KEFRI quarantine facility and parasitoid emergence monitored. Altitude and geographical coordinates were obtained for all plots using a mobile application or GPS apparatus and the readings used to generate distribution maps. Host damage was assessed by assigning different damage category levels as follows: Cat. 1: No canopy damage, Cat. 2: less than 25% canopy damage, Cat.3: between 25%-50% canopy damage, Cat. 4: more than 50% canopy damage. Results indicated that Red Gum Lerp Psyllid was the most prevalent at 47.4% during the dry and wet seasons followed by Eucalyptus Snout beetle 23.2%, Bronze bug 18.9% while Blue gum chalcid was reported at 10.5%. According to the year 2019/2020 results, majority of the trees assessed irrespective of species were 25% attacked (45.11%), followed by those not attacked (30.49%). In 2023, new pests; *Spondyliaspis sp* and *O. maskelli* were identified on Eucalypts. *Eucalyptus camadulensis* had the highest frequency of attack by all invasive insect pests followed by clonal hybrids. Hot spot areas were marked as possible permanent sample plots to be used for monitoring and assessment of parasitoids for implementation of classical biological control program which will enable management of the target insect pests.

Key words: Eucalypts, invasive insect pests, *Thaumastocoris peregrines, Leptocybe invasa, Glycaspis brimblecombei* and *Gonipterus scutellatus,* Central Highlands of Kenya

Diversity of polyphagous Phytophthora species in international retail chains poses a serious phytosanitary risk

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: It has long been known that oomycetes belong among the most dangerous invasive plant pathogens spreading via international trade. Emphasis on the health and safety of traded material is one of priorities of national and international phytosanitary institutions. Given that this issue has been known for a long time, we decided to verify to what extent the relevant measures and control mechanisms were reflected in the quality of the material distributed in the networks of European retail chains.

During 2021 and 2022, 525 samples of 100+ taxa of ornamental conifers (*Cupressus*, *Chamaecyparis*, *Juniperus*, *Pinus*, *Taxus*, *Thuja*) and some other taxa imported from different countries and sold in stores of four of the largest international retail chains were analyzed. The strains were acquired via baiting method and direct isolation and determined by ITS sequencing, cox1 etc.

A total of 71% of samples were found to be positive. A total of 42 oomycete taxa were determined, including at least 25 *Phytophthora* species. Both known and already common in Europe species such as *P. pseudocryptogea*, *P. plurivora*, *P. cinnamomi* and *P. pini* as well as number of less common and lesser-known taxa on these hosts (e.g. *P. chlamydospora xamnicola*, *P.* cf. *multibullata, P. nemorosa, P. nicotianae, P. niederhauseri*, *P. occultans, P.* cf. *ornamentata, P. palmivora, P. xstagnum*) were found; some of them were first detected in Europe. Quite clearly, the environment of big retail chains (network size and operational characteristics – storage, rapid turnover of goods, excessive irrigation, temperature etc.) is very suitable in terms of spread, transition to other hosts and hybridization of these pathogens. In addition, a number of visibly unthriving and infested plants (e.g. by *P. ramorum*) were ruthlessly offered at large discounts and gladly bought by small growers. The distribution of ornamental plants in international retail chains is still one of the significant and insufficiently treated phytosanitary risks.

Early detection tool for Agrilus anxius (Bronze Birch Borer): laboratory and field validation of a LAMP molecular assay

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: *Agrilus anxius* (Bronze birch borer, BBB), a buprestid pest from North America that in its native range attacks weakened or injured birch (*Betula* spp.) trees. However, like other secondary buprestid pests, they can cause significant damage to evolutionary naïve hosts due a lack of co-evolutionary defences. In garden studies, BBB has been shown to cause a significant mortality in the evolutionary naïve European birch trees.

Birch is the third most common species in Sweden and in Finland, and represents up to 13% and 16% of the total timber supply, respectively. It is one of the dominant species in Latvia, constituting 28% of standing forests. In the Nordic-Baltic region, birch is increasingly being planted and promoted in admixtures with other conifers with the aim to diversify and increase resilience in forests against climate change. However, introduction of alien species like BBB could be devastating for the forest sector that is increasing its reliance on broadleaved tree species like birch for the future.

Early detection tools play a critical role to prevent non-native pests and pathogens from being introduced into new areas. Loop-mediated isothermal amplification (LAMP) is a valuable tool that can detect target species with rapid results using environmental DNA in the field. We present work in which a newly developed LAMP assay for BBB is tested both under laboratory and field conditions. Environmental DNA from birch collected from within the infestation areas of BBB in western Canada were tested using a portable Genie II to validate the use of the assay in practice. The results demonstrate the ease of use and ability to readily detect BBB with an efficient, molecular tool to be used for biosecurity tool for European plant protection agencies.

Keywords: early detection, bronze birch borer, LAMP, *Agrilus anxius*, environmental DNA

Ecological and socioeconomic drivers of the biogeographic patterns of global insect invasions

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Biological invasions are largely an unintended consequence of globalization. With increasing mobility, humans have accidentally transported organisms around the world, breaking the geographical boundaries that separated species ranges that persisted for millions of years of evolution. Among animals, insects are the most numerous group of species, with thousands of insect species having been established outside of their native ranges and many of these species causing immense impacts on agriculture, human health and conservation of native ecosystems. Here, we report on an analysis of historical insect invasions in 11 world regions. We use these data to compare frequencies of invasions among different insect orders and among different insect families. Certain groups, such as the Hemiptera, Formicidae and the Staphylinidae are generally over-represented in non-native insect assemblages, while other taxa are under-represented. These patterns generally reflect characteristics of these insects that cause them to enter important invasion pathways and biological characteristics that facilitate invasions. These results ultimately can be of use when conducting invasive pest risk analysis. We also investigated environmental drivers that explain geographical variation in numbers of species in various insect taxa. Results indicate a strong species-area relationship for both native and non-native insects. However, we found that this appears to be driven by an indirect effect of land area affecting plant diversity and that the strongest drivers of insect species richness are native and non-native plant species richness. The substantial effect of non-native plant richness on non-native insect richness suggests that plant invasions create new ecological niches that promote insect invasions.

Effects of Psyllaephagus bliteus on spread of Glycaspis brimblecombei in Western and Eastern, Kenya

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: *Glycaspis brimblecombei* is known to cause 20-30% defoliation, crown thinning and death of eucalypts. The main natural enemy of the pest from Australia is the parasitoid *Psyllaephagus bliteus*, which has been proved to manage *G. brimblecombei.* The current study was designed to evaluate the distribution of *G. brimblecombei* and *P. bliteus* in Western and Eastern, Kenya after National Forestry Resources Research Institute (NaFORRI) released *P. bliteus* in their *Eucalyptus camaldulensis* plantations bordering Western Kenya. Eucalyptus plantations in Western Kenya (Busia, Bungoma and Siaya counties) and Eastern Kenya (Ndufa and Kiamuringa Kenya Tea Development factory plantations in Embu County) were assessed. Ten *E. camaldulensis* trees were randomly selected from each plantation. The Global Positioning System (GPS) Coordinates of the sampled plantations was recorded. Damage categories by *G. brimblecombei* were assigned to sample trees through visual observation. Adult population of *P. bliteus* was assessed by placing two yellow sticky traps on each sample tree. Three assessments were carried out in three different months. Data analysis was carried out using R statistical tool. Distribution maps were drawn using ArcGis to indicate the intensity of spread of the pest and parasitoid in the regions of study. Results showed that Embu County (Eastern Kenya) had the highest *G. brimblecombei* populations 40.67 ± 1.58, recorded in the month of February with damage ranging between 50 – 75%. Tree infestation by *G. brimblecombei* were highly varied across the four counties ($F = 7.44$, $df = 3, 1492$, $p < 0.001$) and time of assessment ($F = 91.91$, $df = 2, 1492$, $p < 0.001$). There were significant variations in the number of exit holes among the counties ($F = 72.72$, $df = 3, 994$, $p<0.0001$) and time of assessment ($F = 5.76$, $df = 2, 994$, $p = 0.0032$). The highest number of lerps with exit holes was highest in both December (1.81±0.21) and June (1.59±0.34) in Bungoma County, indicating that the parasitoid, *P. bliteus* found its way into Kenya. This study will enable initiation of implementation of Bio-control program for sustainable management of *G. brimblecombei* in Kenya.

Key words: *Psyllaephagus bliteus, Glycaspis brimblecombei, Eucalyptus camaldulensis,* distribution, Western and Eastern Kenya

First report and characterization of Fusarium circinatum, the causal agent of pitch canker on Pinus merkusii in Indonesia

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: *Pinus merkusii* is the only pine that occurs naturally in the South of the Equator particularly in the archipelago of Indonesia. Up to 2019, there was no report on disease problems except damping-off. However, In March 2020, dieback symptoms (basal needle dieback, wilting, and dieback of terminal shoot) were first observed on pine planted at the more than 1200 above sea level area. We also found that some bark beetles including *Tomicus* spp were associated with the symptomatic trees. In order to identify and ascertain the characteristics of the pathogen and the diseases, 120 *P. merkusii* trees (with and without symptoms) were collected. Small pieces (1 cm long; two from the roots, stem at the soil level, and the aerial part, also from the leaf, totalling eight pieces) of 20 symptomatic trees were sterilized with 3% sodium hypochlorite, and isolations were performed on potato dextrose agar (PDA). A species of Fusarium was isolated from all infected tissues and pure cultures were obtained by single hyphal tip transfers on PDA, incubated at 25°C for 10 days with a 12-h photoperiod. (1). The species was identified as *Fusarium circinatum* Nirenberg & O'Donnell on the basis of morphological and cultural characteristics (2). They produced white, aerial mycelia, violet pigment, typically three-septate macroconidia with slightly curved walls, single-celled microconidia, and characteristic sterile, coiled hyphae. Microconidia were ovoid or allantoid and born in false heads on aerial polyphialides. (3). Pathogenicity tests were performed by inoculating 5-month-old *P. merkusii* seedlings. Small strips of bark (10 × 1 mm) were cut from the stems and similar-sized pieces of PDA colonized by four isolates of *F. circinatum* were placed in contact with the open wounds and covered with Parafilm. In Total 80 seedlings were provided for pathogenicity tests. First symptoms, basal needle and shoot dieback, were observed at 15 days after inoculation. Between 6 weeks later, all seedlings tested were dead. No symptoms were observed on control seedlings. *F. circinatum* was reisolated from symptomatic seedlings tested. To our knowledge, this is the first report of *F. circinatum* on *P. merkusii* in Indonesia.

First report of Ophelimus maskelli (Ashmead, 1900) (Hymenoptera: Eulophidae) in Uruguay.

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Forest plantations in Uruguay has become one of the higher productive activities for the country, where *Eucalyptus* spp. represents more than the 80% of the commercial plantations. In the last decades the reports of forest pests were exponentially increased. The gall forming insects have caused important injuries in forest plantations worldwide. *Leptocybe invasa* and *Ophelimus maskelli* (Hymenoptera: Eulophidae) are the main gall wasp species in this insect guild. *L. invasa* was found in the year 2011 being the latest *Eucalyptus* insect pest reported for our country. In the summer of the year 2020 we found Eucalyptus camaldulensis leaves with unknown galls in the Tacuarembó city. We collected branches with these galls and the emerged adults were sexed and identified. We observed two species that were determined as a *Ophelimus maskelli* and their parasitoid *Closterocerus Chamalaeon* (Hymenoptera: Eulophide). In this sense, the aim of this work was reported for the first time the presence of Ophelimus and their parasitoid in Uruguay and assess their distribution. In order to evaluate the distribution of *O. maskelli* we realized field trips in *Eucalyptus* plantations and windbreaks in ten departments of Uruguay during February of 2020 to May 2023. When found Ophelimus galls we collected Eucalyptus branches and place in ziplock bags. The samples were kept in a climatic room at 23 °C with photoperiod (12:12) and adult emergences were daily checked. The emerged exemplars were identified, sexed and placed in tubes with 70% alcohol. We found *O. maskelli* galls in six of ten departments sampled. The parasitoid emergences were variable, but in the most of collected sites was higher than 75%. Future prospects will be focus in the study of the impact of this insect pest in the Uruguayan forest plantations and evaluate the parasitism level.

Forest insect biosecurity: what's working, what's not – and what else can we do?

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Considerable effort globally goes into safeguarding against invasions by non-native forest insect species because of their significant environmental, economic, and social impacts. Here, we describe pre-border, border and post-border biosecurity measures that are used to mitigate the arrival, establishment, spread and impact of forest insects, and discuss their successes and limitations using relevant key examples. Some countries (e.g., Australia, New Zealand, USA) have maintained a relatively constant accumulation rate of non-native forest species, despite virtually exponential increases in trade and travel over the last ~150 years, suggesting biosecurity efforts in these regions have had an impact on arrival and establishment. Nevertheless, risk profiles change constantly through globalisation opening new trade pathways and species source pools, and through increased movement of goods and people, and differences in biosecurity strengths between countries. We illustrate the mutual advantages of programs that increase capacity in under-resourced nations to (i) protect their resources and trade, (ii) reduce the flow-on effects of "invasion begetting invasion", and (iii) provide "intelligence" on potential risks.

Risk assessments and pest predictions can be foiled by insects that defy traditional "red flag" metrics and aren't pests in their country of origin, aren't invasive elsewhere, or aren't even known to science until they become invasive. Mitigating these "known unknowns" is challenging; we discuss the utility of border interception data in identifying emerging threats and pathways. There are further dangers posed by pathways beyond our direct control, such as smuggling or the wilful introduction of exotic insects or their hosts, fraudulent practice, ineffective treatment, or deliberate circumvention of biosecurity protocols. We describe post-border surveillance frameworks, including the increasingly important role of citizen science and public awareness in reporting forest pest detections and spread, and reiterate the principle that biosecurity is a shared responsibility that benefits countries, governments, industries, and individuals.

Forest Phytophthora - ecology, diversity and management

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Damage to trees in forests and urban environments caused by *Phytophthora* species are an increasing threat to the vitality and productivity of these ecosystems in many parts of the world, including Sweden. *Phytophthora*, which seriously damages the fine roots of trees and several other woody plants, is efficiently introduced to new environments through imported plant material (mainly non-native plants through the nursery trade). A study was conducted in Southern Sweden aimed to characterise the differences in soil microbial diversity and taxonomic composition between dieback asymptomatic and symptomatic *Quercus robur* trees. The idea is to explore how network community may change across vitalities, and adaptations when there is the presence of oomycetes species and their potential influence on the microbiome. To uncover ecological interactions, the microflora present in soil samples were quantified using a new approach combining high-throughput qPCR Biomark Fluidigm chip technology optimised for oomycete analysis and Next Generation Sequencing. The fungal communities in the soils included a wide range of pathogens and ectomycorrhizal taxa. Amongst the most abundant oomycetes, *Phytophthora plurivora, Phytophthora cactorum* and *Phytophthora gonapodyides* were identified. A specific taxon in the genus *Trichoderma* was strongly correlated with scarcity of pathogenic *Phytophthora* spp. The meta-analysis of the soil microbiome represents an excellent tool supporting the development of biocontrol strategies for the management of diseases caused by *Phytophthora* spp.

From historical cultures to genomic exploration: An investigation of the enigmatic conifer root pathogen Rhizina undulata

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: In the 1970s and 1980s, a number of *Pinus* plantations in South Africa experienced patch death. The causal agent was originally thought to be *Phytophthora cinnamomi*, but the mysterious disease was later attributed to *Leptographium serpens*. However, there was a long-standing debate regarding the ability of *Leptographium* species to act as primary pathogens. This raised doubt regarding the role of this fungus as the cause of the patch deaths. At the time of studying this disease, the available research tools precluded further investigation. In the present study, we revived cultures originally isolated from the dying trees and used DNA sequencing to identify them. *Rhizina undulata* was thus identified as the primary pathogen associated with the disease, some 40 years after it was first studied. Also known as "the coffee fire fungus" because it requires exposure to high temperatures for germination, *R. undulata* is a well-known conifer pathogen, particularly relevant to forestry in Europe and Asia, but surprisingly poorly studied. The availability of cultures arising from the recent reassessment of the patch death problem in South Africa provided the opportunity to further investigate the thermotolerant nature of this enigmatic fungus using modern comparative genomics techniques. The sequenced genome of *R. undulata* was similar to the genomes of other Pezizales species in terms of size and gene content, but it exhibited significant expansions in the heat shock protein 20 (HSP20) and glutathione S-transferase (GST) gene families. Both HSPs and GSTs are known to be involved in heat shock defense in fungi, suggesting that these expanded gene families may contribute to the thermotolerance displayed by *R. undulata*. These findings highlight the importance of preserving cultures for future studies and emphasize the utility of advanced genetics tools in forest pathology.

Genomic biosurveillance of invasive alien tree pests

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Biological invasions by invasive alien tree pests have caused irreversible changes to forest ecosystems worldwide. Early detection for rapid response is key to preventing new invasions or to limit or contain newly established ones. Genomics has provided a new toolbox that is already making a difference in our ability for early detection and rapid response. Rapid and accurate PCR assays are robust and can be used with a variety of host tissues or life stages of insects, fungi and oomycetes. They are used operationally in surveys or inspection activities for the detection of many pathogens, such as the *Phytophthora*, from tree foliage, stems, roots and soil samples. PCR is also widely used to differentiate insect subspecies with different regulatory requirements, such as the Asian and European *Lymantria* subspecies. While PCR targets a few genome regions and is useful for detection, genome sequencing can provide a much fuller picture that can help reveal the genomic signature of the invasion history. The process of invasion, colonization and spread leaves a genomic signature in the invader's genome. This signature can be used to identify populations, assign intercepted samples to putative sources or identify potential pathways. Increasingly, these tools are used routinely in diagnostic labs. By comparing the genomic profile of intercepted samples to global sequence databases, it is possible to assign these unknowns to source populations with high accuracy. Genome reduction approaches, such as target-enrichment genome sequencing, can generate genome profiles at low cost and they can be analyzed rapidly to provide highly accurate results. The capacity to perform DNA-based analyses in the field is causing a shift in paradigm, where samples can be processed rapidly and accurately on-site. Portable PCR assays that can be used on-site are now available and allow rapid and accurate detection and identifications. On-site target-enrichment approaches that can generate genomic data of targeted regions are promising because they can provide taxonomic as well as phenotypic information that will become an essential part of pest-management decision-making.

Genomic insights into the movement of Fusarium circinatum and virulence on the co-evolved host Pinus elliottii

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Pine pitch canker is a serious disease of *Pinus* spp. that is caused by the fungus *Fusarium circinatum*. Endemic in Central and North America and invasive elsewhere, *F. circinatum* is considered one of the greatest threats to pine forests globally. While genomic resources are increasingly available to facilitate the study of this pathogen, little is understood about the interactions between the pathogen and co-evolved pines within its endemic range. Moreover, accurate prediction of host resistance to pine pitch canker is not yet possible. We analyzed *F. circinatum* populations from throughout the southeast United States to investigate relatedness among isolates, identify genetic markers of both pathogen virulence and host resistance, and incorporate the markers into genomic selection models to ultimately improve the resources available to guide the breeding of pitch canker resistant pines. To achieve these goals, disease severity, as caused by 50 different *F. circinatum* isolates on multiple lines of clonally propagated *Pinus elliottii,* is being quantified. Fungal isolates were collected from symptomatic pines throughout the pathogen's endemic range in the southeast United States. Inoculation trials using *P. elliottii* clones provided by the Cooperative Forest Genetics Research Program are being utilized. Whole genome sequences of all isolates have been obtained to analyze relatedness among the populations of the pathogen and to identify genomic regions associated with virulence. Future work will include the comparison of southeast US isolates to those from México and Central America to pinpoint the geographic origin of *F. circinatum*, and sequencing and characterization of resistance genes of the slash pine clones. Genomic selection models will be developed to predict pitch canker resistance more accurately, based on co-associating host resistance and pathogen virulence markers. Examining diverse lines of a co-evolved host and a wide array of isolates will enable investigation of the genomic architecture of resistance, resistance generality to multiple fungal isolates, reveal virulence factors, and identify resistant lines. Better prediction of pitch canker resistance and a stronger understanding of the genetic factors that underpin virulence and host defense are critical for preparing land managers for this emerging invasive threat.

Integrated Pest Management of fungal pathogens in forestry

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Climate change and human activities increase the occurrence, abundance and impacts of fungal pathogens in forests, and these factors increasingly threaten forest productivity and biodiversity. A number of factors currently limit the successful management of pathogens in forests, including the long rotation of forest plantations (compared to agriculture), the limited use, or prohibition of pesticide use in many countries, and uniform stands in plantation forests. More limitations apply to natural forests or protected areas. Integrated pest management (IPM) is an effective and environmentally sensitive approach to pest management that aims to prevent, detect and control pathogens to maintain forest vitality and productivity while reducing negative environmental impacts, but it is currently not widely practiced. Implementation of IPM in forestry would require a switch of traditional, reactive management of forest pathogens to proactive management. However, the problem is complex, as indicated by the diversity of potential pathogens, as well as insect pests, their pathways of introduction and spread, as well as the multitude of factors that affect outbreak dynamics. Thus, promoting healthy and resilient forests by using a holistic approach for IPM should consider multiple risk factors, novel tools and strategies in conjunction with mitigation practices and forest management practices that simultaneously target different pathogens and pests, as well as hosts. In this talk, we provide an overview of ongoing IPM approaches that specifically address pathogens in forestry, identify gaps and propose approaches and needs for effective future management of forest pathogens.

Interactions between invasive pests and pathogens in native chestnut forest

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: The number of invasive pathogens and insect pests in forest ecosystems has increased dramatically in the last century. These introductions often have negative economic and ecological consequences for forest ecosystems and can lead to novel interactions, with unpredictable consequences. Chestnut blight (*Cryphonectria parasitica*) has been present in southern Europe since the mid-20th century and remains a threat to the European chestnut. *Dryocosmus kuriphilus* arrived in southern Europe at the beginning of the 21st century, causing significant losses in chestnut production. Both species can colonize the same trees. To assess the potential interactions between them, we conducted a study in Galicia (NW of the Iberian Peninsula), one of the most important areas for chestnut production in southern Europe. We studied five plots that contained both organisms; in each plot we sampled 10 trees affected only by the insects and 10 affected by both the insect and the fungus. We estimated the level of attack of each tree and analyzed the nutritional quality, water content, and secondary metabolism compounds of five leaves without galls and five leaves with galls from the study trees. We evaluated the effects of these parameters on insect fecundity and larval growth. We also conducted a greenhouse study to evaluate insect preference when offered 20 trees with chestnut blight and 20 healthy trees. In the field, insect attack levels were significantly higher on trees with chestnut blight, especially in plots with a longer attack; however, in the greenhouse, insects displayed no preference for either healthy or infected trees. Chemical analyses revealed no differences in foliar nitrogen or water content of trees affected or not by the fungi. Similarly, the mass of larvae was no different between trees that were healthy or infected. However, the number of eggs per female was significantly higher in trees affected by chestnut blight. There were no differences in the composition of terpenes or phenols between trees. However, the tannin concentration was significantly higher in trees also affected by chestnut blight. Higher tannins induced by chestnut blight may directly or indirectly benefit the gall wasps.

Invasive gall-forming wasps of the genus Ophelimus threaten eucalyptus plantations in Argentina, South America.

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Numerous pests native to Australia and associated with eucalyptus invaded other countries. The genus *Ophelimus* has several gall wasps that are continually expanding and causing damage to the eucalyptus plantation. Two species of *Ophelimus* were detected in Argentina: *O. maskelli* reported in 2013 with its parasitoid, *Closterocerus chamaeleon*, and an unidentified species, *Ophelimus* sp., in 2017. A field survey was carried out in eucalyptus plantations to assess the distribution of *Ophelimus* spp. and *C. chamaeleon*. Twenty-one eucalyptus plantations were sampled from 2017 to 2022, covering four provinces in an extensive productive area. Branches (50-60 cm) with leaves containing developed galls were collected in each plantation. The external morphological aspect of galls was characterized. Adults were identified after emergence according to their morphological characteristics and counted in the laboratory. *Ophelimus maskelli* develops in a single-cell gall and expands to both sides of the leaf blade; galls are round, green, or red and have a smooth texture. Galls induced by *Ophelimus* sp. are also nearly round, smaller, and expand only to one leaf surface; they have a brown-grey color and a rough appearance. *O. maskelli* is present in all provinces sampled in plantations of *E. tereticornis*, *E. camaldulensis*, *E. grandis*, and some hybrids (*E. grandis* x *E. camaldulensis* and *E. grandis* x *E. urophylla*). Besides, *C. chamaeleon* was found at all sample sites. About 14.000 adults (gall wasp + parasitoids) were collected and parasitism ranged from 60 to 100 %. *Ophelimus* sp. was present in Buenos Aires province in *E. viminalis* and *E. cinerea*. Adults of *C. chamaeleon* emerged from galls but in low numbers (parasitism ≤ 0.6 %). In conclusion, *O. maskelli* has a wide distribution and is always associated with *C. chamaeleon*, which seems to contribute to the mortality of the population pest. The spread of *Ophelimus* sp. may represent a threat to eucalyptus plantations in the region. Further molecular studies are needed to identify the pest at the species level. The host range and life cycle of *Ophelimus* sp. and the role of *C. chamaeleon* as a biological control agent of this pest also need to be studied.

LIFE FAGESOS, Phytophthora-induced decline of Fagaceae ecosystems exacerbated by climate change: implementation of improved integrated pest management

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: The outbreak of alien invasive plant pathogens, such as *Phytophthora* adversely impact natural and semi-natural forest ecosystems. Rising temperatures and extreme climatic events are amplifying the impact of *Phytophthora* diseases on evergreen oak and chestnut forests thought the Mediterranean basin. Limited public awareness, sensible human impact on forest areas and the current EU fertilizer regulations restricting the use of the most effective and eco-friendly disease mitigation compound, K-phosphonate, further heighten the risk of disease epidemics. Challenged forest ecosystems need improved tools and strategies to enhance their adaptation to the outlined issue, finally ensuring their preservation as important natural carbon sinks. The project LIFE FAGESOS, started in September 2022, aims to propose and apply new integrated pest management protocols, that can be tailored to specific traits of the target ecosystem implemented by an extensive multi-actor network. The consortium comprises 13 multi-actor partners, including research institutions, enterprises, local authorities and growers and several stakeholders in Italy, Portugal and Spain. Over the first year mesocosm trials, which include new biostimulant and antagonistic microorganisms as well as products already available in the market, have been undertaken to evaluate their potential use, in alternative to K-phosphonate, along with hygiene measures to prevent disease spread. A disease risk model to identify the areas at risk of introduction of the disease and a remote sensing-based monitoring system have been implemented. These tools will support informed decision-making for policymakers and forest managers. Finally, FAGESOS will encourage cooperation among entities involved in forest management and conservation, ensuring a holistic and integrated approach to address the outbreak of plant athogens and enhance forest resilience.

Molecular Characterization and Phylogeny of Foliar Pathogens in Select Native Forest Tree Species in the Philippines

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Foliage diseases have been projected to become more prevalent as sporulation and infection of many foliar fungal pathogens intensify with frequent warm rain events. More intermittent outbreaks of foliar diseases could likely occur in the Philippines during warm and wet seasons, although seasonal drought may slow down foliar disease impact. However, the lack of basic molecular information on many foliar fungal forest pathogens in the Philippines limits fungal identification and understanding of fungal pathogen lifestyles, which further impedes efficient disease management and appropriate phytosanitary measures. This study characterized the morphological and molecular features and elucidated the phylogenetic relationships of foliar fungal pathogens on Philippine native trees and palms. Examinations from pure cultures and DNA of fungal pathogens isolated from symptomatic tissues of native species such as *Pterocarpus*, *Litsea*, *Pongamia* and *Areca* revealed common and unique tropical foliar pathogens including one that is potentially causing new disease on native palm species. While information from this study contributes to the global fungal identification system for pathogen surveillance and plant quarantine, further investigations are needed to fully understand the impact of fungal foliar pathogens on forest ecosystems and industries.

Morphological and Molecular Identification of Pine Bark Beetles Infesting Pinus kesiya in the Philippines: Insights for Pest Management

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Pine bark beetles are considered to be one of the most destructive pests of Pinaceae in North America and Central America where most species are found to be native. Outside their native host range, pine bark beetles can cause widespread mortality in novel and more susceptible host trees. In the Philippines, *Ips calligraphus* (Germar) is known to infest Benguet pine, *Pinus kesiya* Royle ex Gordon, since 1966 and is now widespread in Northern Luzon. In a recent study, species of *Ips* DeGeer and *Dendroctonus* Erichson were found to infest *P. kesiya* in Benguet, but no morphological evidence was provided. This study aimed to identify pine bark beetle specimens collected from Benguet and Pangasinan, Philippines, based on morphological characteristics and molecular analysis using the mitochondrial *cytochrome c oxidase subunit I* (*COI*) gene. PCR amplification of the *COI* fragments was carried out using the barcoding primers LCO1490/HCO2198 and validated through agarose gel electrophoresis before being subjected to bidirectional Sanger sequencing. Results revealed that pine bark beetles collected from Baguio were species of *Xyleborus* Eichhoff based on a combination of antennal, pronotal, and elytral characters. On the other hand, specimens from Pangasinan were identified as *I. calligraphus* based on their elytral declivity features, confirming previous reports. Molecular analysis supported this finding, with *I. calligraphus* sharing 99.7% identity with an *I. calligraphus* accession in GenBank. However, for the *Xyleborus* sp. specimen, the best hits, *X. dryographus* (Ratzeburg) and *X. vulcanus* Perkins, only shared 87.4% and 86.8% identity, respectively. Further study on the diversity and distribution of pine bark beetles in the Philippines is needed in order to establish a more accurate basis for morphological and molecular identification, and ultimately contribute to the ongoing pest management program in the country.

Natural regeneration of beech on Phytophthora-infested soils

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Fungal-like, oomycetes of the genus *Phytophthora* are increasingly found in European beech forests where they damage the roots of the trees, weaken the trees and make them susceptible to other disturbances. The infection in the soil cannot be eradicated and therefore new plants may also be affected by the pathogen. The *Phytophthora* spp. can be spread with nursery plants, and natural regeneration could therefore be a better alternative to regenerating forests. However, there is very little information on how naturally regenerated plants are affected by the pathogens already present in the soil. The study explored whether the natural regeneration and seeds were already infected by the pathogen at an early stage of development. We had a unique opportunity to study this issue in a protected area where the *Phytophthora* infection was found in a 120-year-old beech forest where natural regeneration started without grazing damage. Small beech seedlings (2-3 years old) and seeds were collected to study, by means of microscopy, cultivation tests and molecular methods, whether the plants and seeds were already infected by the same *Phytophthora* species found in previous studies in the large trees and in the soil. The results of the study showed that *Phytophthora* was not widespread in the plant material since it was found in only one seedling out of the ninety sampled, and in any of the seeds collected. The research was carried out as a collaboration between SLU Alnarp and Söderåsens National Park (County Administrative Board of Skåne) with the aim that results could be translated into practical advice to stakeholders regarding regeneration strategies. This study is one of the first studies that examines the practical possibilities to adapt to *Phytophthora* damage in forest environments.

New fungi associated with sentinel plants from North America in Italy

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Sentinel plants are used to detect potentially harmful organisms before they are introduced to new countries. Through the project, "A global, reciprocal sentinel gardens approach to assess risk of invasion by alien pathogens and insect pests of important woody plant species", led by Pierluigi (Enrico) Bonello at Ohio State University, *ex patria* sentinel plantings were established in Florence, Italy, in 2019 using seven North American tree species. Monitoring led to the detection of leaf lesions on the plants. Subsequent isolations and Sanger sequencing for multiple genes were performed. Sixty-seven different strains were obtained, of which: 25 were known to be pathogenic on these hosts; 7 are considered new species or subspecies; 10 have not yet been determined to species level; 13 were not known to occur in Europe; 5 are widely distributed but not known to occur on these hosts; and 7 are considered to occur in Europe but not on these hosts. For 10 selected strains, pathogenicity tests were conducted in plants and on detached leaves in the laboratory, using both spore suspensions and mycelium slurries for inoculation. Results of the study are forthcoming and will be discussed at the meeting.

New insights on the Ophiostoma novo-ulmi – Geosmithia associations

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: In Europe as in North America, elms are devastated by Dutch elm disease (DED), caused by the alien ascomycete *Ophiostoma novo-ulmi*. Pathogen dispersal and transmission are ensured by local species of bark beetles, which established a novel association with the fungus. Elm bark beetles also transport fungi of the genus *Geosmithia* that are also found in scolytids' galleries colonized by O. *novo-ulmi*. Widespread horizontal gene transfer between *O. novo-ulmi* and *Geosmithia* was recently observed.

The relation between these two fungi in the DED pathosystem, i.e., *O. novo-ulmi* and *Geosmithia* species from elm, including a *G pumila* GFP-tagged strain, were grown in dual culture, and mycelial interactions were observed by light and fluorescence microscopy. Growth and sporulation of *O. novo-ulmi* in the absence or presence of *Geosmithia* were compared. The phenotypes of the two fungi were also characterised individually and in dual culture using phenotypic microarray (PM) techniques. The impact of *Geosmithia* on DED severity was tested in vivo by co- inoculating *Geosmithia* and *O. novo-ulmi* in elms. A duplex qPCR molecular technique was also developed to identify the presence of both fungi within elm plants and on the body of elm bark beetles.

The results of the numerous tests show a close and stable relation between the two fungi, and that some *Geosmithia* strains exhibits aggressiveness (*in vitro*) towards *O. novo-ulmi*, and we observed hyperparasitic behaviour of *Geosmithia*. These results prove the existence of a new component in the complex of organisms involved in DED, which might be capable of reducing the disease impact on elm trees.

Overcoming the invasion paradox: Population genomics and phenotyping provide clues to the repeated emegence of P. ramorum in the US and Europe

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Oomycete pathogens threaten food, fiber, and forests around the world. *Phytophthora ramorum*, the causal agent of sudden oak death has repeatedly emerged in both the Western USA and Europe. Divergent lineages of *P. ramorum* have survived millions of years reproducing primarily clonally. A phenomenon, known as Muller's ratchet, predicts that asexual populations experience a high genetic load increasing their risk of extinction. However, most outbreaks of introduced exotic plant pathogens are the result of clonal expansion from a single introduction. The separate outbreaks of EU1 and NA1 in forests of the western United States, replicated natural experiments, can be used to understand this invasion paradox. Populations of the EU1 (n =160) and NA1 (n =135) were sequenced and phenotyped to examine how mutation impacts epidemic development. These samples were collected during the first 5 years of each epidemic. Re-sequenced populations yielded 106,070 high-quality SNPs in genic regions; 55,913 were polymorphic within NA1 and 22,700 within EU1. Low diversity in the EU1 population is contrasted with higher cryptic diversity in the NA1 population. These differences are mostly attributed to losses of heterozygosity (LOH), a chromosomal aberration resulting in the spontaneous loss of one allele or chromosomal regions in the diploid genomes. LOH is correlated with reduced aggressiveness, sporulation, and growth rates in most NA1 isolates. However, there are rare examples of increased aggressiveness. LOH is much less prevalent and less severe in the EU1 population. This implies that there may be a system regulating LOH, or that there is a reproductive mechanism that is more dysfunctional in the NA1 population.

Pathogen evolution in the era of globalism: case study with invasive Cronartium ribicola and native Cronartium comandrae hybrids in North America

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Invasive pathogenic fungi increasingly threaten tree species resulting in possible fundamental ecosystems changes around the globe. Besides being more aggressive towards new hosts, non-native fungal species carry additional risks for the health of forest ecosystems via interactions with native species. Interspecific hybridization plays a key role in the evolution and emergence of novel fungal pathogens, and when it occurs between native and invasive species, can lead to unforeseen and potentially serious consequences. Early detection of hybrids, before they become prevalent in ecosystems, can help resource managers develop timely risk-assessment strategies. The objective of this study was to determine whether hybrids (CrxCc) of two rust species, non-native invasive to North America *Cronartium ribicola* (Cr) and native *C. comandrae* (Cc), previously detected in Canada, were present in forest ecosystems of Wyoming and Colorado, USA. In total, 726 and 1452 individual aecia from 178 lodgepole (*Pinus contorta* ssp. *latifolia*) and 357 limber (*P. flexilis*) pines were collected from 25 sites in 5 national forests from 2019-2021. Using morphological and molecular analyses, 71 aecia collected from 25 *P. flexilis* trees had intermediate morphology and contained heterozygous SNPs in the Dcon10 and Dcon35 genomic regions. Population analyses revealed the presence of 4 and 9 CrxCc hybrid genotypes in Dcon10 and Dcon35, respectively. The distribution of these genotypes varied by geography and year. Different CrxCc aecial genotypes were frequently sampled from the same cankers in the same year, indicating multiple independent hybridizations and perennial presence of CrxCc. Aeciospores from 2 CrxCc aecia were capable of infecting the alternate host *Ribes nigrum* and produced urediniospores on *R.nigrum*leaves in a growth chamber. Overall, these results suggest that, even though low in frequency, CrxCc is persistent in the studied region, and has pathogenic potential. Hybrid expansion into the large range of susceptible pines could have cascading impacts on forest ecosystem health.

Pathogenicity of Oomicetes Isolated from Declined Alders in Spain

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Alder decline is caused by different oomycetes, such as *Phytophthora alni* species complex and *P. plurivora*. This disease affects alder, one of the most ecologically important riparian tree species. The pathogens mainly affect the root and the lower parts of the trunk, producing bleeding cankers, as well as crown dieback and yellowish leaves. Solla et al. (2010) detected *P. alni* complex species in Spain for the first time, where a decrease in alder population has been detected in recent decades. As a response to this problem, we are performing a research program on alder protection and restoration against the oomycetes causing the alder dieback. The aim of this work was to evaluate the pathogenicity of the oomycete species involved in the alder decline. To this end, we have identified different oomycetes on the wood and soil of affected alder trees coming from different places of Spain to perform pathogenicity tests. The pathogenicity of the different oomycete species was tested on alder seedling through different inoculation methods: by flooding, by watering and by bleeds, using mycelia and zoospores. Differences in pathogenicity among oomycetes was detected and discussed in the context of the alder decline.

Keywords: Oomycetes, Phytophthora spp.*, alder, alder decline, pathogenicity*

Patterns and drivers of Scolytinae invasions in the Southern Hemisphere

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Non-native insect invasions are increasing globally and can have significant negative effects on forest ecosystems. While forest insect invasions have been mainly studied in the Northern Hemisphere, there is a significant knowledge gap regarding the Southern Hemisphere. By filling this gap, we can gain a more comprehensive understanding of global invasion patterns and dynamics, allowing us to better predict and respond to future invasions. Scolytinae (Coleoptera: Curculionidae) are a diverse group of forest insects known for their successful invasion abilities and role in tree mortality. We explored geographic invasion patterns of Scolytinae in countries of the Southern Hemisphere and evaluated the importance of potential invasion drivers, including trade volume, climatic similarity and heterogeneity, and forest heterogeneity. Analyses were conducted separately for main feeding guilds: ambrosia beetles, bark beetles, and seed and twig feeders. We identified a total of 75 non-native Scolytinae species in the Southern Hemisphere, with Brazil having the highest number of established species (31), followed by South Africa (21) and Australia (19). We found a positive relationship between species host breath (number of plant families) and the number of colonized countries. We observed contrasting patterns and drivers explaining the number and origin of non-native species among feeding guilds. Non-native ambrosia beetles were predominantly native to the Indo-Malay region (55%), and climatic similarity between the donor region and the recipient country was the factor that best explained this pattern. Most established bark beetles were native to the Palearctic region (65%), and the variable that best explained this pattern was the trade volume between the donor region and the recipient country. The origin of seed and twig feeders was dominantly tropical: Afrotropic (32%), Neotropic (23%), and Indo-Malay (23%), and this pattern was related to forest and precipitation heterogeneity and import volume. Overall, our results suggests that difference in biological traits of each feeding guild influences their invasion process in the Southern Hemisphere. It highlights the importance of international trade on bark beetle invasions, while climatic conditions appear to be the key factor for ambrosia beetle invasions, and a combination of several drivers affects the invasion of seed and twig feeders.

Peekers and Streakers: Voyeurism into genomics of a Vascular Streak Disorder isolate

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Recent emergence of dieback and vascular streaking disorder (VSD) has been reported in several states in the eastern USA and recovered from more than 20 different tree and shrub species. The affected plant species include ecologically important native plants and economically valuable ornamental crops that are grown and sold for use in managed landscapes, parks, and restoration projects. VSD manifests in infected host plants with symptoms such as dieback, general plant decline, and streaking in stems. Despite ongoing pathogenicity testing, the exact cause of this disorder remains elusive. Our preliminary evidence suggests an association with a *Rhizoctonia*-like fungus tentatively identified as *Ceratobasidium theobromae* (syn. *Rhizoctonia theobromae*). As we address the challenges associated with isolating and maintaining the cultures in laboratory conditions, there is a notable knowledge gap in the genomics of the fungus suspected to cause VSD. Whole-genome Illumina sequencing of a local isolate from VSD-symptomatic *Cercis canadensis* in Tennessee has yielded valuable insights into its genomics. Assembly of the approximately 9kbp nuclear rDNA region from the Tennessee isolate is serving as a reference for mapping the available reads from 82 Ceratobasidiaceae isolates, including *Ceratobasidium* (n = 14), *Rhizoctonia* (n = 50), and *Thanatephorus* (n = 18) generic representatives. Variant analysis revealed that the Tennessee isolate is clustered with other *Thanatephorus* isolates, suggesting a separation between *Ceratobasidium* and *Rhizoctonia* clades that have been collected from different host species. Successful mitochondrial assemblies have not yet been obtained, however, when the *R. solani* mitochondrial genome is used as a reference, only 10 of the 88 Ceratobasidiaceae isolates and yielded sequence variants. No differences were observed between the Tennessee isolate and the reference *R. solani* mitochondrial genome. This evidence supports rDNA mapping results, in which the Tennessee isolate was grouped within isolates representing the perfect stage of *Rhizoctonia* - *Thanatephorus*. To facilitate the assembly of a high-contiguity nuclear genome for the suspected VSD causal agent, and to allow classification of the Tennessee isolate within the Ceratobasidiaceae family, an analysis of long-molecule DNA sequences is ongoing.

Performance of emerald ash borer (Agrilus planipennis) on three European Fraxinus species

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Emerald ash borer (EAB - *Agrilus planipennis*) is a wood-boring beetle native from East Asia that following its accidental introduction into North America in the early 1990s, caused widespread mortality of millions of ash (*Fraxinus* spp.) trees. In Europe, EAB was first detected in Moscow in 2003 and shown to have the potential to kill native European ash (*F. excelsior*). Since then, the beetle has spread westward and in 2019 it was confirmed in Ukraine. EAB is expected to further spread across Europe due to both natural dispersal and anthropogenic activities. Meanwhile, in the last few decades, large-scale decline and mortality of European ash has resulted because of the invasive fungal pathogen *Hymenoscyphus fraxineus*. The combined effect of these two threats could prove to be highly destructive, posing a serious risk of extinction for European ash. Additionally, other European *Fraxinus* species are affected by ash dieback, including *F. angustifolia* and *F. ornus* to a lesser degree, but may be severely impacted by EAB.

In this study, we aimed to: i) investigate the volatile profiles of the three native European *Fraxinus* spp. to explore potential host selection cues for EAB and how it influences EAB performance, and ii) characterize host tree defences involved in the interaction of EAB and in trees with dual stressors *H. fraxineus* and EAB. The study utilizes saplings of three European ash species: *F. excelsior*, *F. angustifolia* and *F. ornus*. For each species, 10 replicate trees were subjected to one of three treatments i) healthy controls, ii) *H. fraxineus* inoculated, and iii) trees infested with EAB and inoculated with *H. fraxineus*. Volatile organic compound emission will be analysed using gas chromatography-mass spectrometry to examine quantitative and qualitative variation among host volatile profiles in relation to larval survival and development. To look for interspecific differences in host chemical defences, phenolic metabolite extracts from phloem tissue will be analyzed using liquid chromatography–mass spectrometry. The results of this study provide insight into the performance of EAB on European native *Fraxinus* species and the phytochemical traits involved in the interaction between EAB and *H. fraxineus.*

Pests and diseases of Cinnamomum cassia in Vietnam

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Cinnamon (*Cinnamomum cassia* Blum) is a valuable multi-use tree in Vietnam. It is extensively utilized in the food, medical, pharmaceutical, and animal husbandry industries and play a significant role in the economy of highland regions, alleviating poverty particularly among ethnic minorities there. It is prioritized as a non-timber forest product in Vietnam's afforestation programs, and some 200,000 hectares have been established across several provinces. However, damage from bark and leaf pests, as well as shoot and root pathogens reduce the quality of these trees and are a challenge to sustainable cultivation. Comprehensive surveys have been undertaken to accurately identify the full range of pests and diseases present so that more targeted control measures can be implemented.

A total of 50 species of pathogenic fungi, oomycetes, and algae were identified, including 37 new records specific to cinnamon in Vietnam. Additionally, three potentially new species were discovered. Pathogenicity testing using excised cinnamon branches revealed that out of the 78 tested isolates, 15 caused very severe lesions, 18 caused severe lesions, 13 caused moderate lesions, 21 caused small lesions, and 11 were non-pathogenic. The most frequently isolated pathogen was *Phytophthora cinnamomi*, as well as *P. heveae, P. multibullata, P. × vanyenensis*, and an undescribed *Podosphaera* species which cause root rot,wilting and powdery mildew. Other frequently observed diseases were witches' broom (Phytoplasma), leaf spot (*Collectotrichum* spp.), and stem canker (*Diaporthe* spp).

Eighteen pest species from 16 families and 5 orders were recorded to affect cinnamon in nurseries. White-striped flower thrips (*Echinothrips americanus*) emerged as a severe pest of cinnamon in both Yen Bai and Quang Nam nurseries. Of these 65 species were causing harm in Yen Bai and 45 species in Quang Nam. Dominant pest species in forest plantations included the Vietnamese oak silkworm (*Cricula vietnama*), the nine-spotted moth (*Biston suppressaria*), the grayish-brown moth (*Krananda semihyalina*), and the bark borer (*Aetherastis grandisalba*).

These surveys have provided valuable information for growers and managers, enabling them to promptly identify and address potential threats with appropriate treatments. Addressing these challenges is crucial for enhancing productivity, ensuring sustainable cinnamon cultivation, and fostering environmental protection in Vietnam.

Pests and diseases of Macadamia in Vietnam

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: The macadamia tree has been successfully introduced and cultivated in Vietnam for its highly valuable nuts. Its economic significance, coupled with adaptability to various climatic and soil conditions, in areas of the highland regions of the Northwest, Central Highlands, Northeast and North Central Coast, have led to widespread plantings which in 2022 totalled ~ 30,000 hectares; ~10,000 hectares dedicated to pure cultivation and 20,000 of mixed species (Vietnam Macadamia Association).

However currently the health of Macadamia trees in Vietnam is being negatively impacted by a range of pests and diseases damaging leaves, flowers, fruits, and branches. This research summarises comprehensive surveys of the pests and diseases of Macadamia trees in nurseries and cultivated plantations in the Northwest (Lai Chau, Dien Bien, and Son La) and Central Highlands (Dak Lak and Gia Lai) regions. A total of 12 harmful insect species, belonging to 8 families and 5 orders have been identified in nurseries. Among them, the most significant is the Red-Banded Thrip (*Selenothrips rubrocinctus*). Five fungal species from three families and three orders have been identified, with *Colletotrichum fructicola* recognized as the most damaging fungal pathogen pathogen in macadamia nurseries. In cultivated plantations, a total of 19 harmful insect species belonging to 13 families and 5 orders have been identified, with the Black Citrus Aphid (*Toxoptera aurantii*) causing the most damage. Sixteen fungal pathogens from 8 families and 7 orders have been identified. The most notable is *Phytophthora cinnamomi*, an oomycete responsible for gummosis on trunks and branches, and *Eremothecium coryli* which causes yeast spot the macadamia nuts.

This information from this comprehensive investigation provides invaluable insights which will assist managers and macadamia growers to select appropriate management strategies, particularly organic approaches. By doing so, they will mitigate the potential threats of future outbreaks and enhance the productivity and quality of macadamia nuts from Vietnam.

Phytophthora species associated with alder declined forest in Spain

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: The riparian forest ecosystems have an especial importance for the maintenance of the balance with the hydric sources in our country. Alder (*Alnus lusitanica*), one of the most important trees that conform this ecosystem, is affected by the alder decline, caused by pathogenic oomycetes including in the *Phytophthora* genus. *Phytophthora alni* complex includes *Phytophthora xalni*, *Phytophthora uniformis* and *Phytophthora xmultiformis* as the principal oomycetes described. The objectives of the work were to identify the *Phytophthora* species associated to alder decline in Spain. For this purpose, multiple unexplored river ecosystems in the Northern and Western Spain were sampled in areas were the disease has been described. Oomycetes identification was performed by extracting DNA from the alder wood and mycelium of isolated oomycetes and analyzing by conventional PCR, and qPCR, with specific primers to amplify the ITS region. Preliminary results show that in addition to *Phytophthora* species, many oomycetes could be involved in the disease. We have isolated other oomycetes like *Globisporangium* sps. and *Phytophytium* sps. that were found in other plant trees described as pathogens. This study will help to know more about *Phytophthora alni* complex and also for the management of this decline via biocontrol treatments.

Key words: Oomycetes, *Phytophthora alni* species complex, alder, alder decline.

Predicting the European Invasion of the Oak Lace Bug: A Species Distribution Modelling Perspective

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Biological invasions pose significant threats to ecological and economic stability worldwide. The oak lace bug (*Corythucha arcuata*), a North American species, has rapidly spread across 24 European countries in just two decades, signalling its potential establishment as a major pest for European oak communities. This invasive species has the potential to negatively impact oak growth, vitality, and reproductive success in both the short and long term. To effectively understand and manage its environmental impact, it is crucial to conduct a comprehensive assessment of its distribution and identify risk areas for further spread within Europe.

In this study, we gathered presence data from 19 countries using various sources, including expert observations, citizen science reports, and GBIF data, which were meticulously verified by national experts. By employing advanced machine learning techniques, we developed a species distribution model that incorporates both current and future climate conditions, with the distribution of host species acting as a covariate. Additionally, we conducted environmental systematic sampling to account for the non-equilibrium of the invasive species with the environment and removed geographically distant absences that were environmentally close to the presence data.

Our findings highlight the dual role of climate and host species in driving the distribution of the oak lace bug in Europe, with the potential distribution of sessile oak and Turkey oak emerging as important predictors. Currently, the species is mainly confined to the southern regions of Europe. However, considering the distribution capacity of the species, climate change dynamics, and potential host distribution, it is likely to expand its range into new territories in Central and North-eastern Europe.

This study provides a comprehensive dataset of the oak lace bug's current presence as well as its potential distribution under different climate change scenarios. This dataset serves as a valuable tool for forestry and environmental science professionals, facilitating the development of integrated monitoring and pest management strategies that protect forest ecosystems and human health.

RELATING FARM AND LANDSCAPE TREE STRUCTURAL PROPERTIES TO FALL ARMYWORM (Spodoptera frugiperda J. E. Smith) MANAGEMENT IN AFRICA: EVIDENCE FROM ZAMBIA

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Fall armyworm (FAW) is a serious agricultural pest threatening food and livelihood security in the continent of Africa. This pest is challenging to control due to its resistance to pesticides and genetically modified cultivars, and high pesticide costs. To find environmentally friendly and cheap options for managing this pest, agroecological options are being considered as a priority research area globally. This study aimed to understand the influence of farm and landscape-level tree characteristics on FAW damage and incidence, natural enemies, and maize yield in Zambia. The study established 90 circular tree survey plots across the three major agroecological zones during the 2019/2020 crop season. Farm tree data included species identification and diameter at breast height, while landscape tree cover was estimated using remotely sensed data in QGIS and R. Data on maize yield, natural enemies, FAW incidence, and damage were made available by the NORAD Project team. Multiple linear regression and Kruskal Wallis test with Dunn multiple pairwise comparison tests were used to model the effect of each predictor variable.

The results indicate that FAW incidence and damage declined with increasing farm-level tree diversity and landscape-level tree cover, but landscape-level tree cover was only marginally significant. Farm-level tree basal area was not significantly associated with FAW incidence or damage. The abundance of natural enemies did not significantly associate with landscape tree cover, but farm-level tree diversity and tree basal area were negatively associated with natural enemy abundance. However, none of the tree cover variables were significantly associated with maize grain yield, due to the overall low FAW incidence and FAW damage in this study.

Overall, the study concludes that tree diversity and landscape tree cover have a positive effect on controlling FAW abundance and damage, which should be considered when designing tree-based agroecological options for FAW management. The findings have important policy implications for natural resource management and the design and deployment of sustainable integrated pest management (IPM) technologies for managing FAW in Africa and other invaded regions.

Risk of oak wilt further north: exploring linkages between potential vectors and springtime oak phenology in North America

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Oak wilt, caused by the invasive pathogen *Bretziella fagacearum,* is currently confirmed in 24 states in the U.S., including Michigan. Canada, where the DNA of the pathogen has been detected on beetles known to transmit the disease, is at risk of oak wilt becoming established. The disease has been present throughout the Lower Peninsula of Michigan and just near the Wisconsin border in the Upper Peninsula of Michigan for decades with no apparent expansion across the Upper Peninsula. In a cooperative international effort, vector activity, climate variables, and spring bud phenology were monitored at sites across the Upper Peninsula, Michigan (including one control site with oak wilt), and partner sites across Canada (including Ontario and New Brunswick). Our objectives are to evaluate timing and relationships between host phenology, nitidulid beetle vectors, and environmental factors potentially limiting oak wilt progression north. As these factors are impacted by human movement of materials and climate change, a better understanding of northern expansion risk is critical for oak wilt prevention.

Since 2021, each partner site has used three methods of trapping beetles: artificial wounding of oak trees and windvane and Lindgren traps baited with nitidulid pheromone and fermenting bread dough. At least eleven species of nitidulids have been collected from artificial wounds in Michigan and in Canada, including known oak wilt vector species at sites without the disease. Additional nitidulid species have been collected in traps including new records. In the 2021-2022 spring field seasons, nitidulids were observed in traps well before being collected in wounds, suggesting attractiveness to wounds may be delayed compared to flight traps, potentially not until leaves were expanded. Bud phenology was included in 2023-2024 field protocols, allowing the exploration of relationships between vectors and host phenology. We anticipate models incorporating vector flight and degree days with observable tree phenology may allow managers to refine the high-risk prevention period. This may allow improved predictions of when the disease will expand beyond its current northern range increasing preparedness.

Science to underpin international standards for the international movement of forest products

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Global forests are integral for regulating water cycles, contributing to carbon sequestration, and providing habitat that supports biological diversity while also playing an important role in supporting the economy through sustainable harvesting for forest product trade. However, global trade of forest products presents a potential pathway for pests to enter novel forests. To reduce the risk of pest movement associated with traded products, phytosanitary measures such as treatments to eradicate pests are fundamental. Applying pest-risk reduction measures prior to moving forest products provides a safeguard that reduces the risk of post-entry incursions, and the reliance on resource-intense surveillance, quarantine and eradication programs.

Gathering efficacy data on treatments that reduce pest risks underpin the development of standards for phytosanitary measures. Guidelines for the implementation of phytosanitary measures are outlined and described in regional and international standards for phytosanitary measures. Creation of these standards requires science to ensure practical, environmentally and economically feasible recommendations. Standards are subject to review and updating as more data becomes available.

A current example of science supporting regional and international standards for phytosanitary measures is the use of a carefully calibrated heat treatment apparatus to determine the specific lethal dose (time and temperature) for forest product pests. Current research findings will be presented.

Sentinel plantations in China – early warning for threats to economically important European and North American tree species

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Non-native Invasive tree pathogens and insect pests have caused significant damage to global forest ecosystems and industries. The increasing frequency of invasions is attributed to economic globalization, changing land use, and environmental change. Sentinel gardens are a versatile method that uses host trees planted in a non-native range (ex-patria planting) to document potentially new damaging agents to the country/continent of origin of those planted trees. At least in principle, this method can effectively detect non-native invasive pathogens and insect pests in advance of their potential intercontinental movement. Through an international collaborative project, we established twin plantations of North American and European tree species in Nanjing, China in 2021. Equivalent plantations, using identical planting schemes, were established in Alnarp, Sweden, and Florence, Italy, with Asian and North American species, and in Columbus, Ohio, and Portsmouth, New Hampshire, in North America with European and Chinese species. We then monitored the trees for signs and symptoms of pathogen attack for two years, followed by fungal pathogen isolation and identification through morphological and molecular methods. The aim of this sub-project is to proactively identify potentially invasive and damaging pathogens present in China that may threaten trees in North America and Europe if they ever reached those shores.

Spatially implicit models to explore the utility of Wolbachia infection to control forest diseases vectored by insect pests

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Many forest diseases are transmitted by insect vectors, and manipulation of the contagious properties of the vector population plays a key role in suppressing disease spread. *Wolbachia* is a symbiotic intracellular bacterium that is harboured by many species of invertebrates, including insects. Recently, it has been reported that some *Wolbachia* can suppress the propagation of plant pathogens in insect vectors and reduce vector competence. In addition, *Wolbachia* has a desirable property to spread autonomously among vector populations via cytoplasmic incompatibility, which confers a fitness advantage to *Wolbachia*-carrying insects over non-carrying ones. If we can find conditions under which artificially established *Wolbachia*-carrying vectors can spread within wild populations, then the release of such vectors may effectively control the spread of forest diseases over large areas.

In our study, spatially implicit models that account for the mating behaviour of both sexes are used to explore the desirable conditions in which *Wolbachia*-carrying insects can propagate in the early stages of release. We conduct simulations with the model parameterized to represent two types of insects: coleopteran-like insects, which are long-lived and capable of multiple mating but have low daily reproductive rates, and lepidopteran-like insects, which are capable of mating only once per generation, have an ephemeral reproductive stage, and have high reproductive rates. We change key parameters related to the degree of cytoplasmic incompatibility, the vertical (transovarial) transmission rate, and the reduction rate of vector competence. Specifically, Allee effects (the positive relationship between population size and per capita growth rate) caused by mate-location failure in the very low-density situations are incorporated into the models. We will discuss which type of insects and what condition and how many inoculations are required for successful *Wolbachia* applications in practical forest disease management.

Specific isothermal DNA amplification assays for biotypes of the Myrtle rust disease pathogen Austropuccinia psidii

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: *Austropuccinia psidii* is a fungal rust pathogen causing myrtle rust disease to trees in the Myrtaceae around the world. At least four different biotypes have been described and are distributed in distinct geographic regions: the pandemic biotype largely at Hawaii and within regions of Oceania and Southeast Asian, Central America, the Caribbean and Colombia; the South African biotype in South Africa; and the guava and eucalypt/rose apple biotypes in South America regions. Potential introductions of biotypes to other regions are a cause of great concern as bioclimatic modeling has identified suitable conditions for their movement into new geographic areas. For example, the eucalypt/rose biotype poses a threat to Hawaii, Australia, and New Zealand, while the pandemic biotype threatens regions in Brazil and Uruguay. To distinguish *A. psidii* biotypes and monitor their potential movement, we designed specific and sensitive isothermal DNA amplification assays for the four characterized biotypes. These assays have been tested using purified DNA as well as crude-extracted DNA from *A. psidii* spores collected in the field, with ongoing testing by collaborators around the world. These assays are also currently being used to monitor sentinel plantings in Hawaii. Preliminary results show that the developed assays can be used with little technical expertise and inexpensive equipment, making it useful for field monitoring. The assays will help in the development of regulatory protocols for preventing spread into new areas and improve management strategies for minimizing the damage caused by *A. psidii*.

STRENGTHENING PHYTOSANITARY RESEARCH PROGRAMMING AND COLLABORATION: FROM EUROPEAN TO GLOBAL PHYTOSANITARY RESEARCH COORDINATION

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: In a world of increasing global trade and movement of people, the risks to trees from the introduction and/or outbreaks of pests have increased significantly in recent decades.These challenges are truly global in nature and require significant capacities, resources and sophisticated infrastructure that cannot be found within the limits of a single country. The Euphresco network for phytosanitary research coordination and funding started in 2006 to support phytosanitary research programme owners and programme managers to develop and take advantage of synergies amongst national research programmes and activities in Europe. The success of Euphresco as a primarily European network for phytosanitary research coordination has set the ground for discussions on the development of initiative(s) to address the needs of other regions of the world and on global phytosanitary research coordination.

The EUPHRESCO III project aims to enhance national and regional phytosanitary research coordination and to set the foundations for global phytosanitary research coordination. The project will focus on i) the development of a global strategic research agenda, ii) the organization of joint transnational calls on shared research priorities and iii) the shaping of governance, structures and operations of a global network for phytosanitary research coordination. These activities will be shaped through bottom-up alignment actions that involve research stakeholders and top-down alignment actions that involve research funding organizations.

During the project, capillary consultations of stakeholders (i.e. policy makers, research funders, scientists, industry, farmers and foresters, civil society) that operate in plant health at national and regional level will be organized under the leadership of selected organizations that will lead discussions of stakeholders within a geographic region or of experts on a specific research topic.

The presentation will provide an opportunity to explain the work on forest/tree health and to consult the IUFRO international community.

The emerging threat of Ganoderma root rot in Eucalyptus plantations in Indonesia

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Ganoderma root rot is a disease that affects the roots of various tree species worldwide. In Indonesia, this disease has particularly affected *Acacia mangium* plantations in the past. Although several *Ganoderma* species are present in the country, *Ganoderma philippii* is the primary pathogen causing disease in Indonesian *Acacia mangium* plantations. To mitigate the damage due to Ganoderma root rot, various other *Acacia* and *Eucalyptus* species as well as their hybrids have been planted in areas where the disease is present. Since 2021, outbreaks of Ganoderma root rot have emerged in *Eucalyptus* plantations throughout Sumatra, Indonesia. Disease symptoms include characteristic red rhizomorphs on the bark surface of infected roots with light yellow to white mycelia present under the root bark. Within the roots, characteristic red streaks are commonly observed. Above ground symptoms include yellowing of leaves and subsequently rapid wilt and death of trees. Stumps left in the soil after felling appear to be an inoculum source for new disease outbreaks, as field observations suggest that the disease spreads via root-to-root contact. The aim of this study was to determine which *Ganoderma* species is the causal agent of Ganoderma root rot in the affected *Eucalyptus* plantations and to determine whether stumps from previous rotations might be a source of inoculum for the current disease outbreaks. A total of 167 isolates were collected in six locations in Sumatra from newly infected trees, and 194 old stumps were excavated in two locations where Ganoderma root rot was sporadically observed. All 167 isolates were identified as *Ganoderma philippii* based on DNA sequence data. Of the 194 stumps that were excavated, 100% had typical symptoms of Ganoderma root rot in the remaining roots. Root-to-root contact was observed between these infected stumps and dying trees adjacent to these stumps. The results confirmed that *G. philippii* is the primary cause of the emerging root rot problem in *Eucalyptus* plantations. Furthermore, that the pathogen is spreading actively via root-to-root contact. However, further investigations to determine whether freshly cut stumps are infected after felling is planned to fully understand the dispersal of the pathogen to implement effective management strategies.

The Pine Pandemic Preparedness Plan (P4): A proactive approach to responding to high-impact invasive pests and diseases

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Southern U.S. forests are considered the wood-basket of the world, and provide major economic and ecological benefits regionally and nationally. Most of the economic benefits are from native planted pines (*Pinus taeda* and *P. elliottii*) that are grown as single species and are intensively managed. Longleaf (*P. palustris*) and other pine species also provide many ecosystem services. While these forests have not, as of yet, experienced major mortality from non-native pests and pathogens, their sustainability could be at risk from novel biotic threats. In response, a diverse group of personnel from diverse disciplines and agencies developed the Pine Pandemic Preparedness Plan (P4) to provide guidelines for stakeholders to respond rapidly, efficiently, and effectively to any new incursion in southern U.S. forests. The P4 is a proactive approach, usable by anyone, flexible, and exportable across regions. The four central components of the P4 are: 1) Communication; 2) Detection and diagnosis; 3) Delimitation and assessment; and 4) Response. These components are actionable, strategic, sequentially linked with each other, and provide additional support to current state and federal emergency responses. We present details of the P4 components, discuss ways to engage in the plan, and solicit input from the larger forest health and forestry community in the plan.

The regulatory context of international trade of forest products

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: Wood, wood products and other forest products may contain pests (insects, nematodes, fungi, bacteria) if they have not undergone phytosanitary treatment. Live plants and wood, especially wood packaging, are internationally regarded as the main source for the introduction and spread of these pests. Demand for trade in forest products is constant and often changing, e.g. increases in trade of round wood and the current movement towards climate-neutral energy leading to an increased demand for international trade of wood chips.

To counteract the phytosanitary risk of international trade of plants and plant products, the International Plant Protection Convention (IPPC) was developed in 1952. The IPPC is an intergovernmental treaty of 184 signatory countries, which aims to protect the world's plant resources from the spread and introduction of pests and to promote safe trade. The IPPC established numerous International Standards for Phytosanitary Measures (ISPMs) as the main tools that govern the activities performed by National Plant Protection Organisations to achieve the Convention's objectives.

A number of ISPMs directly influence the trade of forest products including: wood packaging (ISPM 15); phytosanitary treatments (ISPM 28), and the international movement of seeds (ISPM 38) and wood (ISPM 39). Other ISPMs protect forest health in other ways by influencing trade in forest products by governing: plants for planting; the movement of used vehicles; pest status; phytosanitary certification system etc.

Arguably the best known ISPM, ISPM 15 'Regulation of wood packaging material in international trade', describes agreed phytosanitary requirements for solid wood packaging (e.g. pallets, boxes, dunnage) used in international trade. Since publication in 2002, it has been revised several times to refine the requirements or introduce new phytosanitary treatments based on best practice and scientific knowledge generated largely by international scientific collaboration led by the International Forestry Quarantine Research Group. Implementation of ISPM 15 is a global regulatory success story; the movement and spread of forest pests has been reduced while allowing greater facilitation of market access for some countries.

Unveiling a hidden menace: Less known but increasingly emerging in the Southern Hemisphere

T1.1 Biology, ecology and management of pest and pathogen invasions in forests: a global perspective

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Abstract: The first recognized disease and insect (pest) pandemics affecting natural forest ecosystems were recorded around the start of the 20th Century in the northern hemisphere (NH). Notable examples include Dutch Elm Disease, Chestnut Blight, as well as infestations by the spongy moth and pine wood nematode. Since then, new pandemic diseases have continued to emerge in the NH, with increasingly shorter intervals between outbreaks. It is believed that the relatedness between tree genera (congeners) across Asia, Europe, and North America play a significant role in facilitating these pandemics. In contrast, the southern hemisphere (SH) has experienced fewer recorded pandemics. These can be attributed to factors such as limited human and product movement between SH continents, which reduces opportunities for pathogen introductions. Additionally, the greater diversity of tree genera in the SH may contribute to this disparity. However, the SH is now witnessing the emergence of new and severe tree disease pandemics caused by host-specific pathogens. Examples include myrtle rust caused by *Austropuccinia psidii* and the polyphagus shot-hole borer, *Euwallacea fornicatus*. Moreover, numerous pests with the potential to spread between countries in the SH have been discovered, posing significant disease risks. Unlike in the NH, plantation forestry in the SH predominantly utilises non-native tree species, which serve as "bridges" for pests to invade natural forest environments. To better understand this growing threat to the future of tree health, valuable insights can be gained from research on tree pest pandemics in the NH, which must also emphasize the need for a robust global approach.

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

A 'Get-Save- Return' process continuum runs on phosphorus economy among subtropical tree species

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Plants allocate nutrients to new leaves via making a cost–benefit trade-off between root nutrient absorption ('get') and leaf nutrient resorption ('save'). This active trade-off in nutrient acquisition pathways may cause a passive trade-off between resorption and decomposition ('return'). However, whether these nutrient-associated processes are linked and form a 'get-save-return' (GSR) continuum,
and its linkages with the above-ground leaf economics spectrum (LES) and the below-ground mycorrhizal association remain unclear. Here, we present the first empirical evidence of a direct link among multiple nutrient-associated processes and tested this continuum hypothesis by synchronously integrating root nutrient absorption, leaf nutrient resorption and leaf litter decomposition of 15 co-occurring tree species hosting either arbuscular mycorrhizal or ectomycorrhizal fungi in subtropical forests of China. Across species, there was an active trade-off between phosphorus (P) absorption and resorption, which further caused a passive trade-off between P resorption and leaf litter decomposition, indicating that the GSR continuum exists and runs on P economy. However, these processes associated with nitrogen economy were not well linked. Interestingly, the loading scores of species on the LES were positively correlated with root P absorption, negatively with leaf P resorption and positively with leaf litter decomposition. These linkages indicate that species running in the 'fast lane' had greater root P absorption, lower leaf P resorption and faster leaf litter decomposition than species running in the 'slow lane', and that the process-based GSR continuum follows the trait-based 'fast-slow' LES. Furthermore, the continuum on P economy emerged evidently in the ectomycorrhizal tree species rather than in the arbuscular mycorrhizal tree species, indicating critical control of mycorrhizal association over the continuum. Overall, these results demonstrate the existence of the GSR continuum on tree P economy, which conforms to the economics spectrum theory but varies with mycorrhizal association type. Our findings provide a process-based framework for mechanistic understanding of the whole plant nutrient economy and ecosystem nutrient cycling, and facilitate improved predictions of biogeochemical models.

Above and belowground phenology of four tree species with contrasting root and leaf traits

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: The turnover of fine roots and mycorrhizal hyphae is a major source of necromass for soil organic matter formation. Although much is known about leaf phenology, little is known about root phenology and the factors that control it, or how aboveground and belowground phenology interacts. Knowledge of the length of the growing season below ground and the longevity of fine roots is crucial for estimating necromass inputs to soils.

In this study, we access the leaf and root phenology and the development of mycorrhizal hyphae of four tree species (*Acer platanoides, Carpinus betulus, Tilia cordata, and Quercus robur*) growing in either monocultures or mixtures at the B-tree experimental site in Austria. Root growth is monitored using 96 minirhizotron tubes installed at the site to 40 cm depth in late 2021. Measurements were carried out from January 2023. To estimate the growth of mycorrhizal hyphae, ingrowth bags were buried at the beginning of March 2023. Initial data indicates the start of root growth in 2023 in February for *Tilia cordata* and *Acer platanoides*, in early March for *Carpinus betulus* and in late March for *Quercus robur*. In parallel with the belowground measurements, a leaf phenological study is being carried out to record the progression of leaf growth and senescence. On non-rainy days, images were taken every 7 days with the camera of an iPhone 13 smartphone placed approximately 10 cm above the ground, oriented horizontally and aimed at the canopy above the rhizotron tubes. The images were then processed using CAN-EYE V6.495 software to quantify the number of green pixels. Bud break in 2023 occurred around the end of March for Carpinus betulus and *Acer platanoides*, mid-April for *Quercus robur* and late April for *Tilia cordata*. Our data thus indicate a generally earlier onset of the root growing season, and large differences between the synchronicity of above- and below-ground growing seasons within species.

Belowground carbon dynamics in various urban green spaces

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Urbanization is an increasingly prevalent global phenomenon, leading to significant modifications in land use and the transformation of natural environments into urban landscapes. Cities are urgently seeking solutions to reach carbon (C) neutrality due to climate change. For this purpose, quantifying soil and vegetation C storage is needed in urban green areas. Fine roots are playing a vital role as they often form the only tree litter input into the soil due to heavy management in urban green spaces. Fine roots are also key players in the formation of most stable soil carbon and in the biogeochemical cycle of many green ecosystems. The urban green areas do not have much competition in the canopy layer, but the root growth could be hindered by limiting belowground soil space in addition to other complications such as soil compaction, pollution and low water content. In this study, we followed tree growth and longevity in three urban green spaces (Garden, Forest and Street) in Helsinki, southern Finland. We aim to figure out how fine root growth dynamics and morphological traits are affected by urban site types, and by extreme weather events such as summer droughts. Moreover, the study allows to link the root growth phenology to whole-tree organs' growth *in situ*. The gained results on the belowground litter C input in urban soils provide crucial information on carbon dynamics in urban green areas which will be further implemented in land-surface models.

Continuous-cover forestry affects the stabilization of soil C through continuous root litter inputs and root exudates

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Trees fix and store atmospheric carbon (C), about half of which they transport belowground. This C enters the soil organic carbon (SOC) pool as root exudates and root litter and feeds soil microbiota. Microbial necromass and microbial exudates in turn contribute to the SOC pool and simultaneously stabilize C in the soil. Root derived tannins furthermore contribute to SOC stabilization in interaction with fungal residue. Recent studies suggest that clear-cut harvesting disturbs the belowground food web in forests. Retaining a certain number of living tress and living roots to sustain the belowground ecosystem may mitigate post-harvest losses of SOC. Continuous cover forestry has been suggested as a way to protect the SOC storage.

We studied how continuous-cover forestry (CCF) affects SOC stocks and stability in boreal forests through its effects on living roots, compared to clear-cut based rotation forest management (RFM). We hypothesized that (1) more effective use of rooting space leads to higher amounts of living tree roots and root derived tannins in uneven-aged CCF plots than in even-aged RFM plots and in clear-cut plots without trees and (2) the undisturbed soil in CCF holds higher amounts of mineral-associated organic matter (MAOM) and higher shares of chemically stable organic matter. We carried out measurements in Norway spruce (*Picea Abies* Karst.) dominated experimental forest plots of the Natural Resources Institute Finland in central Finland. We sampled (1) clear-cuts, (2) even-aged forests (both representing RFM), (3) uneven-aged forests (representing CCF) and (4) uncut control forests.

We determined living tree root and fine root biomass, understorey and dead roots and calculated annual belowground litter inputs. We measured soil C content and calculated soil C stocks. We analysed the amount of root-derived condensed tannins. To evaluate the effects on C stabilization we separated particulate organic matter (POM) and MAOM and we distinguished the different soil organic matter fractions within the POM fraction with chemical extraction. We analysed amino sugars, and used glucosamine and muramic acid as indicators of fungal and bacterial necromass.

We will discuss potential effects of the forest management system on the long-term SOC storage based on our results.

Contribution of Root Dynamics to Carbon Balance of Agroforestry Coffee Plantations - a Case Study in Costa Rica

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Accurate carbon budgets are important when estimating the potential benefits of reforestation programmes for climate change mitigation. Including crop specific data makes estimates more accurate. Coffee is an important crop, often grown in agroforestry systems considered to sequester carbon. However, little is understood about contributions of plant roots to the system carbon balance.

Results will be presented from a study on soil carbon dynamics in agroforestry coffee plantations, in a long term experiment in Costa Rica. The experiment was set up in 2000, to compare organic and conventional coffee production systems under various types of shade. The current study focuses on the effect of shade trees on belowground carbon. The three treatments used were i) coffee, full sun ii) coffee+*Erythrina poeppigiana*; *and iii) coffee+Terminalia amazonia,* all with moderate conventional fertilization.

Carbon stocks have previously been estimated at the site, but without including root biomass and turnover. Those results showed that large aboveground biomass alone cannot explain changes in soil carbon storage in these agroforestry systems.

The aim of this study was to study belowground biomass and production, and how that correlates with soil carbon stocks and aboveground biomass. Fine root turnover was estimated using sequential coring in combination with root litter decomposition. Root biomass data was collected from August 2022 to July 2023. The results from this study will be used to calculate carbon budgets for these coffee plantations, incorporating fine root dynamics.

Decomposition of fine-roots of different species in a cool-temperate forest zone in South Korea

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Plant litter decomposition in terrestrial ecosystems constitutes one of the largest annual fluxes of global carbon (C) and nutrient cycling. Especially fine-roots are great components of net primary production and their decomposition is crucial for plants to return C and nutrients to the soil. Fine-root decomposition is affected by several factors as climate, litter quality, soil chemical properties, and soil microorganism activity. The decomposition rate also differs among different root diameters, since tissue chemistry varies with the diameter. Therefore, this study aims to analyze the decomposition of fine-roots of different species in Gariwang Mountain, Pyeongchang, South Korea. Four different sites were selected, each one dominated by a different species: *Quercus mongolica, Pinus koraiensis, Pinus densiflora*, and *Larix kaempferi*. Then, the sites were subdivided into 3 plots of 20x20 m. The climate is classified as cool-temperate and the altitude in the sites varies between 933 m and 1.065 m. Soil chemical properties and microorganism activity will be analyzed at each site. To estimate the decomposition rate, litterbags of 10x10 cm size with 115 µ mesh size will be used. Samples of each species were collected, divided into 4 diameters, and placed in the litterbags. The amount of samples in the litterbags differ by diameter: 0 – 0.5 mm (0.08 - 0.1 g), 0.5 – 1 mm (0.16 - 0.2 g), 1 - 2 mm (0.3 g), and 2 – 5 mm (0.5 g). In December 2022, 768 litterbags (4 species x 4 diameters x 4 replicates x 3 plots x 4 collection times) were buried. In 2023, the litterbags are planned to be seasonally retrieved after 4, 6, 9, and 12 months. After collection, the samples will be oven-dried and weighed to determine the biomass loss. The initial root quality (C, N, P, K, Ca, Mg, cellulose, hemicellulose, and lignin) and morphological traits (specific root length and area) will also be determined. It is expected that the decomposition rate will increase exponentially with the temperature and the lowest decomposition rate will be observed in the winter. Also, the decomposition of very fine-roots will be higher compared to bigger root diameters.

Early Overyielding in Mixed Plantations is driven by Above- and Belowground Species-Specific Adaptation

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Forests face significant challenges in the context of climate change, and mixed forest plantations have been proposed as a promising approach to enhance ecosystem stability and productivity. While mixed forest plantations are known to exhibit higher ecosystem productivity compared to single-species plantations, there is a research gap in understanding the interplay between above- and belowground productivity, specifically regarding how aboveground productivity patterns relate to belowground dynamics. To address this critical aspect, we conducted a comprehensive forest inventory of a young mixed forest plantation, where four tree species were planted in four different mixture variants (monoculture, acquisitive two-species mixture, conservative two-species mixture, four-species mixture). We used linear mixed effect models to quantify belowground productivity and distribution and its relationship to aboveground parameters such as growth rates, crown characteristics, and biomass.

Our findings revealed that initial effects of tree species mixtures on aboveground growth could be observed as early as six years after planting even before light competition occurred. Biomass allocation patterns were found to be strongly influenced by species composition after nine years. The most diverse and intermediate diverse stands, particularly those with acquisitive tree species, exhibited high aboveground biomass accumulation, surpassing monoculture yields by 1.5 to 1.9 times. In addition, belowground biomass showed a similar trend, with the most diverse stands achieving significant overyielding in fine root biomass. Intermediate diverse stands, however, exhibited species-specific patterns, with acquisitive species achieving clear overyields and conservative species producing lower yields. These differences in biomass accumulation at various diversity levels may be explained by functional trait-specific differences in above- and belowground biomass allocation.

By shedding light on the dynamics of tree diversity and its impact on niche construction, our study provides valuable insights into enhancing above- and belowground ecosystem productivity in mixed forest plantations. The findings underscore the significance of managing forest ecosystems with a diverse species portfolio to promote both stability and productivity.

Effects of environmental factors on daily root growth phenology in southern boreal forests

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Boreal forest soil carbon storage is largely attributed to roots and root symbionts. Fine root growth and turnover significantly affect belowground carbon cycling. Climate change, including temperature increases and precipitation shifts, directly impacts fine root growth and overall the tree growth. However, compared to the detailed observation of aboveground components, there is limited knowledge about the growth of roots, especially regarding their growth patterns. To address this knowledge gap, we conducted a study in a mature Scots pine stand in southern Finland in 2018, a year marked by an unexpected summer drought. We used flat-bed scanners to scan and capture daily images of the belowground organs. Specifically, we categorized the roots into two types based on their morphology: pioneer roots and fibrous roots. The growth phenology of aboveground organs, including shoots, needles, buds, and secondary xylem, was estimated using a validated process-based model describing the carbon balance of a tree (CASSIA).

Our results revealed a positive correlation between soil temperature and root growth. However, the growth patterns of the two root types exhibited significant differences. The relationship between root growth and soil moisture varied across the different scanners due to the spatial heterogeneity of soil moisture distribution. We found that pioneer roots showed greater resilience to harsh environmental conditions compared to fibrous roots. Pioneer roots emerged and ceased growth at temperatures 2°C lower than fibrous roots. Interestingly, the drought had no significant impact on pioneer root growth, while fibrous roots immediately halted their growth in response to limited soil moisture. Additionally, the growth of roots displayed a delayed start, peak, and cessation compared to aboveground organs.

We recommend that future carbon allocation models for boreal forests should incorporate separate consideration of the growth phenology for belowground and aboveground organs. Moreover, distinguishing between different root types is crucial, as their growth responses to environmental factors differ. By integrating these factors, we can enhance the accuracy of carbon allocation models and gain a comprehensive understanding of root growth dynamics in boreal forest ecosystems.

Fertilization fosters positive tree mixture effects on soil respiration, largely independently of changes in community root trait structure

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract:

1. Eutrophication is expected to change functional structure of plant communities. However, it remains unclear how the shift in community functional trait structure impacts soil respiration (Rs) in forests, which is one of the most important pathways of the carbon cycle.
2. Here, using a young tree diversity × fertilization (nitrogen and phosphorus) experiment with six European species, we test our hypothesis that fertilization amplifies positive tree mixing effects on Rs indirectly through changes in community-level root traits linked with the root economics space and belowground ecosystem functioning. Specifically, we expected that fertilization enhances positive tree mixing effects on (1) root length density of metabolically active absorptive roots (aRLD), (2) fine-root nitrogen content (fRN) and (3) biomass ratios of absorptive to transport fine roots (ATR), leading to positive tree mixing effects on Rs.
3. Soil respiration was marginally higher in species mixtures than could be expected from monocultures under fertilization, while Rs was unaffected by species mixing in unfertilized plots. When each community-level root trait was analyzed separately, species mixing tended to shift community root trait structure toward one that is resource acquisitive and metabolically active (high aRLD, fRN and ATR), with the trend reinforced by fertilization. A subsequent multivariate analysis with a piecewise structural equation model showed that tree species mixing effects on fRN and ATR increased with fertilization, while the responses of community root trait structure to fertilization did not mediate the observed marginally positive effects of fertilization on Rs in mixtures relative to monocultures.
4. Our study provides novel experimental evidence that fertilization tends to positively amplify species mixing effects on Rs in young tree communities, but largely independently of changes in root traits typically used to quantify root metabolism and root interactions with soils. This suggests that other biotic (e.g., soil microbiota) and/or abiotic factors (e.g., water availability) may be essential to understand the tree diversity-soil respiration relationships. Nevertheless, our study highlights that tree diversity effects on CO_2 emissions should be addressed to assess co-benefits for forest-based climate change mitigation and biodiversity conservation.

Fine root biomass and production in European forests

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: The allocation of photosynthates to fine roots represent a major carbon flux from trees into the soil. Assessing fine root dynamics is thus of great importance for a better understanding of belowground C, in the context of biodiversity as well as of climate change. This study was carried out at the six FunDivEUROPE field sites (www.fundiveurope.eu), established in the main European forest types for assessing the effect of tree species diversity on ecosystem functioning. Root biomass was assessed in all 209 plots of the network, whereas a subset of 65 plots was used for estimating root production. Plots were established in Finland (boreal), Poland (hemiboreal), Germany (temperate beech), Romania (mountain beech), Italy (thermophilous deciduous) and Spain (Mediterranean mixed). The tree species richness gradient ranged from 1–3 species in Finland to 1–5 species in Poland and Italy. Root biomass was estimated with the soil coring method and root production with the ingrowth core method within the forest floor and 0–20 cm layer of the mineral soil. We assessed the significance of various variables related to stand, soil and climate, and how they affected tree fine root biomass and production. We observed a positive but nonsignificant effect of tree species richness for both root biomass and production. The most significant factors explaining root biomass and production were soil stoniness and clay content. Soil clay content, when included in the models, overruled all other factors. Tree root biomass peaked at a clay content of 15–20%, whereas biomass and production decreased with increasing soil clay and stoniness in the whole dataset. Root biomass increased whereas production decreased with increasing mean annual temperature. Consequently, this resulted in a higher root turnover in colder climates. Similarly, we also observed a decreasing trend in soil C with higher mean annual temperatures.

Fine root production and turnover rates across different land-use types in suburban area of Central South Korea

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Roots play a vital role in ecosystem functioning, contributing to biomass production, nutrient cycling and carbon sequestration. However, little is known about fine (0-2mm) and small (2-5mm) roots dynamics of different land-use types and their processes. Here, this study aimed to investigate seasonal root mass, root production and turnover rates in different land-use types including grassland (ZJ), apple orchard (MP), temperate coniferous forest (PD) and temperate deciduous forest (QA) to gain insights into root functioning and how root dynamics vary across different land-use types. Sequential coring was used to study the vertical distribution and dynamics of the root system and roots were characterized into two root diameter size classes (0–2 and 2-5mm) sampled at depth up to 30cm. Root annual production was analyzed and quantified using Simplified Decision Matrix. The overall root mass (0-5 mm diameter up to 0–30 cm soil depth) was in order: ZJ>QA>PD>MP. The vertical distribution revealed that more than 60% of the fine and small roots mass were allocated in the uppermost soil layer (0-10cm) and decreased significantly with depths in ZJ, PD, QA, while in MP, the biomass was more uniformly distributed across soil depth. Although these land-use types situated in similar climatic condition, soil characteristics were significantly different, which influenced trends in seasonal root biomass, necromass, production and root turnover rate. The mean turnover rates of small roots (2-5mm) were about 1.1 to 2.1 times higher than that of fine roots (0-2mm) in ZJ, PD and MP. Understanding root dynamics in different land-use types can provide insights into their contribution to ecosystem processes, the adaptive strategies of plants, and, which can be useful for improving suitable management practices for each ecosystem.

Key words: fine root; biomass; necromass; production; turnover rate; grassland; apple orchard; temperate coniferous forest; temperate deciduous forest.

Fine-root related carbon fluxes in forests under changing environment: from root research methods to root-rhizobiome functioning

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Root studies are increasingly prominent, and an extensively increasing number of root datasets has great potential to improve our understanding of ecosystem functioning and sustainability in the context of rapid global changes. We address two topics in root research, both of which are related to the impact of environmental changes on fine root growth and dynamics and which affect future projections of the soil organic carbon cycle.

Yet, root research is still time-consuming, and we lack comparisons of the estimates of fine root biomass, production, and turnover measured with different research methods at the same forests. Here we analyzed fine root production (FRP) and turnover from 13 boreal-hemiboreal coniferous forests with three methods: ingrowth cores, ingrowth meshes, and minirhizotrons. In hemiboreal forests, FRP was measured twice, with a 4-6-year interval. Total FRP (trees+understory) and understory root production didn't depend on the method it was measured, while the mean FRP of conifers was significantly higher as measured by ingrowth core compared to ingrowth mesh method. The estimate of FRP and turnover seems to be stable for at least the next 5-years if any major disturbance does not happen. We found that ingrowth dynamic of roots differed along the north-south gradient, which should be taken into account in modeling root litter dynamics and soil C input.

Another fast-evolving research field is related to root-rhizobiome functioning. Root-rhizobiome contains a large number of interactive and potential drivers – roots, mycorrhiza, bacteria, archaea etc that has an essential impact on ecosystem sustainability and functioning. We will envisage a role of multilateral relations between the fine roots, colonizing EcM fungi and rhizosphere and bulk soil bacterial community structure along different environmental gradients (water, temperature) and discuss how the qualitative changes in fine root functional structure affect biomass allocation pattern and qualitative change in SOM formation.

Investigating fine root dynamics and phenology in temperate forests: a comparative analysis

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Forests play a critical role in the global carbon cycle by acting as substantial carbon sinks. While much attention has been paid to aboveground carbon sequestration, recent research has highlighted the significant contribution of forest soils, particularly through fine root dynamics. Fine roots play a key role in belowground net primary productivity, facilitating carbon and nutrient cycling in forest ecosystems. However, a comprehensive understanding of fine root dynamics and functions remains elusive due to methodological limitations. This study aims to compare the effectiveness of methods for estimating fine root production, to investigate fine root dynamics and phenology, and to explore the intricate interactions between below- and above-ground ecosystems in temperate broadleaved and coniferous forests. Preliminary findings revealed notable discrepancies in fine root production estimates among three direct methods—sequential soil coring, ingrowth coring, and the root scanner method—in the same forest types. Annual fine root production accounted for 10-44% of net primary production, with more productive forests displaying higher belowground carbon allocation. The phenology of fine roots exhibited differences between pine and oak-dominated forests, with elevated fine root mortality coinciding with aboveground bud burst. This research sheds light on the intricacies of fine root dynamics and belowground phenology, providing valuable insights into the essential role of fine roots in carbon and nutrient cycling. The findings will have implications for forest management and ecosystem restoration efforts aimed at enhancing carbon sinks. This study deepens our understanding of carbon sinks in forest soils, enabling us to effectively manage forest ecosystems in the face of ongoing environmental challenges. This research not only advances our knowledge of belowground carbon giants but also supports efforts to develop sustainable practices that optimize carbon sequestration in forests.

Litterfall production and fine root dynamics in a Pinus koraiensis plantation for 10 years following thinning intensities

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Thinning must be done in a sustainable and ecologically responsible manner since aggressive thinning negatively impacts forest ecosystem health and function by modifying soil physicochemical characteristics, fine root dynamics, and litterfall production. Here, we investigated the long-term changes in fine root biomass and necromass, litterfall production, and soil physicochemical properties in a 50-year-old *Pinus koraiensis* plantation for ten years in different thinning intensities (based on diameter at breast height, DBH). Three thinning treatments were used: control (CON), low thinning (LT) or double thinning in 1975 (15%) and 2007 (38%), and high thinning (HT) or triple thinning in 1975 (15%), 2000 (25%), and 2007 (66%). The soil physicochemical characteristics in the plantation were compared between soil depths. Fine roots of *P. koraiensis* and understory vegetation were analyzed by diameter class and soil depth. Leaf, twig, and miscellaneous litter in 2007 and needle, understory leaves, twig, and miscellaneous litter in 2018 were also analyzed. In 2018, soil pH, OM content, and total N were the highest at HT and lowest at LT treatment. Available P2O5, CEC, K+, Ca2+, Mg2+, and EC were significantly higher at CON and/or HT than LT. Fine root biomass were the highest at CON, intermediate at HT, and the lowest at LT in 2018. While the fine root biomass decreased by 59% (149.7 g m-2) in 2018 compared to that of 2007, the necromass increased by about four times (108.1 g m-2) in the 0-20 cm soil depth. Fine root biomass (83%) and necromass (78%) were mostly distributed in the 0-20 cm soil depth. Litterfall decreased with thinning intensity, i.e., CON (7,000 kg ha-1) > LT (5,998 kg ha-1) > HT (5,238 kg ha-1). Overall, *P. koraiensis* plantation showed significant changes in soil physicochemical characteristics, fine root biomass and necromass, and litterfall production over time, and the magnitude of the effects varied depending on thinning intensity. Results reported herein provide the threshold at which sustainable and ecologically responsible thinning should be performed for *P. koraiensis* plantation to help maximize the climate change mitigation potential of thinning.

Microdialysis for measuring the root exudates in the rhizosphere

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: A significant portion (20%) of the carbon (C) assimilated through photosynthesis by plants is subsequently released by their roots into the soil in the form of exudates in the rhizosphere. Changes in plant root exudation profiles during extreme climate conditions and their species-specific metabolic components need more attention. Moreover, for a comprehensive understanding of the belowground microworld, it is essential to explore non-destructive assessment techniques for native soil areas. The aim of this work is to measure plant root exudates in the rhizosphere to understand their role in C cycling and plant response to climate change using microdialysis as a minimally invasive technique that can be used to simulate, measure and quantify the root exudate content.

In the current study, 36 three-years-old Norway spruce (*Picea abies)* seedlings were grown in growth chambers (Percival Scientific Inc, USA) at a constant light intensity. Drought simulation was undergone by manipulation with several parameters: air humidity (RH was decreased to 10% compared to control), air temperature (was increased by + 6°C), and soil moisture (the threshold for watering was decreased to 45% and 60%). Overall, there was three microdialysis (CMA Microdialysis AB) collection sessions of root exudates: (i) before the drought simulation (control); (ii) the period after the simulation, and (iii) the recovery period. After the final microdialysis campaign root carbon exudates were collected following the culture-based cuvette method. Analysis of root exudate samples was performed by Vario TOC analyser for total organic carbon and by high-performance liquid chromatography-mass spectrometry (HPLC-MS) to determine the profile of plant secondary metabolites.

For understanding the effect of drought on the root exudation profile we analyzed metabolic profile of root exudates and the TOC. In addition, we compared the amount of TOC that was collected using the new microdialysis technique and the well-known cuvette method. According to the literature review and experimental comparison of the two methods, the pros and cons of the microdialysis technique were analyzed. The perspectives of microdialysis for plant root exudate studies will be discussed during the presentation.

Soil carbon pool may become vulnerable by waterlogging in forested peatlands

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Forested peatlands are a globally significant carbon pool. Decomposition rate in forested peatlands is largely controlled by soil water-table level, but also roots, their chemistry, and microorganisms play roles in the stabilization of soil organic carbon (SOC). Weather extremes including waterlogging will become more common with climate change, but so far, drought has obtained much more research interest than waterlogging that potentially affects SOC pool. Our hypothesis was that soil waterlogging decreases stable SOC formation through the decreased amounts of fine roots, tannins, and root-associated microbial necromass compared to non-waterlogged soil. We studied the effects of waterlogging on carbon pools, soil enzyme activities, soil and root chemistry, and biomass, necromass and community composition of soil fungi. *Pinus sylvestris* rhizosphere was investigated in a controlled-environment experiment with and without waterlogging and in a wetter and a drier forested peatland site. Generally, stable SOC content and its share of total SOC content, tannin content, enzyme activities, and live fungal biomass were lower in the experiment in waterlogging than control treatment, and lower in the wetter than the drier forested peatland site. Ectomycorrhizal fungi were more abundant in the fungal community of the drier than the wetter site in the deepest studied soil layer. In the wetter site, stable SOC content and the communal proportion of ericoid mycorrhizal fungi were highest in topsoil containing more roots than the layers deeper in soil. To conclude, specific root-related SOC stabilization mechanisms are present in forested peatlands where waterlogging consequently can make their SOC more vulnerable due to lowered C stabilization via root-microbial interactions and decreased root growth.

Soil Compaction Effects on the Abundance, Dynamics and Characteristics of Fine Roots and Mycorrhizal Associations in Forest Soils

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Logging-induced soil compaction poses a significant threat to soil habitat functions, particularly to root systems and their symbiotic relationships with mycorrhizae. Understanding the consequences of soil compaction is essential for sustainable forest management, as intact forest ecosystems play a critical role in climate change resilience and mitigation efforts. Remaining knowledge gaps highlight the need for comparative studies of different harvesting methods, fine-scale analysis to understand the spatial heterogeneity of compaction effects, and the interactions between soil compaction, root growth and mycorrhizal associations.

To gain a detailed insight into these complex relationships, we conducted an empirical Before-After Control-Impact study in a beech-dominated forest in Lower Austria. Different harvesting methods (harvester-forwarder with/without tracks and cable-yarding with motor-manual-felling), were applied in the winter 2022/23, taking into account previous harvests (18 years earlier). Our study used a transect approach to determine spatially explicit effects on standing root biomass and growth rates by using soil cores and in-growth cores, respectively. Transects were placed transversely across the tracks, covering areas directly (tracks, cable-yarding corridor) or indirectly (between the wheel tracks, marginal areas) affected by the logging activities. Comprehensive assessments of root biomass (distribution), nutrient content, anatomy and morphology were undertaken. In addition, logging effects on mycorrhizal morphotypes, mycorrhization rates of root tips, and hyphae growth (in-growth bags) were analysed.

Preliminary data show a significant influence of both recent and historical timber harvesting on the standing root biomass, indicating altered patterns of root growth and distribution, with significant

differences between and within transects. Our results indicate that different harvesting methods cause widely varying degrees and patterns of soil compaction – with contrasting effects on fine root dynamics.

The long-lasting consequences of soil compaction, hindering root system establishment and mycorrhizal symbionts, underlines the importance of maintaining soil as an intact habitat. The implications of this research are relevant for sustainable forestry practices, emphasising the need for appropriate soil management strategies to mitigate the negative effects of logging related soil compaction to ensure the long-term functionality of the soil as a habitat for roots and mycorrhizae.

Stand age-induced tree diversity and size inequality control aboveground biomass and soil organic carbon with abiotic drivers in South Korean forests

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Forest biomass and soil organic carbon (SOC) are crucial for the terrestrial carbon cycle. However, the mechanisms underlying the interaction between trees and site properties (e.g., stand age, climate, soil) that drive the SOC remain unclear. We assumed that tree diversity, functional trait identity, and stand structural attributes regulate aboveground biomass (AGB) and SOC. Vegetation data from 125 plots dominated by 11 major tree species in South Korea were used to investigate these relationships. We analyzed the effects of tree diversity, community-weighted mean, stand structural attributes, and abiotic drivers such as stand age and topography, climate, and soil variables on AGB and SOC. We also tested the effect of AGB on SOC's biotic and abiotic drivers. We performed multimodel inference test with model averaging approach and piecewise structural equation modeling to compare and quantify the effects of the predictors on AGB and SOC. Stand age, species richness, and stand the standard deviation of diameter at breast height significantly affected AGB, but their effect on AGB varied depending on the dominant tree species. For SOC, elevation-related climatic drivers (i.e., mean annual precipitation, mean annual temperature and aridity), soil pH, species richness, and AGB directly regulate SOC. Dominant tree species also modulated the SOC. Our results show that the interactions of biotic and abiotic determinants with dominant tree species are important in both AGB and SOC despite the differences in the direction and magnitude of their effects. Therefore, our study suggests that understanding the interactions of biotic drivers with site-specific conditions, which determine the forest ecosystem's carbon cycle, is crucial in expecting the global carbon cycle.

Temporal variations in tree root dynamics and its implications on carbon balance in Peninsular Malaysia

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: Different components of net primary production (NPP) control the balance of tropical forests particularly, in terms of being a net carbon sink or source. Fine roots with a diameter ≤ 2 mm are essential for plant growth and the global carbon cycle but they are often neglected in NPP estimations. Approximately 10% to 60% of total NPP in tropical forests are contributed by fine roots production and 0.33 of the annual global NPP is used to produce fine roots. Fine root production (FrP) is influenced by root decompositions (Frd), necromass (FrN), turnover (FrT), biomass (FrB), standing litterfall (Lf), soil respiration (Rs), and climate. Our objective was to determine how fine root dynamics (Frb, FrN, Frd, FrP & FrT) vary with time with regards to the factors controlling it. Sequential soil core sampling and the root bag technique were used in a tropical forest at 120 days interval for two years at Jengka, Pahang, Peninsular Malaysia. Continuous inflow method was used to estimate FrP, FrN, and Frd. The litter and fine roots stocks were 3.34 and 0.98 Mg C ha^{-1}, respectively. The annual decomposition decay constant *k* was -0.6168 $year^{-1}$. Frb, FrN, and Frd correlated with mean air temperature whereas Lf correlated with Rs, Frb, and Frd. Total FrP, FrN, Frd, and FrT ranged as 627.80 –791.05 g m^{-2} yr^{-1}; 854.10 – 704.80 g m^{-2} yr^{-1}; 585.22 – 511.89 g m^{-2} yr^{-1}; 0.71 t $year^{-1}$, respectively. Inter-annual variations were prominent in our site whereby higher fine root biomass and litterfall were recorded during higher precipitation but drier periods restricted root decomposition, resulting in higher fine root necromass, affecting NPP. This study confirms the need to estimate temporal variations of belowground carbon allocation of roots and the necessity of including fine root dynamics and soil respiration in NPP ecosystem modeling for tropical forests.

The above- and belowground phenology of Picea abies in response to different drought episodes

T1.2 Carbon sinks in forest soils as controlled by fine-root dynamics

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Abstract: The air temperature in Estonia is projected to increase, affecting the growth of economically and ecologically significant tree species, especially young *Picea abies* seedlings used for regenerating forests. There is a close relationship between the aboveground parts and the development of the root system. We estimated the effects of increased temperature, decreased air humidity, and soil moisture on the shoot and root growth dynamics in *Picea abies*. We analysed the senescence dynamic within fine roots by separately measuring young and older root growth. Additionally, we studied the effect of potential asynchrony between above and belowground phenology caused by these changing climate factors.

Three-year-old Norway Spruce (*Picea abies*) seedlings were grown separately in transparent boxes in growth chambers. We conducted two separate experiments where drought episodes were simulated by decreasing relative air humidity and soil moisture and increasing air temperature in short and long-term scales. Images of fine root growth were taken with a smartphone, and images were analysed by the deep learning method-based program RootPainter. From that, we have data on the total fine root projection area and the area of young white root tips. Shoot growth was measured manually throughout the experiment.

The shoot phenology followed a well-known pattern; the length of shoots increased fast at the beginning of the growing season and stabilised after seven weeks of growing. At the same time, the fine root growth proliferated. High temperatures with lower relative air humidity showed longer needle growth, and the fine root senescence was also more pronounced than in the high-temperature treatment without the change in relative air humidity. The relative growth rate of young fine root tips was almost twice as high as the relative growth rate of older brown roots. In the second experiment, the spruce saplings showed continuous root growth even though they experienced strong drought without watering. After experiencing three weeks of harsh drought, the spruce seedlings showed clear recovery underground, especially in immense pioneer root growth. The asynchrony of above and belowground phenology in Picea abies caused by drought episodes along different time scales will be discussed.

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

A Study on Stand Growth of Larix kaempferi by Thinning Intensity over 9 years

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: This study was carried out to understand the change of stand growth of Japanese larch (*Larix kaempferi*), which is one of the major plantation species in Korea. The permanent plots in 45 sites were established in 2013. Each site consists of three plots by thinning intensity: unthinned, light thinning and heavy thinning. The thinning was carried out based on the basal area in the year of plot establishments, and the thinning intensity was 20% for the light thinning plot and 40% for heavy thinning plot in each site. The measurement was repeated every 3 years, and it was performed three times for 9 years. According to the last measurement, the stand age in all sites, and the unthinned plots were, on average, 24.5 cm in diameter at breast height (DBH), 23.1 m in height, and 835 trees/ha in stand density. On the other hand, in the light and heavy thinning plots, DBH and height were higher; 27.5–29.1 cm in DBH and 23.6–24.3 m in height while the stand densities were lower; 412–601 trees/ha. Additionally, the growth changes of DBH, height, basal area, volume and carbon sequestration by thinning intensity were analyzed to examine the thinning effects. The DBH growth was highest in heavy thinning plots, followed by light thinning plots and the unthinned plots. As the stand age increased, the differences between thinning intensities decreased in each site. The height growth was not significantly different by thinning intensity. The stand basal area growth was high in a descending order of control, light thinning, and heavy thinning plots due to the differences in the number of residual trees after thinning. The stand volume growth and carbon sequestration rate were the highest in control plots. This study can offer fundamental information about the thinning effects on the sawtimber production and carbon sequestration rate of Japanese larch and its potential for enhancing sustainable forest management.

A supra-regional field trial in Thuringia/Germany to test different management options for the reforestation of disturbed spruce areas

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: The impact of extreme weather events such as droughts, heat waves, storms and the associated intensification of bark beetle outbreaks in spruce forests in recent years, has lead to a vast loss of spruce trees in Thuringia and other regions in Germany. There are various options for the management of disturbed areas, but their pros and cons are not clearly resolved. The ResEt-Fi consortium implemented a supra-regional field trial to test how specific practices for deadwood management affect the ecological conditions and subsequent reforestation dynamics of natural regeneration and planted trees. It aims at generating climate-stable mixed forests by an ecological valuable transition offering socio-economic benefits. For stakeholders and forest practitioners, it is planned to create guidelines and showcase scenarios for facilitating the selection of management procedures that fit optimally to the regional conditions and goals for mid- and long-term development.

The investigations focus on disturbed areas in three particularly affected model regions distributed across Thuringia, each characterized by specific ecological site conditions: 1. Southern Harz Mountains ('Südharz'), 2. Western Thuringian Forest ('Marksuhl'), and 3. Thuringian Slate Mountains ('Neuhaus'). A nested experimental design integrates different silvicultural strategies for dealing with disturbed areas, comprising (a) clearing, (b) high stumbs and (c) dead wood patches, which are compared with undisturbed sites as control (d). Furthermore, subplots with artificial regeneration and deliberately spread deadwood are additionally included in the investigations. Local climatic conditions of the treatments are recorded intensively, as are the comprehensive aspects of soil ecology, succession of vegetation, and effects on fungal communities, birds and wood-dwelling beetles. Taking all this information into account, predictions of the dynamics of various scenarios are derived by process-based simulations.

Changes in aboveground and belowground biomass partitioning of trees planted in the Desert Region of Mongolia in different irrigation regimes

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Increasing land degradation and desertification remain serious issues in Mongolia, a country with a low density of the natural forest, limited precipitation, a large number of livestock, and, most importantly, an arid environment. Planting more trees that are adapted to the specific environment is an obvious strategy to tackle this recurring issue. Thus, our research is focused on irrigation on afforestation sites of *Ulmus pumila* L., *Tamarix ramosissima* Ldb., *Elaeagnus moorcroftii* Wall. ex Schlecht tree species for a over decade using four different irrigation regimes. Aboveground (leaf, stem branch) and belowground (fine roots, small, medium, large, very large, tap root) biomass and carbon contents of trees were determined. The biomass of all species was increased under 12 L h^{-1} irrigation regimes and the lowest biomass was found under 4 L h^{-1} irrigation regimes, except *T. ramosissima*. Furthermore, *U. pumila* showed the highest biomass than the other species. As expected, tree carbon and CO_2 sequestration were higher in *U. pumila* and *E. moorcroftii*. Overall, we concluded that these planted tree species exhibited similar responsed and were effective under irrigation.

Changes in tree seedlings and understory plants following soil scarification and amendments in a northern hardwood forest

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: A combination of global changes (e.g., soil acidification, invasive species, forest management, climate) impacts the regeneration dynamics of sugar maple-dominated stands in northeastern North America. More specifically, there are concerns about the regeneration of sugar maple and other high-value species due to the expansion of American beech and its bark disease, killing mature trees, compromising fiber supply and other ecosystem services. Here, we set up a field trial to study the effect of soil scarification, amendments (nitrogen fertilization, liming, and wood ash), and their interactions, on tree species establishment following understory vegetation removal in a beech-invaded sugar maple stand to promote the establishment of high-value species (i.e. sugar maple and yellow birch), to control beech regeneration, and help reduce the impacts of beech bark disease on stand development. Collateral effects of these treatments on understory vascular plant communities were also monitored. After four years of monitoring, we found that maple-beech stands with well-drained soils were promising sites for the success of sugar maple and yellow birch establishment. Soil scarification had a limited effect on sugar maple and beech establishment while it enhanced that of yellow birch, pin cherry and red maple. The combination of soil scarification and amendments was more effective in promoting the recovery of yellow birch and pin cherry and controlling the recovery of beech and red maple than their separated effects. Lime amendment promoted sugar maple establishment without favouring competitors such as yellow birch, pin cherry and red maple, and limited beech establishment. Scarification reduced species richness and functional diversity of understory plants and was further amplified by soil amendments. Overall, our results suggest that combining soil scarification and amendments on targeted site types could help fine-tune tree establishment conditions in northern hardwood forests but may impact the resilience of non-targeted understory plants.

Comparative study of forest structural diversity, birds and plant species diversity between mature oak forest and Plantations in Basque Country

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Biodiversity has declined rapidly over the last 50 years, with severe implications for human health and well-being, societal resilience, and sustainable development. The main direct cause of biodiversity loss is land use change which drives an estimated 30% of biodiversity decline. Forests, when sustainably managed, play a crucial role in regulating climate, providing renewable materials or halting biodiversity loss. However, the spread of intensively managed monospecific even-aged forest plantations raises the question of how this land use can affect biological diversity at local level. Moreover, most of these forest plantations include exotic species that may not be suitable as habitat for many local species. Sixty percent of Atlantic side of the Basque Country (north of Spain) is covered by forest systems, but monospecific even aged exotic plantations cover as much as 68% of forest area, while English oak forests, the main potential forest system in the region, only cover 5,1% of this area.

Our hypothesis is that this simplification of the forest system reduces resources and shelters for native species, negatively affecting their survival and reproductive capacity.

The objective of this study is to determine differences in forest structure, the amount of deadwood, and small scale biodiversity (plant and bird species) among four forest types: semi-natural oak forest, eucalyptus, Japanese larch and radiata pine plantations. All four types of forest are located at similar altitudes and climatic conditions. We stablished three plots of 18m radius in each forest type.

Based on preliminary results, plant and bird diversity tend to be higher in oak semi-natural forest and lower in plantations (lower in eucalyptus than in conifers). Forest structure is different among all type of forest related to its own natural development and management. Oak semi-natural forest is more uneven-aged and random distributed, having a higher presence of deadwood. Plant diversity tend to be higher in oak seminatural forest and lower in plantations (lowest in eucalyptus). However, there is a higher presence of shrubland species in eucalyptus plantations. The same pattern is observed in avian diversity although differences between conifers and oak seminatural forest are smaller due to similar age characteristics.

Continuous cover forestry will not benefit biodiversity without improved environmental considerations

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Continous cover forestry (CCF) is often considered a better option than rotation forestry for biodiversity conservation and pest insect management. However, for species depending on old growth structures like old trees and dead wood CCF induce the same basic problems as rotation forestry in terms habitat loss.

In this project we evaluate the effects of one type of CCF, selective felling, on the beetle community in a field experiment including nine locations in central Sweden. At each location there are two treatments and a control: one even-aged stand that is managed by traditional rotational forestry, as well as two un-even aged stands that have either become selectively cut or left untouched as a control. By putting out two different kinds of insect traps, flight intercept traps and malaise traps, which together catch a large part of all flying insect species, we examined how the beetle assemblage responded to the different management methods. We examined species richness, assemblage composition, and occurrence of beetles of conservation concern, and pest bark beetles and their enemies. We found that the beetle assemblage in the clearcut stand was different from those in the selectively cut and the control stands. Selective harvesting did not substantially change assemblage composition or the abundance of species of conservation concern of pest bark beetles. However, selective felling reduced the amount of deadwood and large trees compared with the control. Thus, CCF can potentially benefit species that thrive in continuous forest but measures must be taken to ensure habitat availability in selectively cut stands.

Contrasting mitigation and adaptation forest management strategies: unraveling the effects on biodiversity and ecosystem services

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Boreal forests play an important role in climate change mitigation, biodiversity conservation and the provision of vital ecosystem services. Changing climate is likely to increase the frequency and the severity of forests disturbances. Hence, increasing disturbances may offset the past and ongoing efforts to increase carbon sequestration in forests and halt biodiversity loss. While forest disturbance risk prevention measures i.e., adaptation management, offer solutions to safeguard future timber yields, the effects of adaptation management on biodiversity, climate change mitigation potential of forests and other ecosystem services has received little attention. In this study we contrast the effects of mitigation versus adaptation forest management on the resilience of boreal forest ecosystems in a changing climate. We address the following questions: 1) How does adaptation management affect the carbon sequestration and storage potential and other ecosystem services of boreal forests in a short and long term in a changing climate? and 2) What are the synergies and trade-offs of mitigation and adaptation management on selected biodiversity indicators? To address these questions, we used a process-based forest landscape and disturbance model iLand that models interactions with climate change and disturbances dynamically. We simulated combinations of seven forest management scenarios and three climate scenarios in two different forest landscapes with ten replicate runs for 80 years. The forest management scenarios included business as usual scenarios and mitigation and adaptation scenarios with changes in rotation lengths and in the shares of deciduous trees in regeneration. Our findings highlight the complex interactions between disturbance risk prevention, biodiversity, carbon storage and sequestration and other ecosystem services. The results help to guide forest managers and policymakers in planning conservation and mitigation efforts, maximizing multiple benefits and enhancing forest resilience under a changing climate.

Dynamics of biomass evaluated with remote sensing in Pinus pinaster in Portugal

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Above ground biomass was estimated with an allometric functions with crown projection area on a per area basis, for *Pinus pinaster* stands in Portugal. The allometric function is a linear function with crown projection area as explanatory variable derived from the vegetation mask of high spatial resolution satellite images. It was attained with contrast split segmentation over normalized different vegetation index. The above ground biomass was calculated on a per square grid of 500 m^2, for high spatial resolution satellite images of 2004, 2007 and 2011 and its dynamics evaluated. During the period under analysis two types of disturbance occurred forest fires and salvage cuttings (to control the pinewood nematode). The results indicated a trend towards the decrease of above ground biomass from 2004 to 2007, due mainly to forest fires and salvage cuts and an increase in *circa* half of the area from 2007 to 2011. The increase in above ground biomass was due to growth as well as natural regeneration mainly in the burned areas. Overall, the advantages of monitoring biomass with remote sensing data are the monitoring of the entire area (without conversion or extrapolation methods), it is a simple method, especially indicated for stands and/or forests where disturbances and natural regeneration occur, and its implementation in a geographical information system is straightforward being a useful tool to forest management and planning. Moreover, the monitoring of above ground biomass can be done at several temporal and/or spatial scales enabling increasing the flexibility in monitoring above ground biomass and carbon.

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Effects of thinning intensity on growth, species diversity of understory vegetation and forest productivity of Korean pine plantation

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: In the context of sustainable forest management, the cultivation goal of artificial forests should not only meet the demand for wood production, but also consider ecological service functions such as carbon sequestration, biodiversity protection, and forest productivity maintenance. Density regulation is one of the important measures for silviculture. In the past, the stage adjustment of artificial forest density was mainly aimed at increasing wood production. Under the premise of considering wood production and main ecological service functions, further research is needed to determine the reasonable density of artificial forests at different stages. This paper takes the 71 year old Korean pine plantation in Caohekou Town, Benxi City, Liaoning Province, China as the research object, to explore the impact of different intensity (extreme intensity, intensity, moderate intensity, weak intensity and control) thinning modes on the growth of Korean pine plantation, timber volume, understory vegetation species diversity and soil physical and chemical properties, and comprehensively evaluate the forest growth, timber yield, understory vegetation species diversity and forest productivity through Entropy-Topsis method. The results showed that there were significant differences in growth status, wood yield, species diversity of undergrowth vegetation, and soil physical and chemical properties under different thinning intensity models. If the management goal is to increase the large diameter timber output of Korean pine plantation or protect the species diversity of understory vegetation, it is recommended to adopt the moderate thinning mode; if the goal is to maintain forest productivity, it is recommended to adopt extreme intensity thinning mode; If you want to simultaneously consider the above three aspects, it is recommended to prioritize the moderate thinning mode, followed by the extremely intensive thinning mode.

European forest potential for carbon sequestration and biodiversity conservation under different silvicultural regimes

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Climate change mitigation and biodiversity conservation are deeply connected and must be considered jointly. Forests are of primary relevance for both these major environmental challenges. Our study aimed to assess the synergies and trade-offs between thesechallenges in European forests. We used forest structural and biodiversity data from 2,282 sampling units across 12 European countries merged and harmonized in the framework of the COST Action "BOTTOMS-UP" (CA18207). We calculated living trees and deadwood carbon stocks, according to IPCC guidelines, and species richness for six taxonomic groups (Birds, Epiphytic Bryophytes and Lichens, Saproxylic Beetles and Wood inhabiting Fungi, Vascular plants). The species richness of each taxonomic group in each sampling unit was standardized through rarefaction and extrapolation curves. We used boosted regression trees to estimate the relationship between the scaled species richness of different taxonomic groups in relation to carbon stocks and other covariates, including forest type, silvicultural regime and sampling protocol. Since biodiversity conservation should focus not only on the number of species, but also on their identities, we used species-only distribution models (MaxEnt) with GBIF occurrences to assess the climatic suitability for each species in the dataset at the continental level. Obtained climate suitability was extracted for each “BOTTOMS-UP” sampling unit and modeled against presence/absence data in the platform through GLMMs by taking into account the silvicultural regime among the fixed effects.

Species richness response to carbon stock was generally positive for saproxylic and epixylic groups, but it varied greatly across taxonomic groups and carbon pools, with a diverse impact of and silvicultural regimes across taxonomic groups. Forest multifunctionality for carbon sequestration and biodiversity conservation may be achieved only by accounting for different responses when planning silvicultural strategies. Indeed, by analyzing the responses of a wide range of forest species, we were able to assess the effects of different silvicultural regimes on biodiversity in European forests.

Forest management and climate change – forest management trends in the forest offset market in the United States

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Land management interventions such as forest management have gained significant traction in the last few years as instruments in increasing carbon (C) sequestration in working lands of the United States. Indeed, storing C in forests have been identified as a key nature-based solution pathway. While the importance of forest management in maintaining and potentially enhancing the terrestrial C sinks has been well established, C as a management objective in the practical context of silviculture and forest management is a relatively new concept. Yet a new emissions trading market, the Voluntary C Offset Market in California, has been dominated by offsets originating from managed forests. Furthermore, almost two hundred million forest C offsets have been issued through the California Cap-and-Trade-Program and Voluntary Offset Market yet little information is available on the practical forest management applied in these projects.

Improved forest management (IFM) has been identified as one of the forestry-related land management pathways with significant climate change mitigation potential. Currently, IFM is loosely defined and how it translates into practical forestry and connects to sustainable forest management (i.e., best management practices) as a whole, has not been identified in detail. **Here, we assess IFM, evidence for the potential for different IFM practices to sequester C, and gaps in IFM and the incentives for their adoption.** We offer specificity to IFM through reviewing existing best management practices and additional silvicultural practices.

Growth and biomass production of major tree species in Korean forests: Implications for forest management and climate change mitigation

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: The role of forests as a major carbon sink is becoming increasingly important in mitigating climate change and achieving carbon neutrality. In particular, Korea's forests were established as a reforestation and greening project after the Korean War and have reached a harvest age of 40-50 years, so there is increasing interest in managing forests before and after harvesting. It is necessary to develop a forest management plan for each tree species in order to improve the carbon sequestration capacity of the forests.

This study was conducted to evaluate the growth and biomass production characteristics of *Larix kaempfi* (LK), *Pinus densiflora* (PD), *Pinus koraiensis* (PK), and *Quercus mongolica* (QM), and to investigate the effects of past forest management practices and climatic factors on the growth of each tree species in Mt. Gariwang, Pyeongchang, Gangwon-do, Korea.

The study stands were located at an elevation of 900-1000 m and on the same southeastern slope. Mean tree height, DBH, and stand density were 10.34-18.54m, 21.04-35.54cm, and 267-758 trees ha-1 across all stands.

For the growth characteristics, aboveground biomass was measured by tree inventory and stem coring. Belowground fine root biomass was measured by soil coring. For the productivity survey, aboveground litterfall was measured with a litterfall trap, and belowground fine roots were measured with ingrowth cores. To obtain data on the site environment, soil characteristics, understory vegetation, and historical climate characteristics were also investigated. Net primary production (NPP) was estimated as the sum of woody biomass, litterfall and fine root production.

Preliminary results of this study showed that most of the fine roots were distributed in the 0-20 cm soil depth and leaf litter accounted for 70% of the total litterfall. NPP follows the order QM > PK > LK > PD. Tree growth seems to be more influenced by annual precipitation than by annual temperature change.

The results of this study will be able to provide basic data for establishing species-specific forest management plans in response to future climate change.

Influence of silvicultural scenarios on potential forest use, carbon storage and biodiversity in tropical forest landscapes

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Human-modified forest landscapes are widespread in tropical regions. They are important for climate change mitigation and biodiversity conservation, but also for food security and wood production. The multitude of initiatives aiming to protect and restore forests in these landscapes often faces the challenge of trade-offs between different objectives. On the level of forest stands, there is robust knowledge on trade-offs associated with different wood production systems. However, there is a lack of understanding about their landscape-wide impacts. Studying these impacts is challenging because land use in tropical regions is highly complex and empirical data on the landscape-level are scarce. Additionally, deforestation for agriculture has a huge influence on landscape-level outcomes. It is thus important to account for interactions between wood production and deforestation risks.

We extended the land sharing vs sparing framework to wood production in old-growth and restored forests and developed silvicultural scenarios of meeting wood demands in human-modified tropical forest landscapes with either high-intensity or low-intensity wood production systems. We then quantified impacts on carbon storage and biodiversity in different stylized virtual landscapes in Ecuador, Zambia and the Philippines for each scenario using a modelling approach. Our probabilistic and spatially implicit model simulates a time frame of 30 years and includes the following main components: 1) landscape-wide fuelwood and timber demands based on estimations of per capita demand and population; 2) biomass growth and wood production estimated using simple and robust growth equations; 3) different wood production systems with distinct deforestation risks estimated based on remote sensing data, and 4) changes in species richness due to loss or degradation of natural habitat estimated using a species-area relationship model. For each silvicultural scenario and landscape, we run 1000 iterations and present results from a sensitivity analysis that estimates the contribution of input parameters to the overall output uncertainty.

Preliminary results of our exploratory model suggest that it is more favourable for landscape-wide carbon storage and biodiversity to meet wood demands using low-intensity wood production systems. Our model shows the importance of considering landscape-level outcomes when comparing wood production systems in the tropics.

Long-term effects of (slow-release) liming in Norway spruce stands reveal soil restoration boosting tree productivity, and herb layer biodiversity

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Norway spruce (*Picea abies* L.), a fast-growing conifer, has been managed to meet the growing demand for wood as it boasts a high revenue while having the ability to cope with acid soils. However, because of climate change, this tree species is currently experiencing severe beetle-induced diebacks. Furthermore, multiple (fast) rotations and ongoing atmospheric deposition have exacerbated the nutrient deficiencies of K, Ca, and Mg leading to poor tree vitality and low productivity.

A multitude of field experiments were deployed in the 90s to alleviate these nutrient imbalances in the soil. They encompassed additions consisting of (mixtures of) rock powders, dolomite or wood ash (Ca, Mg and K), and other mineral fertilizers (P and S). However, an important knowledge gap remains because the long-term effects on belowground restoration, aboveground productivity, and herb layer biodiversity are paramount to assess the future feasibility and sustainability. To this goal, we resampled experiments (28-35 years after application) in 2022 and cored 250 trees.

In 1987, three experiments with broadcast fertilization (±5 Mg/ha, plots 1 ha) were set up in mountainous Vorarlberg (AT) forests ($pH_{topsoil}$-$CaCl_2$ = 3.0, tree age_{1987} = 110-185 yo) with sites varying from crystalline stony podzols to albic luvic stagnosols (von Mersi et al., 1992). Furthermore in 1995, in Baden-Württemberg (DE) on a gleyic luvisol ($pH_{topsoil}$-$CaCl_2$ = 3.0, tree age_{1995} = 56 yo) a broadcast comparison (1-10 Mg/ha, plots 2500 m^2) of phonolite rock dust, dolomite, K_2SO_4 and wood ash was laid out (von Wilpert & Lukes, 2002).

Belowground, soil pH and base saturation increased while carbon stocks changed and yielded more carbon in deeper horizons. Aboveground, the BAI (ranging from 1000-4000 mm^2/year), increased up to 50% for K-deficient stands in Baden-Württemberg while more subtle increases (+10-20%) were found due to lower N deposition, smaller amendment dose, and higher tree age in Vorarlberg. Total ecosystem carbon increment generally increased (+10-40 Mg C/ha) after amendments, and herb layer biodiversity was increased. In conclusion, soil ameliorative treatments are promising to boost Norway spruce productivity but the gain is highly site-specific and care must be taken to preserve climate resilience.

Partial harvesting for climate mitigation in forests of northwestern British Columbia

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Canada is one of the world's largest producers and exporters of timber products, with almost half of the country's wood coming from clear-cut harvesting in British Columbia. Implementation of partial harvesting can increase carbon retention and has the potential to offer a transformative and sustainable alternative that promotes regional and global climate mitigation goals. Additionally, increased structural complexity and the maintenance of biodiversity and other ecosystem services promote adaptation in partially harvested landscapes. However, it is unknown how clearcutting versus partial harvesting affects carbon dynamics and other ecosystem services at a landscape scale, particularly if a larger area is harvested in order to meet the demand for wood. We used the landscape model LANDIS-II to simulate forest stand growth and mortality, disturbance, and harvest in northwestern British Columbia's interior cedar-hemlock zone. We implemented three harvesting intensities (30%, 60%, and clearcutting) across a range of realistic harvest rates in mature and old-growth forested landscapes, then compared carbon storage and sequestration. We also assessed the impact of harvest waste residue burning and harvested wood product storage on carbon dynamics and analyzed changing road density and forest structure. Empirical data from inventory plots and long-term partial harvesting trials and the stand-level model SORTIE were used to parameterize and validate LANDIS-II. Our results highlight tradeoffs between carbon storage and wood production: as expected, we found that reducing harvest intensity increased carbon storage and decreased wood production. Harvest volume targets could be maintained by increasing the area harvested, but differences in carbon dynamics across forest ages and partial harvesting approaches were strongly mediated by overall harvest rate. Due to their high carbon storage and sequestration rates and lower merchantable volume, old growth forests represent a promising carbon mitigation tool in northwestern British Columbia. Decision support tools developed using our results will support Provincial and First Nations land managers in British Columbia who are working to balance complex harvest, carbon mitigation, and ecosystem services goals.

POTENTIAL OF DIPTEROCARPS AS FOREST PLANTATION SPECIES AND FOR CARBON SEQUESTRATION IN MARGINAL AREAS

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: *Anthoshorea roxburghii* and *Hopea odorata*, both from the Dipterocarpaceae family, are native to the mixed dipterocarp forest of Malaysia and are classified as 'Vulnerable' in the IUCN Red List of Threatened Species. Both species have been promoted not only as plantation species but also suitable to be planted in open area of degraded sites including ex-mining and logged over areas in Malaysia. This paper aims to 1) determine the growth, biomass and carbon accumulation in *A. roxburghii* and *H. odorata*, 2) determine suitable sites as plantation species and 3) explore the possibility of the two species for rehabilitation of degraded or problematic sites. Results show the growth performance of both species in marginal or degraded areas besides ability to sequester carbon. Eleven years old *A. roxburghii* can grow with mean annual increment in diameter at breast height (MAID) of 1.73 ± 0.65 cm with an estimated aboveground biomass (AGB) of 126 Mg/ha. Meanwhile, seven years old *H. odorata* recorded average MAID of 1.80 ± 0.53 cm and AGB of 33 Mg/ha. FIndings from this study thus indicated that *A. roxburghii* has higher potential in terms of biomass as well as carbon accumulation on degraded sites.

Restoration of Introduced Species Plantations through Native Shade-Tolerant Species: The Case of Abies holophylla in South Korea

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: As biodiversity loss becomes a growing concern, biodiversity conservation and forest restoration have emerged as critical topics. Restoring severely damaged areas by immediately reintroducing native shade-tolerant species presents challenges. In such cases, plantation with introduced species is often initiated to gradually improve the damaged environment over time. This approach encourages the natural invasion of native species from adjacent natural forests, facilitating the recovery of species composition and biodiversity. Korea has predominantly implemented plantations using introduced species like *Pinus rigida*, *Robinia pseudoacacia*, and *Larix kaempferi* for soil stabilization or timber production, whereas the establishment of plantations with native species remains limited. This study aims to propose a silvicultural practice that achieves the forest restoration through natural regeneration or underplanting of *Abies holophylla*, a native shade-tolerant species, with the goal of biodiversity conservation. We examined changes in the stand structure of two types of *Larix kaempferi* plantations in the central region of the Korean Peninsula to understand native species invasion and restoration processes. *Larix kaempferi* plantations were grouped as (1) plantations with remaining *Abies holophylla* individuals as mother trees and (2) plantations located adjacent to natural stands of *Abies holophylla*. After 40-60 years of plantation establishment, the importance value of *Abies holophylla* exceeded that of the planted species. Active natural regeneration of *Abies holophylla* in the understory was observed, suggesting the potential of stand development into *Abies holophylla* stands. Furthermore, we assessed the survival rate and growth of underplanted *Abies holophylla* seedlings in closed-canopy stands after 20 years of planting. The survival rate and growth of these seedlings demonstrated the feasibility of underplanting as a means of advancing native species establishment. The results suggest silvicultural practices such as natural regeneration or underplanting of native shade-tolerant species could be tried in forest restoration efforts aiming at biodiversity conservation.

Short-term Study of Abies kawakamii and Tsuga chinensis var. formosana in Central Taiwan's Forests

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: *Abies kawakamii* and *Tsuga chinensis* var. *formosana* are the major species found in the high mountain forests of Central Taiwan. These forests are particularly vulnerable to the impacts of climate change due to their specific bio-climatic and topographical requirements. In this study, we conducted tree-by-tree censuses in the 6-ha Hehuan-Mountain forest dynamic plot, located in the upper part of the Tsuga forest zone and the lower part of the Abies zone. All free-standing trees with a diameter at breast height (DBH) ≥ 1 cm were identified, measured, and mapped in 2008 and 2022.

During these two surveys, a total of 14 species were recorded in the plot. The most abundant species was *A. kawakamii*, accounting for approximately 58.65-58.72% of the total number of individuals, followed by *T. chinensis* var. *formosana* as the second most abundant species (17.52-17.22% of total stem density). Both *A. kawakamii* and *T. chinensis* var. *formosana* exhibited a decrease in stem density over the 14-year interval. Despite the substantial decline in stem density, the basal area of *A. kawakamii* increased from 30.32 to 34.78 m^2 ha^{-1}. However, the basal area of *T. chinensis* var. *formosana* decreased from 11.10 to 9.02 m^2 ha^{-1} due to the falling of numerous large trees (DBH ≥ 150 cm) and limited recruitment of new individuals. Using biomass calculations and bootstrap simulation based on Chave et al. (2015), the biomass in this plot was estimated to be 789.69 Mg ha^{-1} in 2008 and 808.74 Mg ha^{-1} in 2012, indicating a significant increase in biomass. Our 14-year field investigation yielded contrasting results to the predicted population decline and limited upward migration of *A. kawakamii* based on species distribution models (SDMs). Our research suggests that *A. kawakamii*, a tree species found above 3,000 m in Taiwan, maintains a stable population with individual and biomass increment. Conversely, *Tsuga chinensis* var. *formosana*, occurring at elevations of 2,500-3,100 m adjacent to A. kawakamii, exhibits negative population growth without an upward range shift.

Trade-off between woody diversity and millet yield in agroforest parklands in central southwestern Niger

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: The ever-increasing rate of population growth in Niger combined with the demand for food, sometimes results in the scarcity of agricultural land. This leads to the abusive cutting or even disappearance of trees in the fields in order to have space available for agricultural production. This use of land to the detriment of trees can be a competition for the woody diversity present in the fields. The present study, carried out in two agro-ecological zones (Sahelian zone in the department of Kollo and the Sudanian zone in the department of Gaya) of Niger, aims to find a balance between these two situations. The main objective is to study the trade-off between agricultural production and woody diversity in agroforestry parks in southwestern central Niger. The work was based on an inventory of the woody stratum in two (2) villages of each department, i.e. forty (40) plots of 50 m x 50 m in each village and the establishment of forty (40) yield squares of 5 m x 5 m in each village. Weighing was done on ear weight and stem weight in each yield square. The results showed that the woody flora of the Sahelian zone and the Sudanian zone is 37 and 17 species respectively. The results of dendrometric parameters such as cover, basal area, Shannon diversity index and regeneration density were significantly higher in the Sudanian zone, but there was a slight difference in the density of trees per hectare. The bell-shaped structural analysis reveals a renewal or good functioning of the woody stands. The results of the trade-off analysis reveal a slight difference between zones. The trade-off between trees cover and seed yield of millet was 638 ± 125 kg/ha in the Sahelian zone and 679 ± 374 kg/ha in the Sudanian zone; and between ear yield of millet was 2025 ± 578 kg/ha in the Sahelian zone and 1819 ± 1206 kg/ha in the Sudanian zone. Thus, a trade-off model emerged from this study in two agro-ecological zones of Niger.

Key words: trade-off, woody diversity, agricultural production, agroforestry parks, central southwest, Niger

Use of introduced species to facilitate native species establishment in forest restoration

T1.3 Challenges for silviculture to meet demands from carbon sequestration to biodiversity conservation to forest restoration

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Abstract: Many parts of world forests are suffering from exploitation, degradation or land conversion. Forests are a major carbon sink that helps to mitigate climate change and provide habitats for majority of terrestrial organisms. Efforts to restore forests are put into action in many areas. One of primary consideration for forest restoration is the selection of tree species that would be introduced to damaged areas. Severely damaged areas need forest restoration efforts; however, their environment is often too damaged to conduct restoration practices with native species that require better environment such as mature forest condition. In this case, step by step approach in a long-time scale may be needed. Korea was heavily deforested in early- and mid-20th century. National reforestation project launched and planted about 2.9 billion trees from 1973 to 1978. Major species used for reforestation during that period was *Pinus rigida*, *Robinia pseudoacacia*, and *Alnus* spp. that were introduced pioneer species. As soil condition improved, native species came back whereas introduced pioneer species became senescent without further regeneration. The introduced pioneer species acted as intermediaries in forest restoration to native forests. The application of exotic species in forestation has advantage of less natural enemies especially insect pest and diseases, whereas there is a risk that the exotic species would thrive, continue to regenerate and even expand to occupy habitats for native species. Selection of right tree species is a key factor in forest restoration. Introduced species that could facilitate native species restoration may be used in severely damaged area where even native species could not stay. Introduced species plantation would be an intermediate stage toward mature forest of native tree species in restoration process following forest stand development.

T1.4 Climate Smart Forestry

Adapting Forest Infrastructure to Climate Change Risks: Modeling and anticipating the consequences of changing patterns of precipitation

T1.4 Climate Smart Forestry

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Abstract: According to ICCP projections for Central Europe and other regions of the world, heavy rainfall events will increase in frequency and especially in intensity, often resulting in severe damage or even destruction of forest infrastructure such as roads, culverts and bridges. Soil erosion, siltation of waterways, landslides and downstream flooding are often negative consequences for both the forest and the public. In addition, instead of infiltration and recharge, forest water tables and water sources are at risk of drying up as early as spring. Water runs off at the surface and is "lost" to supply vegetation, leading to drought risks and calamities later on.

Hydrological modelling combined with high-resolution GIS-based surface models makes it possible to predict rainfall events of varying intensity and to model the associated surface runoff. Based on this, the design of roads and the capacity of water control infrastructure can be critically evaluated in detail with the aim of minimising damage and reducing water run-off from the forest. A set of technical measures necessary and viable to achieve these objectives is proposed. Comparative cost/benefit calculations for the implementation of these preventive measures versus "business as usual" with the risk of damages support appropriate management decisions.

The concept is presented as an example for a case study in the southern Black Forest, Germany. It can be applied generally if the necessary data are available: High resolution DGM and related information on soil and vegetation cover combined with actual and predicted climate data are available.

Advancing Climate Smart Forestry Adoption through Improved Forest Carbon Measurement Tools and Resources

T1.4 Climate Smart Forestry

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Abstract: In the United States, it is estimated that forests offset 10-15 percent of annual economy wide greenhouse gas emissions. Emerging research is indicating a trend toward a weakening forest carbon sink across some regions due to the increasing severity, frequency, and size of forest disturbances. Efforts to expand the adoption of forest management practices to improve forest health and resilience and enhance carbon sequestration have been introduced through both public and private sector mechanisms at many scales. This has increased the demand for user-friendly guidance and tools to quantify the impact of climate-smart forestry; better definitions of what constitutes climate-smart forestry given the continuum of management intensities and ecosystem types; as well as research to identify and improve models for projecting stand dynamics in a changing climate. This oral and/or poster session will introduce some of the latest national-scale efforts to improve and deliver consistent science-based measurement, monitoring, and reporting resources for climate-smart forestry practices. Among these is the Forest Management chapter in the United States Department of Agriculture 2023 publication "Quantifying Greenhouse Gas Fluxes in Agriculture and Forestry: Methods for Entity-Scale Inventory" which provides guidance and standards for greenhouse gas estimation for private landowners, but also applicable on public lands. This work connects ecosystem accounting for silvicultural practices with an approach for estimating the greenhouse gas flux in wood products, as well as lifecycle quantified potential substitution benefits of using wood products and bioenergy. Application of this consistent, tool-supported quantification approach can also enable national scale reporting toward climate goals, including Nationally Determined Contributions as part of the Paris Agreement.

An economic approach to carbon offsetting and GHG reduction potential through woodland expansion on areas used for livestock grazing

T1.4 Climate Smart Forestry

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Abstract: Voluntary carbon markets involving forestry carbon sinks are experiencing rapid growth. Offsetting greenhouse gas (GHG) emissions through forest-based investment is a source of debate, however, due to allegations of carbon over-crediting and lack of permanence. Improving the credibility of the carbon offsetting process calls for a critical analysis of the potential and feasibility of forest-based investments to generate carbon units that are truly additional and long-lasting.

In this paper we analyse the economic potential of using woodland expansion to offset carbon in areas currently used for livestock grazing using high resolution data for a case study area (Scotland). Our study accounts for spatial variability in timber yield classes for six different types of tree species, including climate effects on timber yield, as well as, soil carbon stock, land cover and livestock stoking rates for main livestock enterprises in the country.

Carbon additionally from planting woodlands, particularly in upland areas of Scotland used mostly for livestock farming, has been questioned by a few recent studies, especially when organic soils and intensive ground preparation practices are concerned (loss of carbon). The latter has important economic implications, as planting trees is expensive and low carbon sequestration rates on poorer quality lands may make woodland expansion an unattractive investment. Furthermore, changing the use of land conveys opportunity costs in terms of livestock farming benefits forgone for landowners and/or land tenants, but also loss of flexibility when land is converted to forest which can result in short–term devaluation of afforested land.

This paper develops an optimal land use change and forest management economic model, that accounts for timber and carbon net benefits, woodland expansion implementation costs at different management intensities, and land opportunity costs from livestock farming, and GHG mitigation potential from reducing stocking rates. The model analyses the cost-effectiveness of land use change and tree species selection decisions under different carbon payment levels, and addresses a hypothetical scenario where there are financial penalties from livestock carbon emissions. We further explore the cost-effectiveness of woodland expansion and the role of spatial heterogeneity in forest productivity, soil attributes, livestock stocking rates and land use typologies.

An exploration of Climate-Smart Forestry to reduce risk, enhance opportunity, and seek alignment across landscapes

T1.4 Climate Smart Forestry

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Abstract: Climate change is presenting a global challenge to society and ecosystems and, in doing so, is changing long-standing human valuation of forests. This shift is encompassing their role in climate mitigation and adaptation alongside traditional forest products and services. Because of their framing as a Natural Climate Solution (NCS) or Nature-Based Solution (NBS), forests have become increasingly important in climate change dialogues, including and well beyond international climate negotiations. In turn, the term "Climate-Smart Forestry" (CSF) has recently entered the vernacular in myriad disciplines and decision-making circles espousing the linkage between forests and climate.

Our analysis shows this new emphasis on climate change in forestry has a wide range of interpretations and applications and finds that CSF remains loosely defined and inconsistently applied across professions and landscapes. Adding to this confusion, it remains unclear how existing guidance on sustainable forest management (SFM) is relevant or might be enhanced to include CSF principles, including those that strive for demonstrable carbon benefits in terms of sequestration and storage. Identifying a science-practice gap, this work explores potential gaps and risks under a current framing of CSF and explores opportunities to increase scale and benefits of CSF principles. Methods include a literature review, qualitative assessment of documents, and statistical analysis of datasets from related studies. Identified risks including overly simplified relationships between carbon sequestration and forest management, 'carbonization' of forest values generally, unintended social effects and unequal access to benefits, and overlooked efficiency gains and economic misalignments. Identified opportunities include social inclusion and equitable benefit distribution, addressing the co-occurring biodiversity crisis, cross-sector and -landscape communication, and supporting a climate-aligned economic transformation.

This presentation will cover (1) current definitions and framing of CSF, (2) CSF risks and opportunities, (3) a broadened CSF definition that includes additional intervention types for multiple scales of decision-makers, and (4) sources of evidence of CSF. This final section will include an overview of key indicators, as well as tools and metrics to safeguard against potential harm.

An Innovative Modelling Framework to Simulate and Optimize the Climate Change Mitigation Potential of the Forest Sector in British Columbia, Canada

T1.4 Climate Smart Forestry

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Abstract: Canada's current strategic forest management planning processes rely heavily on forest management modelling for wood supply simulation and optimization. However, these forest management models typically do not include carbon stock, sequestration and flux indicators. To promote the climate change mitigation potential of the forest sector in British Columbia (BC), Canada, this study aims to build an innovative methodology framework with pure Python to add carbon indicators for both the forest ecosystem and harvested wood products into forest management models for mathematical simulation and optimization. The research area is in the interior of BC. Firstly, a forest management model was built to simulate and optimize forest resources management, and a forest carbon budget model was constructed to quantify the ecosystem carbon dynamics. An improved approach was applied to link the forest management model with the forest carbon budget model to enable setting forest ecosystem carbon as management goals and constraints. A wood product carbon module was then built and linked to the forest management model to track the carbon dynamics and calculate the substitution benefits of harvested wood products. The final modelling framework was run under four scenarios: baseline, maximizing total carbon stock, maximizing total carbon sequestration, and minimizing total net carbon emission. Given current modelling assumptions, I would find which target can optimize the climate benefits of the BC forest sector and provide suggestions for future modelling work. I would also quantify the impact of forest management activities on the carbon dynamics of the whole forest sector in BC.

This research can contribute to including forest carbon in current BC strategic forest management planning processes. The modelling framework is the core of a large forest carbon research project in the UBC FRESH lab. It could be applied in any forest carbon management projects elsewhere in Canada. It can also be further improved and expanded to find optimal long-term management plans to maximize the climate change mitigation potential of the BC and Canada forest sectors. All the data, models, and results in my research will be published online for the public, increasing my research's transparency, repeatability, and credibility.

Application of the Carbon Budget Model to assess the contribution of climate-smart forestry for climate change mitigation in Alpine forests.

T1.4 Climate Smart Forestry

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Abstract: Climate-smart forestry (CSF) aims to tackle complex challenges related to climate change impacts on forests, such as increased mortality from natural disturbances, reduced forest productivity, and implications on social and economic sustainability. However, few studies on CSF have addressed the combined impact of management, climate change and altered disturbance regimes on the real mitigation potential of forests, especially at scales larger than the management unit.

We used the Carbon Budget Model (CBM) of the Canadian Forest Service to simulate the mitigation potential of forests located in Valtellina and Valcamonica on the Italian Alps, according to three management scenarios (from 2020 to 2050). The investigated scenarios are i) business as usual, ii) adaptative silviculture (focused on fire prevention and fire vulnerability reduction) and iii) mitigation based on wood substitution effects (with an increase in producing wood adequate for buildings and other long-term uses).

To overcome lack of climate sensitivity in growth and disturbance modules of CBM, we coupled it with a process based model (3PG), to modify growth curves depending on future climate scenarios (i.e. trends in temperature and precipitations). Moreover, we updated the wildfire regimes by statistically modelling the link between burnt-area and drought indices using historical data, and extrapolated this relationship to expected future drought occurrence. Both climatic variables and change in the wildfire regime were modelled for climate change scenarios RCP4.5 and RCP8.5.

Results show that broadleaves' growth will increase more than conifers', and thus their carbon sink. Nevertheless, simulated frequency of drought in the future results into higher C losses because of increased vulnerability of forests to wildfires. We argue that fire-prevention interventions in combination with CSF might support forest resilience under climate change. Concerning productive management, harvested wood products should be used for long life-span products since this can help to mitigate greenhouse gasses emissions from hard-to-abate sectors like buildings.

Our findings can be helpful in orienting landscape planning towards ensuring forest-based mitigation potential, especially in areas where the combination of various climate-driven forces might limit both the resilience and adaptation capacity of forest ecosystems.

Carbon sequestration in forest soils. How it will change after the extreme bark beetle outbreak and expected change in forest management strategy?

T1.4 Climate Smart Forestry

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Abstract: In temperate and boreal forests C sequestration in soil is usually higher than its stock in aboveground biomass. Although soil carbon is not influenced by forest management directly, its change resulting from ongoing changes and forest management strategies should not be underestimated. Central Europe was recently exposed to extreme bark beetle outbreak leading to extreme spread of clear-cuts and temporary loss of forest cover in range of hundred thousands of ha. Such a rapid change may have considerable effect also on soil properties mainly due to processes in the upper organic (humus) layer. Changes in carbon stock as well as in other chemical properties are expected. Further expected change is connected with the ongoing shift in long-term forest management strategy which should lead towards more diverse forest composition, increased representation of broadleaved species and closer-to-nature silviculture. To describe the current situation and future development in the Czech Republic, we have compiled a large national "Aggregated soil chemical properties database" combining harmonized results from several surveys during the period 2000-2020. These data are compared with dozens soil samplings on large clear-cuts resulting from bark beetle infestation and newly established young stands. Moreover the carbon storage was assessed in relation to different forest management procedures – e.g. tree species composition, stand age and age structure, methods of tending as well as with examples of native old-growth forests. Recent results comparing soil analysis on clear-cuts, however, are rather hazy. On one hand accelerated humus decomposition leads to loss of carbon from the upper organic soil layer on open plots, on the other hand the same layer is often enriched by logging residues biomass which may results even in enhanced carbon stock. Further changes may be expected as a consequence of planned increase of broadleaved stands. Such development can result in lower C stock in the organic layer of forest soils. More stable carbon pool in deeper mineral soil, however, will probably increase. There are also other beneficial effect for several qualities of forest soils – e.g. for carbon sequestration, soil biodiversity or hydrological features due to more complex rooting in deeper soil layers.

Climate and biodiversity-smart forestry and forest restoration across Europe; who does it, why, and how it could develop?

T1.4 Climate Smart Forestry

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Abstract: Climate and biodiversity smart forestry (CBS) and forest restoration emphasize the integration of biodiversity conservation to climate change mitigation and adaptation approaches that synergistically realize multiple ecosystem services. These approaches purport spatially integrating multiple forest management objectives by selecting the "smartest" management practices for enabling synergies within the forest region in question. When it comes to examining the current state of CBS and forest restoration practices across Europe, little can be said, as there is limited country specific information about the different types of CBS and forestry restoration practices implemented by European forestry practitioners. At the same time, there is limited knowledge about the barriers and drivers impacting the implementation of these practices. To tackle these shortcomings, this research examines primary data from (i) inductively analyzed interviews with forestry practitioners in nine countries across Europe (i.e., Finland, Hungary, Italy, Latvia, Netherlands, Portugal, Romania, Switzerland, and the United Kingdom), and (ii) a Europe-wide questionnaire distributed through both a representative general-population survey and through top-down umbrella organizations representing various forestry practitioners. The interviews function to elicit country-specific CBS and forest restoration management practices alongside their respective barriers and drivers to implementation. The survey operationalizes these salient findings and asks respondents to identify their current forest management objectives, the CBS and forest restoration practices they implement, and relevant drivers and barriers to implementation. This data is used to descriptively quantify which CBS and forest restoration practices occur across different countries in Europe and statistically analyzing the extent to which different drivers and barriers shape the implementation of these practices. Aside from providing a concrete overview of CBS and forest restoration practices, the study inductively builds a European-level typology of forestry practitioners based on forest owner objectives. This typology is useful for designing future CBS forest policy scenarios and large-scale agent-based modelling.

Climate-smart forest management in Europe: Beyond carbon dioxide

T1.4 Climate Smart Forestry

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Abstract: Forests are a key plank of European policies to mitigate and adapt to climate change and to promote biodiversity. These policies are starting to become more nuanced with respect to the account of their impacts on carbon storage, considering the effect of long-lived wood products and value of conserving old-growth forests, along with indirect land-use change impacts. However, a CO_2-focused perspective means that many processes are still omitted for the quantification of the true extent of climate effects. Emissions of the greenhouse gases nitrous oxide and methane, short-lived climate forcers and effects from albedo changes and heat fluxes are also relevant. These processes are interconnected and influence the climate mitigation of forests in a complex way and need to be considered.

The CLImate Mitigation and Bioeconomy pathways for sustainable FORESTry (CLIMB-FOREST) Horizon Europe project that runs until 2027 uses a holistic approach to estimate the climate impacts of various management alternatives. The foundation of CLIMB-FOREST is the use of European-wide empirical data, as well as an advanced coupled vegetation and earth-system modelling framework that includes biodiversity indicators and the interaction of forestry stakeholders in a global trade system. This framework is used to model management, forest tree species and climate on short- to long-term in Europe.

We present first results of the climate effects and ecosystem functioning for a range of management alternatives in boreal, temperate, and Mediterranean forests. For example, introducing broadleaved trees in a coniferous forest promotes resilience and increased cooling from higher solar light scattering and latent heat flux of broadleaved trees. On the other hand, higher evapotranspiration might lead to an accelerated soil moisture depletion and reduced monoterpene emissions. The latter would have a warming effect because terpenes produce atmospheric particles, which are effective cooling agents through their involvement in cloud formation. Consequently, understanding these complex climate effects is key for appropriate climate-smart-forestry policies and approaches.

The main outcomes and impacts of CLIMB-FOREST are to suggest alternative pathways for the forest sector to mitigate climate change in entire Europe, create attitude change in the policymaking process and influence foresters to adopt to new forest management strategies.

Climate-smart forest management may decrease vulnerability of forest carbon to disturbances

T1.4 Climate Smart Forestry

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Abstract: Natural disturbances like windthrows or forest fires have an effect on the provision of ecosystem services like timber production, protection from natural hazards or carbon sequestration. After a disturbance, forests release large amounts of carbon and therefore change their status from carbon sinks to carbon source. However, forest management may improve the forest capacity to absorb carbon by decreasing the vulnerability to disturbances. In this study we used simulation tools ForestGALES (windthrow) and FlamMap (forest fire) to model the vulnerability to the two disturbances. We analysed forest stands prone to windthrow and forest fire and proposed forest management in the most vulnerable forest stands, increasing their resistance to the respective disturbance. We simulated the future carbon stock and sink under two scenarios: (1) business-as-usual management, and (2) forest improved using climate-smart forest management to decrease the vulnerability to disturbances. Forest under business-as-usual management led to a decrease in total carbon. Using climate-smart management compared to business-as-usual resulted to an increase of carbon stocks and sink (with additional increase in case of no disturbance). We showed that using disturbance simulation tools may help in decision making process to analyse the most vulnerable forest stands. In combination with simulations of future scenarios of carbon we may be able to direct the climate-smart forestry.

Climate-Smart Forestry and forest restoration: an overview of experimental trials across Europe

T1.4 Climate Smart Forestry

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Abstract: Climate change and other environmental stressors, such as air pollution and natural disturbances, are putting growing pressure on forest ecosystems and their biodiversity. To date, we still have limited knowledge on the effectiveness of various mitigation and adaptation measures to guide forest management decision making. Climate-Smart Forestry and restoration-oriented management are viewed as promising management approaches in order to preserve and restore biodiversity, ensure the provision of ecosystem services, and to support forest adaptation to climate change.

Across Europe, many forest management and restoration experiments and field trials already exist, but a systematic overview of all experiments and trials is still missing. Based on an extensive, systematic review of existing experiments and trials, we developed a public and spatial database of Climate-Smart Forestry and restoration pilots from international and national networks, projects and other initiatives. For each experiment, the geographical location, the experimental design or treatments, the initial state of the forest stands, the year of establishment, and the obtained findings were explored. Trials and experiments were clustered according to the management measures, objectives, geographical regions, and European forest types to highlight the knowledge gaps on Climate-Smart Forestry and restoration. Outcomes can facilitate the implementation of Climate-Smart Forestry and restoration practices across European forest ecosystems. The overview can guide the allocation of public funds to support the establishment of new trials in those European forest types, geographical regions, and management systems that are currently missing.

Climate-smart forestry in Europe under uncertain future climate and other constraints

T1.4 Climate Smart Forestry

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Abstract: Climate-smart forestry aims at combining sustainable forest management with climate change mitigation, adaptation, and the provision of ecosystem services. This is an immensely challenging task which is further complicated by the fact that the future climate and the extent of its consequences such as more frequent forest disturbances are highly uncertain. Nevertheless, despite this uncertainty, forest management strategies need to be made already today. In addition, the demand for wood products is increasing on the one hand while on the other hand, the importance of strictly protected forests is becoming increasingly recognized and is now also included in new legislation in Europe.

Here, we propose a methodology to address this, based on the dynamic vegetation model LPJ-GUESS and robust multi-criteria optimization. Our approach creates forest management portfolios that are viable for a broad range of climate scenarios and offer an optimally balanced provision of multiple ecosystem services such as climate change mitigation, timber provision, local climate regulation, and the provision of various habitats.
Our approach indicates that a shift towards more broad-leaved species and more unmanaged forests is essential to achieve multi-functional, climate-resilient forests in Europe. This, however, entails a strong decrease in harvests, especially those for long-lived products. This conflicts with increasing wood demands, including the use of wood products as a means of climate change mitigation and indicates that trade-offs between ecosystem services need to be made.

Including strict constraints on keeping harvest levels at present-day values further reduces the options for portfolios offering multiple ecosystem services. We thus conclude that climate-smart forestry in Europe can only go together with other measures that alleviate the pressure on Europe’s forests. Such measures could be increasing the forest area, improving the longevity of products and their recycling, and decreasing the currently large share of woody bioenergy in the EU’s energy provision.

Climate-smart forests at the lower tree line: a long-term experiment to evaluate adaptation options under pannonic, summerdry climate conditions

T1.4 Climate Smart Forestry

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Abstract: About 50% of Austria is covered by forests which include a wide range of forest types and climate conditions. Besides productive montane and subalpine forests, regions with lower elevations in eastern Austria are characterized by low forest shares and continental climate conditions. Yet, the remaining forests have a high cultural and recreational value and are important resources for water supply given the low precipitation and intensive agricultural production. These forests are close to the lower timberline and under increasing temperature conditions they might transform into steppe ecosystems. It is therefore of high importance to maintain the forested sites and the ecosystem services they provide.

After severe forest dieback of various native tree species due to extreme drought conditions and pest infections, we established an experimental plantation with 40 different tree and shrub species. The selection of tree species included native and non-native tree species as well as non-local seed provenances to test for various assisted migration schemes. In addition, a control plot for the monitoring of natural regeneration and regrowth was included in the experimental setup. The long-term experiment is aimed to address the following questions: 1) to characterize and compare the survival and growth of various tree species and seed provenances; 2) to analyse the development of above and belowground carbon stocks at the lower timberline; 3) to evaluate the effects of species composition on soil water contents; 4) to monitor the local climate conditions and the change of site climate with increasing forest development; and 5) to monitor the putative long-term side-effects of non-native trees on forest biodiversity.

Here, we report the first results of seedling survival and growth under the enduring drought conditions of the first years after establishment as well as the initial soil carbon assessment on 80 inventory points which were undertaken after forest dieback and prior to planting.

Commercial forestry of Northern Europe will benefit from wider use of silver birch due to its high plasticity of mechanical stability

T1.4 Climate Smart Forestry

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Abstract: In forests of Northern Europe, wind is the most prominent natural disturbance, causing more than a half of all losses of biomass. The severity of wind damages is amplified through the synergy with other disturbances leading to water and temperature stress. This emphasizes the need for climate-smart forest management to link the ecological needs of tree species with their adaptation to wind loading. Silver birch (*Betula pendula* Roth.) has a wide ecological plasticity, and thus a potential to meet requirements of productivity and wind resistance. However, the information on mechanical stability of birch so far has been insufficient; therefore, static tree-pulling test data were obtained in a wider range of growing conditions (140 trees in total). Stronger soil root anchorage was apparent for birch on less stable and more saturated soils, such as periodically waterlogged mineral and drained deep peat soils, as indicated by the increased loading resistance and higher frequency of stem breakage. This implies high capabilities of birch in adjusting mechanical stability. Moreover, under frozen soil conditions, a higher increase in loading resistance was observed for birch on well drained mineral soils, implying suitability of birch for soils with substantially higher wind damage risk. Accordingly, such ability in adjusting mechanical stability on less stable soils decreases the risk of the synergic effects of intensifying natural disturbances on birch. This suggests a potential for wider application of birch in Northern Europe, supporting the approach of climate-smart forestry by coupling ecological plasticity and mechanical stability with regard to the intensifying risks of wind damage.

Enhancing forest models by incorporating forest managers' behavior

T1.4 Climate Smart Forestry

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Abstract: For centuries humans have managed forests for the provisioning of desired products and services to society. Quantitative forest models are frequently used to deal with complexity under uncertain conditions. Many of these models rely on a theoretical concept of how forest management is done. These models also ignore that forest management decisions are shaped by socio-economic factors, such as individual preferences, societal pressure, market aspects, policies and regulations, resulting in different forest owners and managers behavioral responses. Considering this, our study aims to improve the representation of the behavior of forest owners and managers in forest models to provide better decision support systems. By employing agent-based modeling principles, a preliminary framework was developed to define forest management prescriptions that would better reflect real-world conditions. This framework takes into account the impact of socio-economic factors on forest management incorporating the perspectives of multiple forest agents. EFISCEN-space was used as a base model to simulate forest development, as it allows a comprehensive understanding of forest dynamics, while considering multiple environmental objectives and management strategies. In order to assess forest management behavior, a dataset derived from a survey with forest managers and forest owners in two regions of Germany (Baden-Württemberg and North Rhine-Westphalia) was used. The collected data were employed to formulate alternative management scenarios, which were implemented in a practical exercise. During this exercise, forest managers simulated their management decisions in permanent sample plots, providing valuable insights into the motivation behind their actions. Follow-up in-depth interviews were conducted to further enhance the understanding of their decision-making process. Subsequently, we applied the improved tool to explore the impacts of a set of climate-smart forestry practices to provide decision support on maintaining and restoring forest biodiversity, as well as climate change mitigation and adaptation. Finally, we discuss how forest models could be further improved by including forest management behavior and behavioral responses.

Enhancing resilience - a key strategy to support Climate Smart Forestry

T1.4 Climate Smart Forestry

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Abstract: Climate change and enhanced disturbance risks are strongly affecting the social-ecological forest systems and their resilience. Forest owners and managers need concrete guidance on forest management when it comes to climate change adaptation and enhancing biodiversity while ensuring the resilience of forests to disturbances. Similarly, forest value chain decision makers should aim to make their business more resilient to climate change, changed societal demands and increased disturbance risks, affecting the production potentials and climate change mitigation effects of wood products. Climate Smart Forestry (CSF) needs to consider both, forest and value chain resilience. Forest resilience may vary depending on forest typ. Therefore, it is crucial to understand how forest resilience can be increased through management decisions to safeguard sustainable forest ecosystem provisioning and mitigate undesirable impacts. Value chain resilience, on the other hand strongly depends on technology and timber resourcing choices, and finally, the broader societal resilience depends on the societal context, demand and substitution possibilities.

We present results from the Horizon 2020 research project RESONATE, which investigates resilience enhancing measures in nine regional case studies across Europe. Using criteria and indicators derived from model projections with consistent climate scenarios we demonstrate that enhancing resilience is a balancing act: increasing resilience in one part of the social-ecological system may lead to trade-offs in another part of the system. For example, increasing share of broadleaved species and enhancing tree species diversity are crucial climate change adaptation and CSF strategies, which on the other hand may limit climate change mitigation potentials of long-lived harvested wood products made of coniferous wood. By analysing such examples from diverse regional cases we aim to synthesize practice-relevant recommendations for Climate Smart Forestry.

EU climate-smart forestry : which is the best strategy to enhance forest and HWP mitigation potential

T1.4 Climate Smart Forestry

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Abstract: Climate change impacts, adaptation, and mitigation are pressing concerns for global forests and forest management. Climate-Smart Forestry (CSF) is a key approach that combines mitigation and adaptation measures to enhance the resilience of the forest sector and addresses the challenges posed by climate change. Even though accounting for regional features of the forest sector is one of the core aspects of the CSF approach, there is scarcity of studies that comprehensively analyses its effects with detailed spatial and temporal resolutions. In this research, we aim to identify and test a CSF strategy that may enhance the mitigation of the EU forest sector. In order to accomplish this, we used the EFISCEN_space model, which offers a spatially explicit distribution of wood resources at national forest inventory plot level (300,000 NFI plots), including details about the species and diameter per individual tree. For the demand side, we compiled the European Forest Industry Database (EUFID), which encompasses the location and capacity of 6,000 forest industry facilities, distinguishing three value-chains: sawmills, pulp and paper, and bioenergy. The simulations consider various forest management approaches, natural forest dynamics, and the regional industrial pull. For three national case studies (Germany, Norway, and Czech Republic) three scenarios were tested: business as usual, CSF+, and PORT. The CSF+ scenario represents the most ambitious strategy, incorporating a maximum sustainable harvest rate, utilization of residues for bioenergy, and increased use of long-lived wood products. The PORTfolio (PORT) scenario includes specific policy targets of the respective analyzed country. The study indicates which scenario may significantly enhance the forest sector's mitigation potential, including the forest sink, carbon in harvested wood products (HWP), and material and energy substitution. Furthermore, this analysis provides projections of future wood assortment availability under different types of disturbances of the resources. The results emphasize the significance of CSF practices, tailored to local circumstances, in promoting sustainable and resilient forest ecosystems, and may guide policy-makers and stakeholders in taking informed decisions to optimize the forest sector contribution to climate change mitigation.

European Network on Climate-Smart Forestry: connecting researchers and facilitating capacity building

T1.4 Climate Smart Forestry

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Abstract: Climate change impacts, adaptation and mitigation are undoubtedly in the centre of attention for global forests, and forest management, demanding immediate attention. Climate-Smart Forestry (CSF) is designed as a prominent way to address these challenges and is urgently needed to connect mitigation with adaptation measures, enhancing the resilience of forest resources and to meet the needs of a growing population. A critical element of CSF lies in carefully regarding the local circumstances, ensuring the measures are planned accordingly.

We will present an excerpt of the knowledge gathered by the European Network on Climate-Smart Forestry, with representatives from 15 European countries. This network connects researchers working on CSF, stimulating and facilitating the exchange of information and capacity building.

Examples of fundamental and applied research projects will be presented, from e.g. research on tree responses to drought periods to afforestation and forest restoration initiatives. The time for concrete action is now, so we will also discuss possibilities for implementation and upscaling of CSF measures.

Exploring the Versatility of Resilience Components: Applications and Insights in Forest Ecological Research

T1.4 Climate Smart Forestry

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Abstract: The concept of resilience plays a crucial role in ecological research, offering insights into the dynamics and adaptive capacity of ecosystems facing various disturbances. This contribution explores the different uses of resilience components (i.e., resistance, resilience, and recovery indices) in forest ecological studies and highlights their importance in understanding ecosystem dynamics. We discuss how these indices have been employed and improved over time, showcasing their versatility and applicability across diverse research topics and environmental settings. Additionally, we present three examples of the application of these indices to different research contexts.

Firstly, we examine the use of resistance, resilience, and recovery indices in assessing the impact of drought on Mediterranean forest plantations. By quantifying the ability of different pine provenances to withstand and persist in the face of drought, these indices provide valuable information for assessing forest stability and vulnerability, guiding adaptation strategies to climate change impacts.

Secondly, we explore the application of these indices in studying the response of mixed oak-fir forests (Turkey oak and silver fir) vs. pure stands of the same species in a Mediterranean mountain context (Apennine). Here, we relate the variation in resilience components between monospecific and mixed stands with admixture type, tree species, and site aridity, and tree growth.

Lastly, we validate the application of resilience components in investigating the vulnerability of Norway spruce trees to bark beetle infestations in mountain forests in the Swiss Alps. By quantifying the resilience of forest ecosystems to disturbance-driven alterations, these indices help identify vulnerable areas and prioritize interventions to ensure the sustainable provision of ecosystem services.

Through these applications, we showcase the versatility and significance of resistance, resilience, and recovery indices in advancing ecological research and implementing climate-smart forestry. These methods offer valuable tools for assessing ecosystem health, informing conservation practices, and guiding decision-making processes in the face of global change. By integrating these indices into future research endeavours, we can deepen our understanding of ecological dynamics and foster effective strategies for adapting and restoring resilient ecosystems.

Integrating biodiversity protection into Climate Smart Forestry

T1.4 Climate Smart Forestry

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Abstract: European Forests are threatened by climate change, increasing disturbance regimes, and continuous biodiversity decline. For this reason, over the last decade, Climate Smart Forestry (CSF) arose as a conceptual solution for jointly addressing climate change mitigation and adaptation activities alongside biodiversity and ecosystem service provisioning. However, the preservation and enhancement of biodiversity were not given equal importance as climate change mitigation and adaptation, even though they are closely interlinked; biodiversity loss reduces global carbon sinks due to productivity loss, while climate change mitigation can help prevent biodiversity decline and species extinction. To provide more comprehensive management guidance based on criteria and indicators, we propose extending the CSF concept to prominently address biodiversity. Here, we present Climate and Biodiversity-Smart Forestry (CBS) as a wider concept integrating climate change mitigation, adaptation, and biodiversity conservation, to promote resilient forest ecosystems under climate change and disturbances, benefiting society and the environment. CBS is developed and operationalized within the Horizon European ForestPaths project, aiming at holistically co-designing, quantifying, and evaluating forest-based policy pathways. Based on a comprehensive review of scientific and grey literature, we provide a broad definition of CBS and a collection of successful practical examples that highlight existing and potential new CBS measures. A holistic guide for adopting the concept to different European regions and management regimes is offered to support forest stakeholders in identifying and adopting CBS management measures. The guide considers both the good maintenance of European forests and the sustainable provision of their ecosystem services. With a clear definition and specification of regionally relevant requirements, criteria, and indicators, CBS management options can be evaluated to facilitate operational use of this new concept.

Intensive monitoring in different woodlands

T1.4 Climate Smart Forestry

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Abstract: Forest Protection Measuring and Monitoring System is one of the most acknowledged monitoring systems in Hungary which has cooperated with the ICP Forest organisation since 1996. The monitoring system itself has existed since 1988. Intensive monitoring is one of the main parts of Forest Protection Measuring and Monitoring System in Hungary. We currently have seven monitoring sites in different parts of the country. There are two old common beech and two sessile oak, a Black locust, a Scots pine and a Turkey oak forest stands. There are seven open-field areas as control points near each forest site. The meteorological parameters (precipitation, temperature, humidity, wind speed, wind direction) were measured in each open-field area by HWI weather stations near the forest monitoring sites. The throughfall was determined by twelve funnels which were arranged in a regular system. We also used five bucket and one measuring tub in each forest monitoring site to evaluate the yearly interception of the foliage. For the calculation of stem-flow, stem collars (connected with collecting barrels) were settled for each tree. Five stem collars were installed to calculate stem-flow with regard to the distribution of the diameters of the trees in each forest site. Temperature and humidity data were measured with Testostor logger in English thermometer in the wood stocks. The biomass was measured using five 1x1 meter nets in every month in the seven forest sites. We concluded that the dry periods have affected the forests more severely in the central and eastern part of the country in 2021, 2022. The amount of precipitation was extremely low in the vegetation period. Based on our meteorological measurements at the forested sample areas, the average temperature is constantly increasing. The number of heat days (T_{max}≥30°C) and the number of hot days (T_{max}≥35°C) also showed an increase. The canopy loss was significant in our monitoring sites in July and in August. The annual growth of the forest stands also was less than in previous years because of the extreme dry weather conditions. Our data sets proved the positive, temperature-tempering effect of forests in all monitoring sites.

Interactive tree breeding and silviculture in sparse plantations can be climate-smart forestry of Norway spruce

T1.4 Climate Smart Forestry

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Abstract: Forests of Northern Europe are and will remain the main local source of raw material for developing a fossil-free economy (bioeconomy) in the whole European Union. Climate-change-induced alteration of natural disturbances particularly affects one of the main commercial tree species – Norway spruce – triggering discussions on the potential changes of its management. The resulting recommendations often include reduced species area, and applying low-intensity, selective management. We aim to explore different alternative for climate-smart management of Norway spruce – low-density plantations of selected genotypes. Sample trees for destructive analysis were collected and sample plots were placed in such clonal plantations, that have reached dimensions for the final harvest.

The realized genetic gain in DBH reached +24.0%, leading to nearly double mean DBH and similar yield compared to 30-35 years older conventionally managed stands. A distinct relationship between DBH and wood density was not found at a tree or clonal level. Highly heritable branching traits demonstrated the potential for the selection of suitable clones for sparse plantations. Visual strength grading of the sawn material (standards BS4978 and INSTA142) demonstrated a notable variation between clones and the potential to maintain a quality similar to that obtained in conventional management.

Due to improved light conditions, indices of ground vegetation diversity were similar to those in old-growth Norway spruce stands in Latvia. A lack of deadwood, however, was not different than in conventionally managed stands and needs to be addressed at a forest landscape level.

The long-term weather sensitivity of inter-annual height increment indicated higher tolerance and resistance to weather fluctuations for productive clones, hence potential to maintain productivity also in the uncertain future climate. The accelerated growth in the sparse plantation, leading to a shorter rotation period, can also mitigate risks such as drought or wind damage. In addition, the stem cracking caused by prolonged summer droughts exhibited variation between clones, yet no clone-specific relation with growth, hence the potential for selection without increasing risks of this defect.

In summary, the study highlights various benefits of combining tree breeding and silviculture in highly productive sparse clonal plantations, serving as a climate-smart forestry solution for the region.

Is establishment of drainage systems a long-term climate smart forestry measure in hemiboreal Scots pine forests on deep organic soils?

T1.4 Climate Smart Forestry

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Abstract: Forest ecosystems comprise important carbon pools, notably in the trees and soils, with the organic soils being particularly significant. To achieve the climate neutrality goals set by the European Union, it is vital to implement forest management practices that improve carbon storage and reduce greenhouse gas (GHG) emissions. In hemiboreal region forest drainage is the most significant forest management tool with positive long-lasting large-scale influence on tree growth. Moreover, a substantial proportion of Scots pine (*Pinus sylvestris* L.) forests in the hemiboreal region are growing on organic soils and have undergone drainage (in the 1960s). Although recent studies have focused on several aspects of forest carbon storage and GHG emissions from mineral soils, there is a lack of information on the long-term effects of drainage system establishment or maintenance as a climate smart forestry measure on tree carbon stock and soil GHG fluxes from old-growth forests on organic soils.

The aim of the study is to evaluate differences of tree carbon stock and the intra-annual dynamics of soil carbon dioxide (CO_2) and methane (CH_4) fluxes in hemiboreal old-growth Scots pine stands growing on organic soils with contrasting groundwater levels. Six Scots pine-dominated old-growth forests (130 to 180 years old) on deep organic (peat) soils with diverse soil moisture regimes and conditions, were selected and tree carbon stock and seasonal CO_2, CH_4 fluxes (once per three weeks in frost-free period) were measured.

Organic soil drainage has long-term positive (statistically significant) impact on aboveground tree carbon stock, and no effect on soil carbon stock. Old-growth forests with contrasting groundwater levels did not result in notable differences in soil CO_2 emissions, since the CO_2 flux was primarily influenced by soil temperature. Old-growth Scots pine forests, which were previously drained, showed CH_4 uptake throughout the entire growing season. In contrast, in sites with high groundwater levels (undrained), soil CH_4 uptake or release depended on the time of season and was influenced by the groundwater level. Overall, organic soil drainage system establishment and maintenance can be a climate smart forestry measure with a long-term positive effect on tree aboveground carbon storage and soil CH_4 uptake.

Model Based Comparison of Forest Carbon Uptake and CO2 Release Due to Forest Operations for Case Studies in Europe and South Africa

T1.4 Climate Smart Forestry

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Abstract: While carbon sequestration in forests has been studied in high detail, there is less information available about the CO_2 release caused by forest operations in relation to the actual forest growth and status. In order to allow for such comparisons under a broad range of frame conditions, we developed a generic phase-area model. For any silvicultural concept to assess, it requires a set of growth and yield characteristics, including area loss risk estimates, broken down to the main phases of stand development. We kept the set of required information as small as possible in order not to overstrain data availability in practice. The information can come from a broad range of sources; often it is condensed from observational plot data or from runs with detailed stand-level simulation simulation models.

The model allows to populate a given large area with user-defined initial area shares of the different stand development phases; therefore, it can cover all initial situations between an afforestation, and an established normal-forest like equilibrium. From there, the dynamic development of the stand-phase wise areas can be simulated for arbitrary time spans. Damage events are simulated stochastically according to user-scalable scenarios. Growth and yield related simulation results on the whole area are obtained by upscaling the known phase-wise variables to the whole area. As the model provides information for calculating the fuel consumption by harvest, the annual CO_2 release due to forest operations on the whole area can be calculated and put into relation with growth and yield variables related to C fixation. This procedure was used for evaluating silvicultural concepts from case studies in several European countries and South Africa. Our first results suggest a high importance of the initial situation and the disturbance regime for the potential to optimize climate-smart management.

At the time of presentation, the model will be freely available as an R package. The study was supported by the European Union H2020 project CARE4C.

Nature-based Climate Solutions Partnership: Forest Carbon Modeling Research and Development Priorities

T1.4 Climate Smart Forestry

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Abstract: Accelerated emphasis on increasing climate mitigation and adaptation measures throughout the forestry sector is evident across local, state, and national policy spheres in the United States (U.S.). Within the past year, a range of national legislation and policy developments have increased funding and institutional support for public and private sector actors to conserve land sector carbon sinks and enhance carbon sequestration and storage (e.g., Bipartisan Infrastructure Law, Inflation Reduction Act, and U.S. Department of Agriculture Secretary's Memorandum). Refining biometrical methodologies to simulate forest vegetation response to various management actions within the 'Natural Climate Solutions' (NCS) framework has emerged as a major knowledge gap. In response to these national priorities, a partnership was created between the U.S. Forest Service Research and Development and the National Council for Air and Stream Improvement, Inc. (NCASI) to coordinate and advance biometrical research by creating the Forest Carbon Modeling Group (FCMG). Consisting of over 100 experts in academia, government, industry, and NGOs, the FCMG collectively evaluated the relevant science and identified pressing NCS knowledge gaps. Future research priorities identified include: (1) improving consistency in reporting of forest carbon stocks and fluxes following well-defined mensuration practices with uncertainty standardization; (2) enhancing belowground (e.g., coarse root) and soil carbon models; (3) incorporating disturbance (e.g., fire) models in forest carbon projection systems; (4) advancing small area estimation (SAE) techniques to help reduce costs of forest carbon monitoring and assessment; and (5) building the workforce for the future. Refining biometrical approaches to assess forest carbon response to various management actions is a core necessity to inform the implementation and measurement, monitoring, and evaluation of the effect of NCS policies and regulations.

Potential benefits for spruce – beech mixture vs. spruce monoculture from the belowground view

T1.4 Climate Smart Forestry

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Abstract: Growth of *Picea abies* has been shown to profit from growth with *Fagus sylvatica* compared to monoculture, particularly under unfavourable (drought) conditions. In the project HoliSoils, we study soil biodiversity as below-ground factor that may contribute to this beneficial interaction. In addition, the effects of tree mixture on greenhouse gas (GHG) emissions will be used to estimate the potential of climate smart forestry by spruce-beech mixtures and thus attenuating losses of spruce trees during projected increasing hotter and drier episodes.

We have established 3 sites along a precipitation gradient each comprising a paired monospecific and mixed stand. In each stand, soil CO_2 efflux is regularly recorded with or without roots excluded. Representative soil samples were taken for biodiversity analyses.

Preliminary data indicate generally lower soil CO_2 efflux in root free soil (Rh) compared to total soil (Rs), and generally lower emission profiles on the dry site. Rh and Rs both peaked in late spring, but Rs dropped almost to Rh levels during hot and dry summer months. Only for Rs, a secondary peak followed during autumn which got more prominent on wetter sites for spruce. While mixed stands overall had similar emissions, their Rs profiles were marked by having two equal annual peaks in late spring and autumn.

Soil biodiversity in mixture is strongly influenced by the presence of tree species, and its composition differs between monospecific and mixed spruce stands. Fungal community composition differed also between the moist and the dry site.

Product and Carbon Traceability Throughout the Wood Products Supply Chain

T1.4 Climate Smart Forestry

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Abstract: ForesTrust, LLC was introduced by the U.S. Endowment for Forestry and Communities (the Endowment) as the newest venture to take advantage of Blockchain technology. ForesTrust creates traceability in the supply chain, offering the ability to accurately and efficiently track wood and wood fiber from the forest to the consumer and consolidate and ease the financial and administrative burden of forest certification. Forest Carbon and Climate Program at MSU, which will conduct a feasibility analysis and communications effort not only to advance blockchain technology in forest product tracking but also to include the unique, timely, and high-demand emphasis on carbon tracking for credits and climate accountability. As the project explores how blockchain technology can be leveraged as a mechanism for various actors (including private sector companies, timber producers, already those in procurement), this component will focus on how the blockchain system can track carbon stored in Harvested Wood Products (HWPs), embodied carbon emissions, and carbon through the chain of custody. The aim is to support transparency and traceability to overcome both known (illegal timber laundering) and emerging (climate change mitigation) challenges in the forestry sector. This will provide a platform for the forestry sector to improve traceability and present cost and time savings with certification and chain of custody administration. We will identify meaningful carbon tracking mechanisms to include in the platform and present findings. The technology and capabilities created for carbon tracking will expand the market penetration of U.S. domestic wood products.

Restoring climate-resilient hardwood forests for climate-smart ecosystem services in the Lower Mississippi Alluvial Valley

T1.4 Climate Smart Forestry

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Abstract: Bottomland hardwood forests (BHFs) offer a variety of ecosystem services that generate ecological, economic, and social benefits to the local communities and beyond. Yet over two-thirds of BHFs in the southern United States have disappeared over the last century due to land-use change especially agricultural expansion and other drivers. We assess the climate resilience of red oak restoration plantations in the Lower Mississippi Alluvial Valley and the potential of the forests for providing climate-smart ecosystem services including timber, carbon, and wildlife. Our tree ring data analysis reveals that Cherry bark oak (*Quercus pagoda*), Shumard oak (*Quercus shumardii*), and Nuttall oak (*Quercus texana*) are resilient to climate change even under the high greenhouse gas emissions scenario (RCP 8.5) although the maximum temperature from January to August and total precipitation from April to July are negatively associated with tree growth. Restoration of BHFs on working agricultural land can enhance carbon sequestration and wildlife habitat while woody materials and wildlife yielded from the forests promote bioeconomic development in the region.

Spatial and economic robust optimization of selected forest ecosystem services under climate change, considering biodiversity conservation

T1.4 Climate Smart Forestry

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Abstract: We are working under the project Pathfinder of the European Union, and we will perform a spatial and economic optimization of the ecosystem services of timber production and climate regulation, using the proxy of carbon sequestration, plus incorporating a metric for biodiversity conservation (amount of deadwood). The forest growth will be modeled with the European Forestry Dynamics Model (EFDM). This is an area-based matrix model that requires the pair data of consecutive national inventories to obtain activity (no management, thinning, and felling) and transition probabilities (forest development). The model will work with cells of 1 km^2 each, that we will aggregate into sub-regional levels that share similar characteristics, such as, species, type of soil, and region.

Different policy alternatives translated into management strategies will be run within the EFDM, including: a minimum forest conservation (no management), business as usual (BAU), intensified forest wood harvest, and decreased forest wood harvest. We will introduce a variation of the activity probabilities of each of these management options in the model, to generate an array of different outputs needed for the robust optimization. Likewise, different climate change scenarios will be integrated (representative concentration pathways 2.6 and 4.5), by using the process- and data-based hybrid ecosystem model Formit-M, that generate a change in the transition probabilities of the EFDM. These different management strategies will be evaluated and optimized using a multi-objective approach. We will define performance goals and/or constraints, to achieve the diverse objectives considered in our study. Likewise, we will consider multiple and deep uncertainties, such as the different climate change scenarios, and economic parameters, e.g., interest rate, wood prices, harvest costs, carbon costs. Furthermore, a sensitivity analysis will be conducted to identify the uncertainty parameters that affect most strongly the performance and robustness of the optimization.

We expect to show the optimal distribution of management options in Europe, in a spatially-explicit fashion. Plus, identifying the trade-offs between timber production, carbon sequestration and conservation of biodiversity under different climate scenarios and discount rates. At the moment, we are working on the study's framework and expect to have our results by next Winter.

Testing a framework for the assessment and implementation of Climate-Smart Forestry in Mediterranean forests

T1.4 Climate Smart Forestry

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Abstract: Climate-Smart forestry (CSF) aims to balance climate change mitigation and adaptation strategies into sustainable forest management practices, while facilitating the provision of many ecosystem services. Although the attention around CSF has grown in recent years, further efforts are necessary to translate the concept of CSF into social-ecological resilience practices.

This research aims to facilitate CSF assessment and monitoring through a straightforward and user-friendly method, based on the development of a composite smartness indicator set. This method was tested on Mediterranean forests based on data from the Italian National Forest Inventory, namely INFC 2005 and INFC 2015.

The methodology includes: (i) selection; (ii) normalization; (iii) weighting, and (iv) aggregation of CSF indicators. A systematic literature review was carried out to select the indicators, which are frequently used to evaluate adaptation and mitigation over time. The keywords used to implement the literature review were: “climate smart forestry”; “forest management”; “indicator”; “mitigat*”; “adapt*”, using Elsevier’s Scopus® database. A total of 39 indicators were obtained from 78 examined scientific papers. Some of the most frequently cited indicators (e.g., carbon stock, diameter distribution, tree species composition) were used to assess the smartness of the main Italian forest categories.

To compare the indicators with each other, they were normalized through distance to the target, or min-max normalization. Moreover, an online survey (https://forms.gle/BRPDARHH3oaHppmR6) was developed and shared with experts of the forestry sector across Europe to collect opinions about the importance of each indicator facing CSF assessment. These findings were used to rank the indicators through the Analytic Hierarchy Process.

Preliminary results showed an increment of smartness in all forest categories from 2005 to 2015. This increase over time was more pronounced for some forest categories (e.g., silver fir, Norway spruce).

Feedbacks from forest managers are discussed in terms of gaps, uncertainties, and perspectives for improving the assessment and implementation of CSF practices. This study represents a starting

point for the design and application of decision support tools to evaluate and monitor the evolution of CSF, and guide forest managers in their decisions.

The alleviation potential of tree-cutting interventions on drought stress and growth of pedunculate oak and beech in temperate forest

T1.4 Climate Smart Forestry

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Abstract: Climate change threatens forest functioning through hotter droughts, leading to increases in tree mortality and decreasing growth trends in European forests. To maintain the provisioning of ecosystem services, climate-smart forest management has been proposed as a drought alleviation strategy, with stand tending as one of its suggested tools. Thinning, particularly, is expected to reduce competition for nutrients, light, and water, of which the latter is crucial during drought events. However, no scientific consensus exists on the relationship between thinning and tree drought stress, with forest management being reported to reduce, increase or not affect drought stress. Additionally, research highlights the importance of local stand conditions. Therefore, this study aims to investigate the effects of thinning on the drought response in pedunculate oak (*Quercus robur* L.) and beech (*Fagus sylvatica* L.) dominated forests in the Brabantse Wouden, Belgium. We hypothesize that thinning initially reduces drought stress for both pedunculate oak and beech, but may increase drought stress once a certain threshold of management intensity is reached. The threshold is expected to occur at a lower intensity for beech than pedunculate oak. To analyze this research question, tree ring data (yearly time steps) and point dendrometer data (hourly time steps) were collected, providing information on trees' past and present drought responses at distinct time scales. The drought responses are then linked to weather data and the recent history of forest management practices, which was reconstructed using wood sale records dating back to 1975 (tree ring data) and characterized by the competition intensity as experienced by the studied tree (point dendrometer data). Combining these techniques results in a thorough understanding of short-term drought stress and long-term growth trends. Preliminary results based on dendrometer data suggest that beech experiences more stress than pedunculate oak, and this drought response is aggravated by higher management intensities. In contrast, pedunculate oak endures more stress in dense stands, indicating a preference for open canopy structures. Overall, this study provides insights into the complex relationship between forest management practice and drought response of beech and pedunculate oak in temperate forest ecosystems, which can support informed climate-smart forest management strategies.

T1.5 Climate-smart pine forest management

Adaptation Strategies for Scots pine forests at the SW edge of its distribution

T1.5 Climate-smart pine forest management

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Abstract: Global change is modifying Scots pine (*Pinus sylvestris* L.) forests dynamics and triggering new climate-driven threats. Negative impacts are particularly dangerous in its Southern range-edge, where adaptation strategies might be urgently necessary. In this presentation we focus on the South-West distribution area of Scots pine, showing the main impacts observed and proposing adaptation measures based on current scientific knowledge.

Higher temperatures and more extreme and frequent droughts are causing lower growth rates and some decay processes at lower altitudes and more xeric sites, which are often exacerbated by some biotic agents, like mistletoe or pine processionary moth. Moreover, they are the main limiting factors of the Scots pine natural regeneration, inducing changes in the optimum altitudinal range of regeneration that might affect species competitiveness and potential replacements in near future. Under new climate change scenarios, more biotic and abiotic disturbances are expected, including forest fires and storms, which can influence forest functioning and associated ecosystem services.

We reviewed scientific studies on Scots pine in the study area, which address forest dynamics and management under climate change, and describe different adaptation silvicultural measures grouped in seven strategies: 1) Promotion of natural regeneration; 2) Promotion of adaptive evolution; 3) Promotion tree species diversity; 4) Facilitation of natural species substitution at lower altitudes; 5) Reduction of water stress; 6) Promotion of stability against wind; and 7) Pest and disease control. The adaptation measures will be explained and discussed for each strategy, including some examples from our own experiments. Finally, the synergies and possible trade-offs between different measures will be discussed.

Admixtures of broadleaves to Scots pine stands: stabilization or additional stress?

T1.5 Climate-smart pine forest management

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Abstract: Large-scale conversion of pure, even-aged stands of Scots pine (Pinus sylvestris) in Central European lowlands in the past decades has led to large forest areas with European beech (Fagus sylvatica) in a second layer below the conifer canopy. The respective efforts aimed at enhancing ecological stability and habitat diversity, increasing contributions tot he groundwater table, and reducing biotic risks associated with pure Scots-pine stands.

Drastic shortages in rainfall in spring in the recent past (especially 2018-2020) accompanied by high temperatures have caused widespread losses in vitality and frequent individual mortality in many forests in Northeastern Germany, including pine-dominated stands. Relating to these previously unknown decline symptoms, a discussion has evolved about the possibly detrimental influence of deciduous understorey layers on water supply and successive survival of the Scots pine overstorey. During severe drought periods, the additional beech layer is suspected of increasing interspecific competition for water. The positive effects of admixtures would in these cases be countered by negative consequences for the water supply during extreme shortages.

The prove this hypothesis, we carried out comparative analyses of radial increment time series for representative samples of Scots pines from pure and from mixed stands under similar site conditions. Investigations included tree-ring width series and tree-ring index chronologies from various regions. A wide array of derived dendro-ecological parameters were applied to characterize variablility, sensitivity, and responses to monthly and seasonal climate. Additionally, we quantified resilience indicators after particularly conspicuous drought years. Preliminary results show no significant differences in the behavior of trees with understorey to that of trees from pure stands. Further tests based on a larger data set shall provide forest management with reliable information on the competion an/or facilitation relations that could be included into more flexible guidelines for future conversion activities.

Assessing Resilience Components in Maritime Pine Provenances Grown in Common Gardens

T1.5 Climate-smart pine forest management

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Abstract: Maritime pine is a widespread conifer native to the western Mediterranean basin with economic importance in southwestern Europe. Climate change is predicted to increase episodes of drought-induced decline and mortality in Mediterranean forests. Understanding the responses of different maritime pine provenances to drought is, therefore, important to tackle the climate crisis and to guide climate-smart forestry.

This study aims to assess resilience components (i.e., resistance, recovery, and resilience) to drought in five different provenances of maritime pine (Corsica, Tuscany, Portugal, Telti and Limbara), and the relationships with climate variables. Four common gardens were implemented in Sardinia, in the early ’80, to compare these provenances. At each site, all provenances were planted within five 25-tree square plots, and the arrangement of plots were randomized within five (Montarbu, Montes and Usinavà) or three (Uatzo) blocks. In each site 8-10 trees per provenance were selected from which two wood cores were taken. From SPEI analysis, it was found the 2003 as drought year in all sites and, based on this year, the resilience components were calculated. For each index, GLMs were built to predict the possible response of them to climate variables.

Provenances showed differences in growth rates. Tuscany was the least productive, while Limbara showed good growth rates in drier sites. The resilience and resistance had a similar pattern, while the recovery showed an opposite trend, suggesting a trade-off among these indices. Models highlight a noticeable adaptation of maritime pine to the harsh environment conditions of Sardinia.

This common garden study increases our knowledge on the responses of maritime pine provenances in the Mediterranean area, at the boundary of the species range, for which reports are limited. We stress the importance of the analysis of tree rings and resilience components, as well as the establishment of long-term experiments, to determine the response of maritime pine to disturbance-induced growth decline and to support adaptation strategies to climate change for this species, such as assisted migration.

Can silvicultural thinning be used to regulate water utilization in dryland pine forest ecosystems?

T1.5 Climate-smart pine forest management

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Abstract: Evapotranspiration ratio (ER=evapotranspiration/precipitation) and water use efficiency (WUE=gross primary productivity/evapotranspiration), are key functional attributes of dryland ecosystems that reflect water utilization. While the importance of ER and WUE is recognized, understanding the factors that control them remains a challenge. Moreover, hardly any information exists on the ways by which these attributes can be regulated through silvicultural practices. We studied the variation in ER and WUE as affected by silvicultural thinning in dryland forest ecosystems along an aridity gradient. Estimates of Leaf area index (LAI), gross primary productivity (GPP) and evapotranspiration (ET) were based on empirical models relating spectral indexes from high-resolution satellite-sentinel-2A and climatic data from weather stations to flux records from eddy covariance towers. We monitored LAI, ET and GPP during 2018-2022 in two long-term research sites (LTER) of pine forests (*Pinus halepensis*) in Israel – Semiarid Yatir forest and dry-subhumid Kedoshim forest (annual precipitation ~280 and 550 mm, respectively), both have undergone thinning treatments (i.e., control, 300, 200 and 100 tree ha^{-1}) in 2009 as part of a long-term experiment. In the non-thinned (control) plots of Yatir (~320 tree ha^{-1}), LAI, GPP and ET (1.5 m^{2}m^{-2}, 450 gCm^{-2}year^{-1} and 400 mm year^{-1}, respectively) were lower than in those of Kedoshim (~550 tree ha^{-1}, 2.6 m^{2}m^{-2}, 640 gCm^{-2}year^{-1} and 700 mm year^{-1}, respectively). In Yatir, 9-13 years after thinning, LAI, GPP and ET were lower than the non-thinned control by up to ~53%, 40% and 68%, respectively, while in Kedoshim, they were lower by up to ~32%, 30% and 80%, respectively. WUE of non-thinned plots was significantly higher in the semiarid than in the dry-subhumid forest (1.5 vs. 0.93 gC kgH_2O^{-1}, respectively). Moreover, WUE was significantly higher in thinned plots in both forests by up to 37% and 23%, respectively. Finally, in non-thinned plots of Yatir and Kedoshim, ER was ~0.95 and was lower in thinned plots by up to 57% and 64%, respectively. While the thinning effect on ER was attributed to LAI reduction, its impact on WUE was explained by higher leaf exposure to sunlight. Our results demonstrate long-term regulation of dryland forests' ecohydrology through silvicultural practice.

Climate change on pinewoods in inner Spain: observed impacts and proposals for adaptive management

T1.5 Climate-smart pine forest management

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Abstract: The Spanish Northern Plateau conforms a flat land extension occupying the whole river Duero Basin. The inner part of this territory (approx. 2.10^6 ha) is located at 800 m a.s.l, and is characterized by a Continental Mediterranean climate, with very low annual rainfall (< 400 mm), extreme summer drought, and soils with a high content of sand and low water retention ability. This territory, largely depopulated, is mainly occupied by rainfed crops, with fragmented patches of pinewoods covering about 20% of the area. The two main species are the Mediterranean pines *Pinus pinea* and *Pinus pinaster*, whose forests have been traditionally managed to promote the coproduction of nonwood forest products (cone and resin), together with timber and other relevant ecosystem services, as protection against soil erosion.

The Mediterranean pinewoods in the inner part of Spain have been considered as hotspots for climate change. In the recent decades we observed in the territory a significant increment on the mean temperatures, more irregular precipitations, and more frequent and intense heatwaves and extreme drought events. This have resulted in recent impacts as the increment in processed of tree decay and dieback, failure of natural regeneration, reduction in timber and non-timber products yields, shifts of vegetation, and higher frequency and virulence of biotic (native and exotic pests) and abiotic (fire) perturbations.

Facing these impacts, during the last 25 years INIA-CSIC and the Forest Service of Castilla y León have been collaborating in a program for adapting Northern Plateau pinewoods to changing conditions, combining research and practical management applications. Among the tested proposals, we can mention the implementation of more gradual regeneration cuttings, application of early and more intense thinnings, facilitation of species substitution, promotion of structural and specific heterogeneity of the pinewoods, and the development of different climate sensitive models to support forest management decision under current and future scenarios. This program is accompanied by a continuous process of transfer knowledge, feedback and information sharing between researchers and forest practitioners. In the current presentation, we will summarise the main results and outputs of this program, and will show ongoing and future lines of collaboration.

Climate-adapted silvicultural strategies for harvest cuts of Scots pine (Pinus sylvestris L.) stands in Northern Germany

T1.5 Climate-smart pine forest management

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Abstract: Pine stands dominate the landscape in Northern Germany. They are subject to forest conversion towards mixed stands, because of increasing risk resulting from often insufficient mixture and structure. In the six northern federal states the silvicultural guidelines are expert-based adapted towards climate change and schedule pine cultivation even on poorest and driest sites. However, evidence-based studies indicate pines' increasing vulnerability especially in warm-dry weather. The unbalanced age class structure and increasing proportions of strong dimensioned wood also pose challenges for harvest cuts and associated climate adaptation. We question how cultivation area, standing and harvested volume and increment of pine develops by climate-sensitive simulations.

To analyze stand development, the plots of the third German NFI are simulated until the year 2062 using the single-tree growth simulator WaldPlaner. We account for climate change effects using climate projections of the moderate global model EC-EARTH12 in combination with the regional model RACMO and the extreme global model HadGEM2 with the regional model WettReg2013 under RCP8.5. For current stands site index shifts are predicted applying site-sensitive height-age curves. For future stands species suitability strongly depends on site water supply, which is dynamized considering the climate projections.

The simulation further considers two target diameters for pruned and unpruned pine stands. The silvicultural concepts of the investigated federal states are implemented in the growth simulations using targeted basal areas and crop tree numbers. Besides the projection of current stands, two contrasting scenarios concerning the next forest generation are simulated. Based on the catalog of suitable tree species derived from the site water budget corresponding to the respective climate projection, the first scenario maximizes the proportion of future pine by selecting light-demanding species from the said catalog. The second scenario minimizes the proportion of pine by preferring shade-tolerant species. This requires different harvest courses of the current stands by means of shelterwood cutting.

Afterwards, the simulation results are evaluated looking at abiotic and biotic risks. Within the guardrails outlined in this variant study, pine area consolidates after decades of decline, whereas the uneven age-class structure leads to bugwave effects regarding timber usage.

Differing effects of mortality agents on snag persistence in mountain ponderosa pine forests

T1.5 Climate-smart pine forest management

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Abstract: Understanding how snags respond following high-severity crown fires or outbreaks of bark beetles in mountain forests can help resource managers maintain habitat for wildlife. Our study compares these two key mortality agents to predict the persistence and characteristics of snags. The primary tree species in these mountain forests are ponderosa pine (*Pinus ponderosa* Laws.), one of the most widely distributed pines in western North America occurring across 15 million ha from Mexico to southern Canada and from the Pacific Coast to the Great Plains. In the southwestern United States, ponderosa pine covers 3.2 million ha, supporting more than 75 species of birds, mammals, reptiles, and amphibians. The thick bark and sapwood of ponderosa pine snags are valuable to cavity-nesting birds and bark insectivores for nest excavation and foraging. Mortality agents are crucial for modeling snag dynamics, given that the cause of death determines much of the functional pathway as wood deteriorates. Our objectives were to (a) conduct a longevity analysis to predict the lifespans of ponderosa pine snags comparing large-scale mortality events and (b) determine falling hazard based on characteristics of snags that remain standing by agents of mortality. We documented snag dynamics following two high-severity wildfires (burned 1996 and 2000) and 4 bark beetle outbreaks (2002-2005). After repeat sampling 2490 snags for 1 to 13 years post-mortality, we determined that the time to failure (snag fall) was 7.6 (±0.05) years. Mortality agent was the strongest predictor of how long a snag stood, with the hazard of a snag falling 2.5 times greater for beetle-killed than fire-killed snags. We found snags more likely to fall are beetle-killed, with intact tops, greater lean, and a smaller diameter. Inversely, snags more likely to remain standing are fire-killed, with broken tops, larger diameters, and straighter. Our long-term study provides a model for resource managers working with snags immediately following a high-severity fire or beetle outbreak and in predictions of future snag densities. Understanding the longevity of snags helps managers of mountain forests model future risks associated with massive mortality events and track attributes such as snags to the delivery of future ecosystem services.

Effect of site and Tuber borchii inoculation on Pinus pinea growth through the analysis of three consecutive years of plant establishment

T1.5 Climate-smart pine forest management

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Abstract: Stone pine (*Pinus pinea* L.) is a Mediterranean species that produces one of the most important nuts worldwide. In Chile, it shows vigorous growth and high fruiting, and it is considered as an interesting emerging crop. *Tuber borchii*, called Bianchetto truffle, is a mycorrhizal Ascomycete that produces edible truffles, increasingly renowned on the market. Due to its adaptability to different environmental conditions, its cropping can expand to non-native areas. This mycorrhizal fungus has symbiotic root association with various trees, being stone pine its favorite. Considering that stone pine is impacted by climate, we analyzed the impact of inoculation, interaction of the inoculation with environmental effects related to spatial variability, and inter-annual variability on stone pine growth. A multi-environment trial involving three sites was established in Chile. To separate permanent effects (soil) from the random effects (climate), the trial was repeated in three consecutive years, and it was annually monitored for growth, vigor, health, and mycorrhization level. Significant differences were found for height, collar diameter, crown diameter and vigor in relation to the plantation site and year, inoculation and their interactions. Chacaico established in 2019 showed higher height than Pirque and Cabrero for all plantation years, but without differences between inoculated and non-inoculated plants. Pirque for all plantation years, and Chacaico established in 2020 showed the lowest percentage of vigorous trees, without differences among inoculated and non-inoculated plants. Regarding plant survival, it was observed an environmental effect, but not an effect of inoculation nor interactions over this variable. The biplot of the principal components showed that Chacaico site was positively correlated to growth variables. We found a significant negative correlation between growth and maximum temperature, spring hydric deficit and potential evapotranspiration. Root mycorrhization with *T. borchii* was high in all sites and in all plantation years, without statistical differences. *T. borchii* quantity was positively correlated with mean temperature. We conclude that in Chile it is feasible the co-production of Bianchetto truffle and pine nuts in different environments showing both species high plasticity.

Effects of intensive thinnings on wood production and carbon sequestration in boreal Scots pine stands

T1.5 Climate-smart pine forest management

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Abstract: Forest management plays a crucial role in the climate impact of forests by influencing tree growth and carbon storage. Key factors affecting tree growth include decisions during the regeneration phase (such as tree species selection, seed origin, and regeneration method), thinnings (including intensity, number, method), and rotation length. In practice, diversified thinning types and intensive thinnings have become more common due to societal and operational changes. Intensive thinnings aim to achieve immediate and profitable cutting incomes, promote diverse forest structures, transition to continuous cover forest management, or rehabilitate partially damaged stands. These practices involve higher thinning intensities than previous norms.

Empirical experiments have shown that intensive thinning reduces the yield of commercial wood, particularly after thinning and throughout the rotation, with Scots pine being more affected than Norway spruce, especially in young stands. However, most studies employed relatively low thinning intensities compared to those used in today's commercial forests. To address this gap, a new intensive thinning trial was established in Finland nearly two decades ago to examine the effects of extremely heavy thinning intensities and different thinning types on the growth and carbon sequestration of mature pine stands.

Based on this trial, we investigated the effects of thinning intensity on growth and carbon capture and conducted simulations using Motti software to predict future development. Our findings revealed that, across thinned plots, moderate thinnings resulted in higher total volume increment and carbon accumulation compared to more intensive thinning practices, both in observations after 15 years and simulations at final felling. In conclusion, intensive thinnings may offer early higher wood production at the expense of later stages and lower overall total timber production and annual carbon accumulation.

Effects of thinning on short-term transpiration in Scots pine stands in Sweden

T1.5 Climate-smart pine forest management

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Abstract: Scots pine (*Pinus sylvestris*) is the most widely distributed pine species in the world. In Swedish forests, it represents about 40% of the total standing volume. Due to recent and forecasted changes in temperature and precipitation patterns, it is important to understand how this species responds to various management practices, particularly water uptake and growth dynamics. Thinning is one of the key practices in forest management commonly applied on Scots pine forests, and which has significant implications for mortality, growth, aboveground biomass allocation, biodiversity and resistance to extreme climate events e.g. drought. Within this context, our study aimed at evaluating the effects of common thinning practices: unthinned, thinning from below, from above and heavy thinning from below, on individual tree and stand transpiration. We hypothesized that individual trees in the heavily thinned treatment will transpire more and exhibit enhanced growth rates due to a higher resource availability, while cumulative stand transpiration will be lower in this treatment. The study sites are located in central and southern Sweden (Siljansfors and Hallarp, respectively). Tree transpiration was estimated using heat pulse sap flow sensors on selected trees covering the entire diameter distribution per site. Sensors were installed in two blocks (32 sensors in Siljanfors and 40 sensors in Hallarp). Our study is one of the first in describing with high temporal and spatial resolution, the short-term and seasonal transpiration patterns, resulting from various thinning treatments in one of the most economically-relevant species in Sweden and around the world.

Forest thinning as a climate-smart forest strategy to promote early-stage regeneration of maritime pine

T1.5 Climate-smart pine forest management

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Abstract: Evidence of forest regeneration failure under a changing climate and disturbance regime is urging the development of management and adaptation strategies that promote regeneration. Thinning has been shown to reduce the vulnerability of forests to several stressors such as drought, but the alteration of site conditions could negatively influence regeneration due to the narrower range of environmental conditions tolerated by early plant stages (especially under climate change). Therefore, studies evaluating the effect of this silvicultural practice and the interactions with climatic conditions are needed. In this research, we examine the effect of thinning on the regeneration of maritime pine (*Pinus pinaster*) stands in the western Mediterranean as well as how climatic, edaphic and topographic factors influence the effectiveness of this practice. This was achieved by comparing early-stage regeneration dynamics in13 pairs of thinned and control plots along a thinning intensity gradient (23–69 % basal area removal) in the northeastern Iberian Peninsula for 5 consecutive years. Thinning had a strong positive effect on the establishment, density and survival of seedlings, as well as a weak positive effect on primary and secondary growth. Not only was the number of seedlings and survival in thinned plots considerably higher than in control plots (10-fold and 30-fold, respectively) but both increased with increasing thinning intensity. Overall, the positive effect of thinning was greater under drier and warmer conditions, indicating that it is particularly beneficial in alleviating competition in water-limited forest ecosystems. Since water-stress is predicted to increase in the Mediterranean region under climate change, our results suggest that thinning may become an increasingly important management and adaptation strategy to promote the regeneration of pine stands.

Group selection system cuttings as a strategy to diversify Pinus pinaster plantations

T1.5 Climate-smart pine forest management

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Abstract: Adaptation to global change has become a main topic in forest research nowadays, as die-back processes, pest infestations and regeneration failures due to climatic issues are currently affecting forests throughout the world. Silvicultural treatments, especially those oriented to enhance the individual tree resistance to stress conditions and to promote species and structural diversification of the stands, have been highlighted as a solution to adapt stands of different species. Group selection system cuttings are among a group of promising silvicultural treatments, as they are able to promote the creation of uneven-aged and mixed stands in presence of favorable conditions. However, its application is typically limited to shade/mid-shade tolerant species in boreal or temperate conditions, with less examples in shade-intolerant species under Mediterranean conditions, the habitat of maritime pine (*Pinus pinaster* Ait.). Small gap sizes represent also a challenge to regenerate a light demanding species as maritime pine, but have less erosion hazard and landscape impacts than bigger sizes, potential issues in stands with soil protection and social recreation as objectives. This work presents the results from two experimental trials located in 50-70 year old maritime pine plantations in Central Spain, cut in 2017 using gaps with diameters from 1.5 to 3.5 times the dominant height of the stand. Both sites were monitored annually for five years using over 900 one-meter radius subplots distributed within the gaps, looking at maritime pine and other species regeneration while recording ecological parameters that potentially drive the regeneration process. Several models were developed to explain different processes of maritime pine regeneration, such as seed germination and first establishment, seedling survival, growth and root development. Our results were very site dependent. The northern site presented maritime pine regeneration well established (in terms of survival and growth) and distributed within the gaps, with inter-species competition (scrub and herbs), position within the gap and weather conditions as the main drivers of the different processes. Nevertheless, in the southern site, herbaceous competition and browsing were hampering pine seedling establishment. Species diversification was very limited in both sites due to the absence of other species seed trees and browsing respectively.

Implementation of a long-term pine-forest real world laboratory

T1.5 Climate-smart pine forest management
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Abstract: In Brandenburg, in Northeastern Germany, the share of pine (*Pinus sylvestris*) dominated forests is above 70 %. Nowadays, these forests are particularly at risk from climate change and the extreme weather conditions of the last decades. Moreover, for climate protection reasons, there is a real need to bind carbon as long as possible by increasing and prolonging the material use of wood.

To make German forests more resilient and resistant against the challenges mentioned above, forest management aims at increasing the fraction of broadleaved tree species. However and because of the simultaneously increased demand for timber (and especially timber from coniferous tree species), a close interlocking of adaptive forest management and efficient timber use is of enormous importance.

Within the ADAPT-Wald-Holz project, a research group of young scientists develops an adaptive forest-wood management system with a focus on an integrative, efficient and regional value chain. The heart of the project is the forest real world laboratory (or forest living lab). Within that real world laboratory, the effects of pine forest management scenarios on several ecosystem services such as wood production (utilization), C-binding (climate protection), groundwater and drinking water supply (water balance) and microhabitats (biodiversity) are analyzed. Moreover, the effects of both changing climatic conditions and different management scenarios on the mechanical properties of pine wood are analyzed in order to develop standards for timber construction with pine. The results help to customize the regional wood supply chain through timber allocation.

Relevant parts of the research are done forest stands close to Eberswalde, where in each stand three management scenarios and a reference scenario are implemented. These stands constitute the forest real world laboratory. Besides the place for experimental plots, the forest real world laboratory is a transdisciplinary place for scientists, practitioners, society and students. Thus, research needs are identified together with practitioners, results are communicated to the public and student projects raise new ideas.

Integrating Resin Tapping in Maritime Pine Forest Management for Climate-Smart Silviculture: Insights from the RN21 Project

T1.5 Climate-smart pine forest management

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Abstract: Resin extraction can bring multifaceted benefits in the context of adaptive forest management, such as enhanced income for forest managers and local communities, as well as increased human presence and vigilance in the forest, thereby deterring and detecting potential fire hazards more effectively, contributing to mitigating climate change effects on fire recurrence and severity.

This communication presents results achieved under the Integrated Natural Resin 21 project (RN21, supported by the PRR-Recovery and Resilience Plan and the European NextGeneration EU Funds). The project focuses on revitalising the resin sector extracted from maritime pine to strengthen the national bioeconomy. One of the project's main components is to make resin tapping an engaging activity for forest owners so they adhere to its use. The inclusion of resin tapping as a complementary practice in maritime pine forests' management needs to align with appropriate silviculture models that allow for operation profitability and do not conflict with or impede the usual density management practices, namely intermediate thinning. Moreover, resin tapping system, to death (trees are tapped in the four years immediately preceding their cut, by thinning or final cut) or to life (wounds made over several years) with constraints on tree size (minimum tree diameter breast height =20 cm) in the latter, have to be decided and adequately considered in the life span of the forest.

To assess the economic feasibility of integrating resin tapping into maritime pine forest management, the authors defined two initial scenarios, one corresponding to planted forests and another corresponding to naturally regenerated stands (from clear-cutting or after a fire disturbance). The design of suitable silvicultural models that could accomplish the objectives was performed with the ModisPinaster growth simulator.

The identified silvicultural itineraries offer management guidelines for sustainable practices of

density regulation and resin extraction, ensuring appropriate stand development and forest health. Integrating resin tapping in maritime pine management can strengthen bioeconomy while fostering resilience, biodiversity conservation, and cultural heritage. The findings provide valuable insights for policymakers, forest managers, and researchers interested in sustainable forest management practices and the potential of resin tapping as a climate-smart solution.

Ips acuminatus – Diplodia sapinea complex increases mortality of drought-stressed pines (Pinus sylvestris) in boreal forests

T1.5 Climate-smart pine forest management

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Abstract: Bark beetles (Coleoptera: Curculionidae, Scolytinae) have increased in their abundance over wide geographic area in Europe due to several warm and dry summers. Outbreaks of spruce bark beetle (*Ips typographus*) have regularly been in the headlines, but sudden deaths of Scots pine (*Pinus sylvestris*) have also started to attract attention in boreal forests.

Mortality of pines caused by *Ips acuminatus* was noticed for the first time in Finland in 2013. In 2021, sudden deaths of mature *P. sylvestris* in multiple locations in coastal Finland were observed, and *I. acuminatus* had obviously killed the pines.

In addition to *I. acuminatus* galleries and heavily blue-stained wood, trees were tested positive for Diplodia tip blight-disease caused by *Diplodia sapinea*. Other pathogens, such as root rot fungus (*Heterobasidion annosum*) was also observed and it likely contributed to the drought stress of pine trees.

D. sapinea is spreading unnoticed due to its asymptomatic endophytic life stage and is currently emerging as a pathogen in its northern limits. We present results on the distribution of *D. sapinea* expanding northwards in Finland combined with increasing numbers of infestation spots of *I. acuminatus*.

Currently 90 percent of the studied *I. acuminatus* infestations have been positive for *D. sapinea*. Bark beetles that are attracted by host volatiles may sense also compounds released by fungi in host trees. Therefore, we aim to investigate whether there is causality in the interrelation or whether the two species are both attracted to drought and/or heat stressed pine individuals.

Information presented calls for further studies and can be used in both risk assessment and management guidelines to support adaptation to climate change.

Learning from an unprecedented mortality event induced by extreme hot-drought in planted pines in Argentina to support climate-smart practice

T1.5 Climate-smart pine forest management

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Abstract: In contrast to studies focused on natural forests, little evidence exists on the impact of "hotter-drought" events on commercial forestry species planted outside their native range. Here, we report an unexpected and regionally-distributed tree mortality event that occurred recently in commercial pine species across the Mesopotamian region of Argentina, South America. The event was associated with a hotter-drought period during the 2021-2022 warm season preceded by three years of drought and was spatially heterogeneous at regional and local scales. We aimed to elucidate the mortality timing, rate, and magnitude associated with environmental and stand characteristics at local scale to determine which conditions make these productive systems more vulnerable to extreme climatic events. We used high-resolution (10 m) maps based on Sentinel-2 multispectral images to estimate canopy mortality from November 2021 (corresponding to the first field mortality observations) to October 2022, in *Pinus* spp plantations (~25,000 ha) installed in grassland areas. Most (90%) of the stands belong to *P. taeda*, which was also the most affected species at regional level. We found that spatio-temporal heterogeneity in canopy mortality was mainly associated with spatial variation in site quality, but not in stand age and size. Higher maximum accumulated, earlier, and advancing faster canopy mortality was observed in shallow soils (with a rocky impediment at about 50 cm) where soil water availability would probably be scarce and low-lasting. In contrast, the lowest accumulated canopy mortality (near zero during the study period) occurred in stands located on depressed and waterlogged landscape units. Intermediate levels, delayed and slowed canopy mortality were observed in deep soils (>1 m), but within them, higher accumulated mortality was observed in those associated with a shallow water table, where trees developed a shallow rooting system. We here provide evidence showing that at the landscape level, those sites allowing a deeper rooting development and/or where soil water availability is expected to be higher and long-lasting could represent the areas more suitable for climate-smart pine management.

Natural regeneration of Scots pine under varying shelterwood densities in the context of climate change

T1.5 Climate-smart pine forest management

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Abstract: During the last few decades, regeneration of Scots pine (*Pinus sylvestris L.*) in southern Sweden has decreased in favour of planting Norway spruce (*Picea abies*). Majority of the area regenerated with Scots pine is planted, whereas natural regeneration and direct seeding are uncommon. However, in line with the increased need for site adaptation, some of these alternative regeneration methods may still be of interest, especially in the context of climate change. Therefore, the objective of this study was to evaluate the effects of mechanical site preparation and shelterwood density (0, 100 and 200 stems/ha) on establishment of naturally regenerated Scots pine. The study was based on empirical data from two adjacent sites located in southern Sweden (57.06°N, 14.39°E), both of which were fenced. On site I., a total of 1286 seedlings were mapped and monitored annually over a period of 4 years (2017-2020). Results from the last inventory showed that the total seedling density was positively affected by mechanical site preparation and shelterwood density. Additionally, we observed the effect of 2018 drought year, where rich seedfall did not result in abundant germination in the same year. Instead, most of the germination was delayed until 2019, likely due to the unfavourable growing conditions caused by the severe drought. On site II., 667 seedlings were followed for 3 years (2020-2022), where, similarly to site I, mechanical site preparation had a significantly positive effect on recruitment of Scots pine seedlings. The effect of shelterwood density was however less pronounced than in site I. Overall, we show that natural regeneration of Scots pine is possible in southern Sweden, however the method is sensitive to site conditions and environmental variables, especially drought.

Stand structure and growth change according to the long-term repeated investigation of Korean white pine plantations in South Korea

T1.5 Climate-smart pine forest management

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Abstract: This study was conducted to compare the growth change patterns and find out the stand structure of Korean white pine (*Pinus koraiensis*) in South Korea using long-term repeated monitoring. The data were collected from three permanent plots in the Korean white pine plantations located in the North Central region of South Korea (Gangwon Province) for a period of 41 years (1981~2021) with 9 measurements by plot. The target plots were established between 1981 and 1984; average stand age of 49 years according to 2023. The climate in the study area is temperate characterized by hot and humid in summer and low temperatures in winter. Thinning treatments were conducted based on qualitative and quantitative considerations, with initial thinning performed to promote stand development and subsequent thinning aimed at pest prevention and forest tending. The size of the plots is 0.05 hectares (50 m × 50 m), and The growth factors such as diameter at breast height (DBH), height, crown width, crown class, as well as site factors including aspect and slope, were collected to figure out the growth change of the trees. Total increment (TI), mean annual increment (MAI), and periodic annual increment (PAI) of DBH, height, basal area, and volume were calculated for each plot, and then the growth patterns and allometry were analyzed. The results showed a consistent increase in TI with increasing stand age for DBH, height, basal area, and volume. MAI of DBH and height was increased, while the PAI showed a decreasing trend after the specific point, resulting in a crossover pattern. Although the monitoring period for growth analysis might be relatively shorter compared to other countries, this study holds significance in analyzing the long-term growth changes of Korean white pine considering the average stand age in South Korea. Furthermore, as the age class of plantations in South Korea is gradually distributed more at the stage of mature forests, the results of this study can offer fundamental information for future research on the growth of older stands in South Korea and the development of silvicultural manuals.

Stone pine shows no trade-offs between growth and survival over its distribution range

T1.5 Climate-smart pine forest management

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Abstract: In the current context of rapid climate change, understanding adaptation mechanisms and tolerance thresholds to climate in forest tree species is essential for the management of forest genetic resources. The distribution of forest tree species may reflect a trade-off between the populations' growth potential and survival in harsh environments or under limited resources such as at climatic margins.

To test this hypothesis, we focused on stone pine, a Mediterranean conifer largely used for restorative afforestation and landscaping, thanks to its capacity to thrive in full sunlight and its resilience to drought and heat, providing a significant potential for increase the climatic resilience of Mediterranean woodlands. Despite its sparse populations scattered over the Mediterranean area from the Atlantic coast in Portugal to the shores of the Black Sea and Mount Lebanon, the species is characterized by a limited intraspecific genetic variability and high phenotypic plasticity. We used data from an international network of 10 common gardens established in France, Spain, and Tunisia in the 1990s, testing 56 provenances (16,545 tree individuals) covering the species distribution range.

We tested single trait models for height growth and mortality, and a multi-trait model for height growth with mortality as a covariate. Results showed a marginal effect of the provenance on single trait models that is consistent with previous studies. The multi-trait model revealed that growth decreased in sites with increased mortality for all populations, disregarding hence a clear trade-off at least at the studied trial sites. The lack of adaptive differentiation observed among provenances is valuable for the management of ecosystem services this species provides and for the conservation and use of its genetic resources.

Surviving volcanoes and fires and perishing from drought. Effect of climate change and lack of management on pine plantations

T1.5 Climate-smart pine forest management

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Abstract: Episodes of drought-induced forest dieback in conifer forests have been observed in the last decades worldwide, and are likely to become more frequent in the future as a consequence of increasing aridity. Pinus canariensis is an endemic pine to the Canary Islands, able to resprout after severe injury as shown by surviving trees after the eruption in La Palma in 2021. However, during the last decade, a generalized decline of the species in plantations located in the island of Tenerife at altitudes between 1800 and 2200 m has been observed. These reforestations were carried out between 1946 and 1950 and maintain densities ca. 800 trees ha^{-1}. To understand the causes and identify the possible physiological mechanisms involved in the decay, we classified the pine stands according to the degree of affection following an altitudinal gradient, establishing plots at 1,850, 1,950 and 2,050 m on the windward and leeward sides of increasing level of decay. In addition, a plot was established at 1,750 m without signs of decay. Radial stem growth was measured continuously using point dendrometers and physiological measurements were made on healthy and decayed pines.

Trees in the control plot maintained higher values of water potential in summer, while the most stressed trees, with the highest rates of electronic transport, were found in the highest plots, where decay was more intense. We found no significant differences between vigorous and decayed trees in water potential or gas exchange, suggesting that the photosynthetic capacity of remaining needles in decayed (heavily defoliated) trees is not related to tree vigor. However, we observed higher radial growth in vigorous (low defoliated) trees than in decayed trees. We found that daily and annual changes in growth are good indicators of forest decline. Moreover, the generalized lack of cones and regeneration across the altitudinal gradient can compromise the future of pine forests at high elevation in the island. To increase the availability of water and nutrients, two types of thinning intensity were suggested, 50% and 70% of basal area, with and without enrichment of native understory species to study whether more diverse forest are more resilient.

Wildfire, Management and Heatwaves: Conifer Tree Regeneration in a Changing Climate

T1.5 Climate-smart pine forest management

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Abstract: Wildfires have a pivotal role in boreal forests by sustaining forest regeneration and ecosystem dynamics. However, the warming climate has escalated the fire regimes in the boreal forest over the past decade. Consequently, the warming occurring after a fire can create new environmental conditions that pose challenges to the growth and survival of tree seedlings. Implementing management interventions that mitigate these effects holds the potential to counterbalance the impacts of fire severity and warming.

To gain novel insights into how conifer tree regeneration responds to multiple environmental drivers, we performed a field mesocosm experiment. The experiment was conducted within a post-wildfire area located in Västmanland, Sweden, where a severe wildfire took place in 2014. We focused on investigating the interactive effects of fire severity, salvage logging, experimental warming and the presence of understory shrubs on different provenances of planted *Pinus sylvestris* and *Picea abies* seedlings. We found that low fire severity, when combined with non-logging operations, resulted in suboptimal aboveground growth of conifers. Meanwhile, in areas characterized by high fire severity, the practice of salvage logging showed no apparent impact. Further, experimental warming and the removal of ericaceous shrubs increased aboveground seedling biomass, irrespective of fire severity or management treatment. This implies that augmented light accessibility and reduced resource competition from the understory vegetation perform vital functions in promoting conifer seedling growth. The diminished impact of logging in stands with high fire severity can be attributed to factors such as high tree mortality and the open canopy resulting from intense wildfires. Additionally, our study indicates that post-fire warming may expedite the recovery rate of conifer seedlings, regardless of the severity. This study endeavors to enhance our ability to predict the underlying mechanisms driving post-fire conifer regeneration, which are influenced by a multitude of factors such as fire severity, logging activities and the impacts of global warming. By unraveling the complex interactions among these variables, we provide valuable insights that can guide the development of post-fire plantation strategies. These strategies hold significant promise in fostering sustainable regeneration practices, thereby mitigating the risks associated with regeneration shortcomings in an ever-evolving future.

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

Adapting Mangroves to Sea-Level Rise: A Framework Based on Species Traits and Vulnerabilities

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Sea-level rise (SLR) presents an emerging threat to mangrove ecosystems and other coastal forests worldwide. These ecosystems provide numerous ecosystem services to support local livelihoods, biodiversity, and climate change mitigation. Recognizing this vulnerability, adaptation strategies have begun to emerge. However, strategies should consider the varying vulnerability levels among mangrove species given their unique environmental tolerances, regeneration and growth potential, and other functional traits. In this conceptual study, we developed an adaptation framework that integrates (1) the functional traits of mangroves, (2) their vulnerability to SLR as a function of exposure, sensitivity, and adaptive capacity, and (3) the effectiveness of adaptive measures.

Our findings underscore that resistance-oriented adaptive measures may shield mangroves from SLR-induced alterations by promoting sediment accretion, reducing erosion, and fostering forest health. Meanwhile, resilience-oriented adaptive measures aim to facilitate the recovery from SLR-induced disturbances and assist in the landward migration of mangrove species through interventions such as gap thinning. Transformation-oriented adaptive measures encourage substantial alterations in the socio-ecological system, embracing natural colonization processes and proactively introducing mangroves beyond their current range. Thus, a multifaceted adaptive approach is instrumental in preserving the species composition, forest structure, and, consequently, the ecosystem services provided by mangroves, including their potential to act as carbon sinks. Our analysis revealed that the long-term effectiveness of these measures differs according to SLR rates and is further modulated by the functional traits of mangrove species and the local site conditions. Thus, site- and species-specific measures should be prioritized in coastal management plans over generalized solutions. Otherwise, less-adaptive species might be lost in favor of more adaptive mangrove species. Furthermore, a keen eye is needed for potential maladaptive measures, such as focusing on the establishment of monoculture plantations.

By considering a range of adaptive measures, managers of mangrove ecosystems can respond to SLR and help to ensure the long-term health and productivity of mangroves. Although this trait-specific approach derived from our conceptual study is promising, further empirical research and monitoring are required to assess its effectiveness in specific locations. Such research could also enable the application of this approach in similar coastal forest ecosystems threatened by SLR.

Analysis of the development of new governance approaches for the provision of mangrove forest ecosystem services. Five case studies in Colombia

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Little is known about the emergence and development of novel governance approaches for mangrove forest ecosystem services (MFES) provision and their conservation, what drives them, and how they can be fostered to serve as nature-climate solutions. Existing frameworks often deal with single aspects of resource management and thus fail to assess processes, multi-level influences, and interacting dimensions and factors in a system-based understanding. I will present the conceptual foundation and empirical application of an adapted Social-Ecological System framework with additional elements that builds on the idea of complex and interlinked social-ecological-technical-forestry-innovation systems (SETFIS) that allows for the identification of key factors for revealing MFES dynamics to understand the emergence and development of such governance innovations Colombia. The development of the framework was applied previously to many case studies in diverse biogeographical regions for knowledge co-creation as alternative governance and business approaches to current timber-based models. Results out of its application served to further develop the framework and its holistic applicability. The application of the SETFIS framework in five Colombian cases, such as Vida Manglar, a community mangrove reforestation compensation and biodiversity conservation scheme, and Playa Viva, a community managed mangrove forest focusing on conservation and tourism, proofed and validated previous methodological and content-related results of this holistic applicability in the context of coastal blue forests in Colombia. While we observed common patterns in the influencing factors that seem to play a key role in all the cases analysed, we were also able to identify particular conditions for the design and work of governance. These relate to their individual historical development, disruptive events, local context, knowledge sharing, policies and incentives. The key impact lies in assisting the management of mangrove governance innovations, shedding light on their emergence and potential for future development.

Arthropod Diversity and Functional Composition Across Mangrove Areas of del Carmen, Siargao Island, Philippines

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangrove species diversity is well known for larger animals and plant, but little is known about mangrove insects and their significance and yet they perform important roles in the ecology of the habitat. The present study was conducted to determine the diversity of insects associated with mangrove. Eight sites were established based on the geographical location in July 2019 and October 2022. One malaise trap was set up for each site for a total of eight traps per sampling period. A total of 11 insect orders, 3 non-insect hexapod orders, 297 morphospecies, and 1737 individuals were collected and identified. Orders Hymenoptera and Diptera (61 taxa) is the most specious followed by Coleoptera (39), Lepidoptera (34), Hemiptera (16), and Psocodea (12). Phase 1 sampling is observed more diverse than Phase 2 sampling. Phase 2 sampling is more even than the Phase 1 sampling, but Phase 1 sampling is more abundant than the Phase 2 sampling. Viewdeck Phase 1 sampling has the highest diversity. Decomposers, herbivores, pollinators, predators, and parasitoids were observed as arthropod functional guilds in the mangrove ecosystem. This study has shown that the mangroves of Del Carmen have a vast array of insects which will contribute to their biodiversity data and subsequent conservation and management of ecosystem in the Siargao Island.

Blue Forests Unveiled: Mapping, Monitoring, and Reporting the Global Distribution and Anthropogenic Changes of Tidal Freshwater Forests and Mangroves

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: The distribution of Blue Forests - Mangroves and other tidally inundated forests- has changed extensively over the past 60 years, mainly due to direct anthropogenic causes such as deforestation, conversion to agriculture and aquaculture, urbanization, draining, and other modifications to the hydrology. Remote Sensing based mapping has been integral in better understanding the distribution and change of forest, Blue Carbon and Tidal ecosystems, with increasing availability of global and regional datasets that can be used for management and policy decisions, as well as scientific analysis.

Mangroves forest distribution has been extensively mapped and studied on local to global scales, starting with publications such as the Global mangrove Atlas (Spalding et al, 2008), the USGS Global Mangrove Distribution Map (Giri, 2011) and now with efforts such as the Global Mangrove Watch (Bunting et al, 2023). Their status as high carbon density Blue Carbon ecosystems has also resulted in extensive scientific research, advocacy and conservation efforts focused on mangroves. While Mangrove loss has been extensive in the past century, with estimates of 50% of original mangrove cover loss, remote sensing studies show that deforestation rates have declined since 2000. The distribution of changes is highly variable across the globe, depending on socioeconomic, political, climate and other environmental drivers. In this talk, we will provide an overview of the drivers of global mangrove extent and carbon distribution, an overview of historic and current change hotspots, and what is driving changes we are seeing now and into the future.

Other tidally inundated forests are challenging to map using Satellite data and have not historically been mapped on a global scale. Here we will highlight the existing datasets, what gaps exist and how we may be able to address these gaps using Remote Sensing. Through an overview of the advances in data analysis, new satellite missions, data and models, we will describe a framework for the development of maps of blue forest.

Carbon Stocks Assessment of Selected Mangrove Plantations in the Philippines

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Tropical forests play an important role in the climate change as sources and sink of carbon. Thus, mangrove forests have significant role in mitigating the climate change problem. This study was conducted to determine the biomass, carbon stored in the biomass and sediment and carbon sequestration/accumulation rate in selected plantation stands of mangrove in the country. Quadrat Sampling Technique was used with 10m x 10m quadrats established.

Results of the study showed that the mangrove plantation has a mean biomass carbon density of 164.15 tC/ha with ranges from 70.20 tC/ha to 293.03 tC/ha. Aboveground biomass constitutes 73% on the average to the total biomass with belowground biomass 27% of the total. The carbon held in the biomass of the plantation stands which are dominantly *Rhizophora*s in all of the four sites investigated ranges from 32.99 to 137.72 tC/ha or 77.15 tC/ha, on the average. Soil however, accounted to 113.44 tC/ha, on the average and ranges from 57 to 158.15 tC/ha. The combined carbon held by the biomass and upper 30cm depth of sediment in the mangrove plantations studied is on the average 190.59 tC/ha and ranges from 117.56 to 262.45 tC/ha. The total carbon value is equivalent to 699.45 tons of carbon dioxide per hectare that are held and stored in the aboveground biomass, belowground biomass and sediment of the mangrove plantations under study. The yearly rate of carbon accumulation in the biomass of four mangrove plantations studied based on carbon stock and plantation age is 4.01 tC/ha on the average and ranges from 2.75 to 5.15 tC/ha/year.

In conclusion, this study demonstrated the potential of selected mangrove plantations in the Philippines in light of climate change mitigation as a strategy to combat climate change. This implies that mangrove can offer a great potential carbon sink.

Key Words: mangrove, plantation, biomass, carbon density

Climate Change Mitigation Potential of Philippine Mangrove Forests and Carbon emission arising from mangrove deforestation

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangrove forests provide many ecosystem goods and services, and are an important carbon sink in the tropics. However, despite the numerous goods and services they provide, mangroves are being depleted at alarming rates. Carbon stocks in biomass and soil as well as the potential C emissions owing to land use change in mangrove are important parameters to quantify, monitor in the mangrove area, and are vital inputs for assessing the impact of mangrove conversion on the C budget. While the studies are growing on estimating the Ecosystem Carbon Stock of mangroves and C losses arising from their conversion to other land uses, very few reports are available at the country level, including in the Philippines. To address these gaps, this study was conducted in 11 selected coastal areas of the Philippines, spread across the major islands of Luzon, Visayas and Mindanao with the following objectives: 1) to quantify and evaluate the Ecosystem Carbon Stocks of mangrove forest; and 2) to estimate the potential C losses owing to conversion of mangrove forest to other land use. Intensive field assessments combined with laboratory analysis were implemented to achieve the above objectives.

Results of this study revealed that the mean Ecosystem C stocks of mangrove forests based on was 529.7 MgC ha^{-1} (1,944 tCO_2eq ha^{-1}). The potential contribution of our Philippine mangrove to global Climate Change mitigation could translate to about 589.7 M tCO_2eq based on its 2019 total area of 303,381 ha. The mangroves of Palawan had the highest C stock. Potential C losses was 176 MgC ha^{-1} (645.9 tCO_2eq ha^{-1}) or 22% - 25% decline in Ecosystem C stock when mangroves are converted to other land uses.

This study has shown the relatively enormous amount of Carbon stocked and stored in the biomass and soil of Philippine mangroves and suggests the need to protect them from human disturbance. The decrease in C stocks indicates C losses and emissions owing to the conversion of mangrove forests to other land uses. Future research works and other implication of the results will be discussed.

Complementing Natural Regeneration with Active Planting: A New Approach to Mangrove Rehabilitation in the Philippines

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Natural regeneration and active planting are two contrasting approaches to mangrove rehabilitation, each with its own advantages and disadvantages. In the Philippines, most of the rehabilitation initiatives are focused on active planting and a harmonized guideline in rehabilitating Abandoned Brackish Water Fishponds (ABFs) is still needed. A total of sixteen (16) ABFs across different climatic types in the Philippines were assessed in terms of initial mangrove establishment. This study was done to determine the environmental conditions suited for natural regeneration and active planting in ABFs. Multiple Regression Analysis shows that natural regeneration is significantly influenced by surface elevation while other factors such as water pH, salinity and distance to mangrove stands also play a role in natural recruitment. The model shows that at elevations of >0.43 masl, sufficient numbers of mangrove recruits are observed, making it conducive for natural regeneration. Lower elevation areas which are less suitable for natural recruits (<0.43 masl) require interventions such as active planting, preferably with *Avicennia marina*. %Survival of planted seedlings was not significantly different between the lower and higher elevation levels. Results further provide empirical evidence of the suitability of ABFs for rehabilitation. By maximizing the benefits of natural regeneration and lesser cost for active planting, the complementation of these approaches provides an ecological and sustainable, yet practical option to mangrove rehabilitation.

Do tree-mediated greenhouse gas emissions offset blue carbon in mangroves?

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangroves ecosystems have a great potential as a blue carbon reservoir, especially in its soils. Conversely, some of that carbon is emitted, mainly as methane (CH_4) and carbon dioxide (CO_2), through the soil-plant-atmosphere continuum. Although many studies have focused on greenhouse gases emitted from soils, emissions could be being underestimated because trees also mediate soil-produced CH_4 and CO_2, especially by their aerial roots that act as snorkels for trees in flooded environments. Moreover, magnitudes, patterns, and drivers of these emissions remain poorly understood. In this regard, we estimated the spatiotemporal variation of CH_4 and CO_2 from tree stems and aerial roots (stilts and pneumatophores) in three mangrove species along different mangrove ecological types during both rainy and dry seasons. We also searched to elucidate the contribution of mangrove trees to local carbon budget in Ría Celestún Biosphere Reserve (Mexico) and the role of tree anatomy in the transport of these gases. Overall, CH_4 and CO_2 emissions were dependent on the species, tissues, exchange interfaces, and seasons. Dwarf *Rhizophora mangle* had the highest CH_4 emission rates from stems and stilt roots. Basin mangrove forest contributed to increased CO_2 fluxes through the stems and pneumatophores of *Avicennia germinans* and *Laguncularia racemosa*. Rainy season limited CO_2 fluxes but enhanced CH_4 emissions. CH_4 and CO_2 were higher in near-ground tissues such as third-order stilt roots in *R. mangle* – which had a higher aerenchyma tissue – both in dwarf and hammock mangrove forests. CH_4 were positively correlated with lenticels number, but negatively with wood density, while CO_2 was dependent of salinity and sediment temperature in pneumatophores. Also, the number of pneumatophores explained more than half the variation for CO_2 fluxes in fringe mangroves at water-air and sediment-air interfaces. To date, stem CH_4 emissions have been studied in eleven mangrove species worldwide. Therefore, we encourage to accurate our local-to-global carbon estimations including trees into our current carbon budgets and models. It is also valuable to remark that mangrove trees act as CH_4 sources or sinks, depending on physicochemical and micro-environment conditions, thus they must be understood from their basis on plant physiology and anatomy.

Effects of watering regimes and soil media content on performance of propagules and seedlings of three mangrove species of the Kenyan coast

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangrove restoration should be sustained in Kenya in order to maintain the ecological functions of the ecosystem. Restoration through reforestation or planting faces a myriad of challenges among them; inadequate planting materials which are sometimes of poor quality. Therefore, knowledge on mangrove nursery establishment and management is essential in providing sufficient and quality planting materials for sustainable restoration initiatives especially where natural regeneration is unsuccessful. This study therefore, sought to determine the effects of nursery watering regimes and soil media content on the performance of seedlings and propagules of three key mangrove species at the Kenyan coast: *Rhizophora mucronata, Ceriops tagal* and *Bruguiera gymnorrhiza.* Propagules and Seedlings were planted in three soil media i.e. silt-clays (mud), clay-sands (muddy-loams) and sands (pure sand texture). Both planting materials were tested under different watering regimes i.e. flooded by tidal events and in a floating nursery where propagules and seedlings were watered using sea water. Growth performance was measured by germination of (propagules), height, girth, number of leaves and internodes of seedlings.

From preliminary results; The effect of Nursery type, Mangrove species and Soil media significantly influenced seedling's height, diameter, number of leaves (foliage) and number of internodes developed ($P < 0.05$). *Rhizophora mucronata* recorded the highest shoot height and diameter while *Ceriops tagal* the least. Muddy textured soil media with high content of silt and clays significantly affected growth by producing higher shoot heights, diameter, number of internodes but not number of leaves compared to sandy textured soil media. This trend in performance was also observed in propagules and being statistically significant. Propagule germination occurred within the first month of sowing. Rhizophora mucronata propagules had the highest germination, height, diameter with no difference between *Ceriops tagal* and *Bruguiera gymnorrhiza*. Silt-clay soil media had a higher germination, height compared to sand. In conclusion, the flooded nurseries are recommended with silt-clayey mud being preferred soil media for raising *Rhizophora, Ceriops* and *Bruguiera* sp seedlings for restoration initiatives.

Key words: Mangroves, Seedlings, Propagules, Nurseries, Soil media, Watering, Performance,

Empowering Coastal Communities for Effective Mangrove Restoration in Fiji

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Coastal mangrove restoration holds immense potential as a nature-based solution for climate mitigation and adaptation, making it a key contributor to Fiji's economy. Fiji boasts the third-largest area of mangroves in the Pacific, covering approximately 46,600 hectares. The Ministry of Forestry in Fiji has taken significant steps to promote the rehabilitation and sustainable management of coastal and mangrove wetlands. These efforts include establishing demonstration sites, engaging with communities and stakeholders to enhance decision-making processes, developing national guidelines on mangrove use and management, and raising awareness about the importance of sustainable mangrove management. The Community-based Management Guideline for Mangrove Rehabilitation and Restoration in Fiji, prepared based on successful pilot activities by the Ministry of Forestry, aims to empower coastal communities especially women groups, to effectively manage their mangrove resources.

Benefits of Sustainable Mangrove Management: By promoting sustainable use of natural resources, Fiji's Ministry of Forestry recognizes the crucial importance of benefiting both people and the environment, especially in the face of current global climate change challenges. Their collective efforts generate a transformative approach that involves local communities in forest management, leading to their well-being and enabling effective climate change mitigation. This approach has the potential to benefit numerous coastal communities across Fiji. The enhanced version emphasizes empowering coastal communities through good technical guides with the aim of the Community-based Management Guideline. This guideline serves as a "how-to" manual, enabling communities to improve their mangrove resource management. The updated text highlights the transformative approach taken by the Ministry of Forestry, which engages local communities in forest management. This approach not only combats climate change effectively but also has wide-ranging benefits for coastal communities in Fiji. By incorporating these improvements, this provides a more comprehensive and solid overview of coastal community-based mangrove restoration in Fiji.

Establishing tipping point in mangrove ecosystem function

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangrove forests in Kenya are not pristine and the area under them is reducing at an alarming rate due to overexploitation, pollution mainly through oil spills and sewage discharge, conversion to agricultural land, siltation, construction of aquaculture ponds and urban development. Development of rehabilitation and restoration technologies is needed to save Kenya's mangroves from further loss. This study sought to establish indicators of degrading mangroves, determine tipping points in mangrove ecosystem where ecosystem functioning is lost irreparably with an aim of developing evidence based restoration approaches peculiar to different sites. The study revealed that sites dominated by *Rhizophora mucronata* and *Ceriops tagal* were most degraded as species are targeted for poles, high seedling density and low microbenthic populations were observed in degraded sites. Oil spillage and siltation affected mangroves leading to degradation and loss of specific mangrove species. Recovery of mangrove forests degraded as a result of oil spillage and siltation was slow and difficult to achieve without human intervention as compared to human-overexploited sites. The results will guide development of appropriate restoration interventions that can be scaled up by stakeholders engaged in the conservation of mangrove resources.

Key words: Degradation, Ecosystem function, Rehabilitation, Restoration

Human-Driven Degradation Impacts on Mangroves in Southern Sierra Leone

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangroves are important stores and sinks of blue carbon, foster biodiversity, and provide ecosystem services supporting local livelihoods and enhancing coastal protection. However, mangroves are declining in extent and experiencing degradation due to human activities. This study investigated how different levels of human-driven degradation affect forest structure, above- and belowground carbon stocks, tree species composition, and the population structures of dominant tree species. We investigated 19 transects of different degradation levels (pristine, moderately degraded, heavily degraded) in various locations (oceanic, riverine, interior) in the Sherbro river estuary in Sierra Leone.

Results showed that pristine mangroves stored 707 Mg ha^{-1} of carbon including soils to 1 m depth, which is higher than values reported from many other regions in Africa. Degradation resulted in declining basal area, decreasing density of large trees (≥ 30 cm diameter) but increasing stem density of small trees (5-10 cm diameter). All carbon pools declined with increasing degradation across all locations. While above- and belowground carbon decreased by 96 %, soil carbon (up to 1 m depth) decreased by 44 %. Heavy degradation resulted in a change in the dominating species from *Rhizophora racemosa* to *Rhizophora mangle* across all locations. Overall, we found major effects of degradation on mangrove characteristics and minor effects of location. We urge conservation of pristine forests, restoration of degraded mangroves, and the establishment of management systems that are ecologically informed and based on a comprehensive understanding of human-driven degradation impacts.

Management and Conservation of Mangrove Species in Pagbilao Mangrove Experimental Forest, Quezon Province, Philippines

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: The decline of mangrove forests is indeed a pressing issue that requires urgent attention. Reforestation efforts are crucial for sustaining the productivity and genetic resources of mangroves. However, the lack of knowledge regarding superior mother trees and the ideal qualities for high-quality mangrove seedlings poses significant challenges in the Philippines. To address this problem, an inventory survey of mangrove Individual Plus Trees (IPTs) was conducted in the Pagbilao Mangrove Experimental Forest in Pagbilao, Quezon, Philippines. A total of 115 IPTs belonging to 10 families and comprising 24 species were identified ,geo-tagged, and monitored regularly. These established IPTs serve as sources of quality germplasm for the respective mangrove species.

The phenotypic qualities and phenology of the potential IPTs were monitored using the assessment method developed by the Department of Environment and Natural Resources. The identified IPTs displayed desirable characteristics such as being free from defects, having no signs of insect infestation or diseases, prolific flowering, and fruiting, vigor, and dominance. Quarterly, 3,000 quality germplasm samples were collected from these IPTs and raised in the nursery to produce high-quality planting stocks. To enhance the collection and utilization of high-quality germplasm, an Information, Education, and Communication (IEC) campaign on the value of germplasm quality should be conducted. This can raise awareness among seedling producers about the importance of superior mother trees and provide them with the necessary knowledge and skills to identify and utilize high-quality germplasm.

The development of an effective germplasm collection and distribution mechanism is necessary to increase the accessibility of high-quality germplasm from a diverse range of mangrove species. The mechanism should ensure that germplasm from superior mother trees is readily available to seedling producers and restoration projects. By implementing these measures, there can be significant progress in the restoration and conservation of mangrove forests in the Philippines, while also ensuring the availability of high-quality planting stocks for future reforestation efforts.

Keywords: Mangrove Forest, management, inventory, genetic resources, conservation

Mapping of the global mangrove forest governance

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: The scholars found more than 800 definitions of forest used worldwide due to the nature of diversified goods and services that forest owns and provides for the environment. Mangrove forests then possess beyond human thinking goods and services. As a result, society creates governance mechanisms for protecting and managing those resources sustainably for their societal well-being and to fulfil their self-interests over time. On the other hand, the forest issue areas induce the society to establish the regime or regime complexes not only at the international level but also at the regional, national and local levels. These regimes involve rule makers and rule takers, the former setting and modifying, often in conflict and competition, the rules with which the latter are expected to comply. These regimes are furthered as a regime complex or fragmented global governance due to the heap of agreements and regulations that intersect concerning a particular issue or set of issues and conceptualise how the complexity of rules and institutions can, in and of itself, shape the politics of cooperation.

This paper applies the institutional elements research technique to map the global mangrove forest governance. The core-institution method was used to determine which elements were part of the regime. It analysed their policy goals to identify potential synergistic and conflicting relationships among them. The online-based secondary data sources, e.g., regimes websites, will be used for this research. The result assumes the fragmented nature of identified regimes, which will be synergistic and conflicting interactions between regime elements. A deeper analysis may suggest that it ranges from a positive, affirmative assessment of fragmentation to a rather negative one.

Monitoring greenhouse gas emission in different mangrove management: Lesson from Berau, East Kalimantan, Indonesia

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangrove ecosystems provide essential ecosystem services for climate change mitigation that warrant protection and restoration as they keep a huge amount of carbon. It is particularly critical in Indonesia, home to about a quarter of the world's mangrove ecosystems. A national study indicates that avoiding mangrove degradation and restoring mangroves can reduce greenhouse gas (GHG) emissions by up to 67 $TgCO_2e\ yr^{-1}$.

Unfortunately, vast expanses of these mangroves have been deforested, degraded, or converted for other uses. These anthropogenic activities disturb the ecosystem's stabilization and release GHG emissions into the atmosphere. Thus, accurate prediction of the values of mangrove conservation and restoration requires knowledge of the carbon dynamics of intact and degraded mangroves. Our study aims to measure GHG fluxes from natural and managed mangrove ecosystems as well as aquaculture practices in Berau, East Kalimantan. The natural mangrove is located adjacent to the sea, while the managed mangrove areas comprise controlled mangroves. In aquaculture practices, we established monitoring plots in the pond embankment and shrimp ponds. We measure CO_2 and CH_4 fluxes using an LI-COR portable trace gas analyzer equipped with a smart chamber. We installed trenching to quantify heterotrophic emissions in the natural and managed mangrove areas. Meanwhile, we did not trench in the pond embankment and used floating chambers in the shrimp pond.

We found that total gas emission fluxes were highest in the natural mangrove and the lowest in the aquaculture practice plots. We may assume that the carbon was removed during the aquaculture establishment. More information on carbon stock is crucial to understand better the contribution of aboveground carbon to total emissions. Sustainable aquaculture is essential to bridge the needs of mangrove restoration and the community's well-being.

Recognizing the the of mangrove forest as a nature-based climate solution: Empirical evidence from Sundarbans mangrove forest

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangroves are increasingly regarded as a cost-effective nature-based climate solution for critical ecosystem services they provide, including habitat for terrestrial and aquatic fauna, biodiversity conservation, and protection from cyclones. it has repeatedly been claimed in the literature that mangroves store greater amounts of carbon (C) than any other terrestrial ecosystems. This claim, however, is not supported by enough empirical data, particularly from South Asia. Our study provides a comprehensive scenario of the C storage and sequestration potential of mangroves along a successional gradient in the Sundarbans mangrove forest - the world's largest contagious mangrove forest shared between Bangladesh and India. Carbon stocks and fluxes were monitored along three successional (pioneer, secondary, and climax forest) and salinity gradients (i.e. oligohaline, mesohaline, and polyhalite). We used a stratified random sampling approach, and data were collected both through destructive and non-destructive sampling. Carbon stocks were measured in tree biomass, undergrowth, litter/woody debris, fine root, and soil. Both autotrophic and heterotrophic respiration and litterfall were measured as an indicator of C flux in the forest. Our study suggests the highest C stock in the climax forest and less saline zone dominated by Sundri (Heritiera fomes), while the largest C sequestration potential is in the pioneer forest and newly accreted land dominated by Keora (Sonneratia apitala). Our study would be useful for scientists and policymakers to recognize the potential of Sundrabans forest as a nature-based climate solution.

Soil as a reservoir of blue carbon in mangrove forests - the case of Pemba Bay in Mozambique

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Climate change mitigation strategies have highlighted the mangrove forest's role in carbon stock and carbon sequestration. In Mozambique, mangroves occur mainly in sheltered shorelines and river estuaries. Rising water levels, storms, and anthropogenic action (resulting in the overexploitation of resources and, in some cases, changes in land use) are some of the threats to which mangroves are subjected. Efforts are being made to preserve the Mozambique mangroves and restore the destroyed areas by introducing policies, and conservation and management strategies. In this work, the mangrove carbon stock in Pemba Bay, on the northeast coast of Mozambique, was estimated. Data were collected on fifteen inventory plots to describe the forest structure and quantify the carbon pools - considering above and belowground biomass, deadwood biomass, forest floor litter, and soil. In the inventory plots, soil samples were collected, which allowed the characterization of the soil profile up to 1.20 m according to salinity, pH, and organic carbon concentration. Six mangrove species were found in Pemba Bay - *Avicennia marina*, *Bruguierra gymnorhiza*, *Ceriops tagal*, *Rhizophora mucronata*, *Sonneratia alba*, and *Xylocarpus granatum*. *Avicennia marina* was the most frequent species. Stand density varied between 477 and 24,172 trees/ha, in the understory layer, and between 299 and 1,156 trees/ha, in the overstory layer. The organic carbon concentration, measured at different depth soil layers, showed a large range with soil depth, with the highest values in the 35-40 cm soil layer. The mangrove carbon stock in Pemba Bay was estimated to be 309 Mg ha^{-1}, with 71% in the soil (up to 1.50 m), 20% in the aboveground biomass, 6.4% in the belowground biomass, 1.6% in the deadwood biomass, and 0.9% in the forest floor layer. Pemba Bay can contribute to fulfilling Mozambique's carbon commitments, such as mangrove restoration strategies, NDC climate commitments linked to mangrove forests, as well as the extension of Mozambique's marine protected areas (MPA). A further recommendation is to align mangrove stocks and mangrove sequestration studies within Pemba Bay and beyond in Mozambique.

Study on Mangrove Vegetation in Coastal areas of Myanmar: Case study in Kyunsu Township, Tanintharyi Region and Ramree Township, Rakhine State

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: The vegetative composition of mangrove forests and plantations in two coastal areas of Myanmar: Kyuntsu Township and Ramree Township, was investigated in this study. This study focuses on species diversity, distribution, and regeneration. Data were collected by using the circle shape of the sample plot (0.07 ha), and the distance between the sample plots is 100 m. All vegetation within the sample plot was recorded and measured the diameter at breast height and tree total height, and the regenerations were enumerated within 5 m radius subplots that lay at the center of the main plot. In Kyuntsu, all study plots were located in the natural forest area while both 4 plantations and natural forest areas were included in Ramree. The results demonstrated that Byu Oak Saung (*Bruguiera gymnorhiza*) showed the highest importance value index followed by Byu (pho) (*Rhizophora apiculata*) and Madama (*Ceriops decandra*) in Kyuntsu. In Ramree, the importance value index revealed that Madama dominated plantations and natural forest areas, followed by Byu (pho) in natural forest areas and Yae-khayar (*Aegiceras corniculatum*) in plantations. Kyuntsu had high diversity index of H= 0.83 while Ramree's natural forest site had H= 0.68 and plantation sites had H= 0.47. Totally 19 species were recorded in both study sites and, among them, 7 species were found in both study sites as the common species. Kyutsu had big-sized trees compared with both the natural forest area and plantations of the Ramree site. Significant differences were observed in GBH ($p<0.05$, $F = 57.718$) and Ht ($p<0.05$, $F = 390.030$) among the natural forest sites of both study areas. The vegetation regeneration among the study sites indicated different ($p<0.05$) but not significant. Generally, the mangrove forest in the study sites had different vegetation structural formation and species composition which could be attributed to the different agents of degradation i.e. degree of perturbations that greatly depend on human access to the mangrove area. Therefore, understanding the structure and regeneration patterns of the mangrove is critical for developing site-specific management strategies that enhance and preserves the ecological function of the mangrove ecosystem.

The positive impact of restoration and conservation: A case study of Mangroves in Mida Creek, Kenya

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangrove forests cover in Kenya represent approximately 3% of natural forest cover or 1% of national land area. Mida Creek, a tidal inlet in Arabuko-Sokoke Forest, has experienced overexploitation of mangrove forests due to human encroachment and climate change in the past. Significant efforts in rehabilitation and conservation taken place within the Creek for the last 10-15 years; however, the success in restoration has not been well quantified. Therefore, this study aimed at assessing status of mangrove cover, change and degradation in Mida Creek between 1985 to 2022 to ascertain the gains in restoration and conservation initiatives in recent years. GIS and remote sensing techniques were employed for mangrove vegetation analysis. Mangrove degradation, change and recovery over the study period was carried out by analyzing the Normalized Difference Vegetation Index (NDVI) for a period covering 37 years with 1985 as the benchmark. Satellite data for 1985, 2002, 2015, 2017 and 2022 at 30m resolution being processed with remote analysis of water extent and coastal erosion done using Normalized Difference Water Index (NDWI) from satellite imagery. From the results, mangrove cover has been on an increasing trend for the last 37 years (1985-2022). Between 1985 and 2022, mangrove cover increased by 71% from 819ha to 1404ha which translated into a rate of 1.7% per year or 15.81 ha for the last 37 years. On average. There has been an increase in dense (closed) mangrove forest from the year 1985 to 2022 with moderate or regular mangroves decreasing over time with bare lands decreasing too. The area covered by degraded mangroves in Mida Creek was 145ha against the intact or dense mangroves covering of about 1404ha on average as per the year 2022. Flooding and high energy affected Mangroves with time series analysis showing April 2015 and December 2018 recording the highest. In conclusion, there is a positive impact on mangrove restoration efforts in Mida Creek but a few challenges still exist like off-season planting, poor species site marching, pests and diseases, livestock and climate change which derail restoration

Key words: Mangroves, Conservation, Restoration, Degradation, Cover, Mida Creek.

To harvest or not to harvest Mangroves: situation analysis for Kenya

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangrove exploitation support livelihoods for the local people in Coastal Kenya. The government of Kenya permits regulated harvesting of mangrove products in Lamu county under the issuance of licences by the Kenya Forest Service. Exploitation is guided by products demand rather than available stock within these ecosystems. This study assessed stocking rates within management blocks where harvesting is permitted. The assessed stock mainly comprised of dominant mangrove species (*Rhizophora mucronata* and *Ceriops tagal*). The merchantable densities of the dominant species were high for Mazio and Pau utilization classes followed by Nguzo, Boriti and Fito. Pate Island swamps had the highest density of merchantable poles while Southern Swamps had the lowest proportion of merchantable stems per hectare. The results revealed that merchantable stock available in harvestable areas are below annual allowable cut targets in the ecosystem and prompts the need to promote alternative or non – extractive livelihood options such as carbon credit that is gaining prominence globally. The findings will guide the development of harvesting plans to promote sustainable harvesting of mangrove resources and prevent further degradation in areas where mangrove harvesting is being undertaken.

Key words: Allowable off –take level; Resource sustainability and stocking rates

Towards sustainable tourism in protected areas: A carrying capacity study in the Hundred Islands National Park

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: The Hundred Islands National Park is both a popular tourism destination and an ecologically important protected area with unique karst forest and aquatic resources. Like all protected areas in the Philippines, the Hundred Islands is mandated to prioritize biodiversity conservation among its main goals. To balance a well-established tourism industry with its novel purpose, the management must put a mechanism in place that aims to realize and maintain this equilibrium. Presently, the Hundred Islands intends to capitalize on the tourism activity that it supports to become a protected area that is financially independent in terms of supporting its conservation initiatives. The study aims to determine the critical parameters concerning environmental and socio-economic aspects that sets the carrying capacity of the area. Also, the study profiled various aspects needed in determining carrying capacity and provided strategies and recommendations in operationalizing the carrying capacity estimates and use it to harmonize tourism and scientific activity. Furthermore, various strategies on visitor management, resource management and tourism management were identified and enumerated. In the aspect of visitor management, strategies that can help in the improvement of tourism activity and at the same time minimize negative impacts of tourists to the forest and aquatic resources as well as to the local community were identified. Among these include operationalization of the carrying capacity estimates, establishment of distinct visitor flows over time and space, and improvement of signage and key information that influence visitor behavior. For resource management, strategies that guarantee a balance and complementarity between biodiversity conservation vis-à-vis economic activities inside the park are recommended.

Trade-offs between Carbon Stock and Tourism Potential in Different Mangrove Forest Types

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Mangrove ecosystems are increasingly recognized for their potential as significant carbon sinks, contributing to global carbon sequestration efforts. However, efforts to maximize one ecosystem service, such as carbon storage, could potentially diminish others resulting in trade-offs. These trade-offs can have repercussions for local communities that rely on a diverse range of services from these ecosystems. In Thailand, mangrove boardwalks have emerged as popular tourist attractions, offering substantial support to the local economy. Nevertheless, the construction and maintenance of these boardwalks is costly, highlighting the need for a balanced approach to providing ecosystem services. This study aimed to examine the interplay of ecosystem services provided by three distinct forest types in a community-managed mangrove forest located in Eastern Thailand: old-growth *Rhizophora* stands, young *Rhizophora* plantations, and species-diverse back mangroves.

In a comparative analysis of these forests, carbon stock was assessed using standard biomass and soil carbon sampling methods, whereas forest attractiveness was evaluated through visitor surveys and analysis of boardwalk usage data.

Our results revealed that *Rhizophora* plantations exhibited high rates of carbon sequestration due to their rapid growth rates, making them a potential source of carbon credits. However, these monoculture plantations were found to be less attractive to tourists compared to old-growth and species-diverse back mangroves. Old-growth *Rhizophora* forests, despite demonstrating lower rates of carbon sequestration, held a high carbon stock and exhibited significant appeal to visitors. Moreover, the species-diverse back mangroves held lower carbon stock but still maintained high attractiveness.

These findings underscore the potential trade-offs in managing mangroves for carbon storage versus other ecosystem services. It suggests that while plantation-style rehabilitation of mangroves can enhance carbon sequestration capacity, it may diminish the tourism potential and affect other ecosystem services. Therefore, an integrated, multi-objective approach to mangrove conservation and rehabilitation is advocated. Such an approach must balance carbon sequestration goals with the need to maintain diverse, healthy mangrove ecosystems that continue to provide a broad spectrum of ecosystem services, including support for local economies through eco-tourism. Moreover, local communities should be involved in mangrove governance and management to strive for multi-functional mangrove management and ensure sustainable development.

Watershed factors contributing to the erosion of sandy coasts where coastal dune vegetation grows in Japan

T1.6 Coastal Blue Forests: Global Significance, Ecology, Management and Conservation

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Abstract: Sandy coast is one of the most important ecosystems because it has developed a unique ecosystem and has multilateral functions. Many plants adapted to the dynamic environment grow here. In addition, coastal dunes that develop on sandy coasts have attracted attention as protective barriers and buffer zones that prevent seawater from entering inland due to tsunamis and storm surges. Since the late 20th century, increased development and recreational use near the coast have caused ecological destruction and landscape degradation. Furthermore, there is concern that rising sea levels due to climate change will accelerate coastal erosion. Therefore, coastal erosion is an urgent issue for both human society and marine and terrestrial ecosystems.

Most studies of erosion on sandy coasts have used changes in the shoreline as an indicator, and little have targeted changes in the dunes behind the beach. There are also scattered studies that have measured dunes in three dimensions and measured the changing, but none have focused on multiple sandy coasts. Also, there is little study of the relationship between the changes on sandy coasts and watershed factors. This study will overcome the above issues by measuring and utilizing high-definition spatial information from high-accuracy RTK (Real-Time Kinematic) -UAVs (Unmanned Aerial Vehicles) and ALS (Airborne Laser Scanning). In this study, the amount of change (erosion and sedimentation) was calculated from the difference analysis between the DSM (Digital Surface Model) created by RTK-UAV-SfM and ALS to clarify the actual erosion of coastal dunes on the sandy coasts of Hokkaido, Honshu, Shikoku, and Kyushu, Japan. I performed a correlation analysis and generalized linear model to understand the relationship between coastal changes and Watershed variables.

As a result, there is a trend toward many coasts with erosional trends and more erosion of sand dunes. The Honshu trend toward erosion. In Hokkaido, Shikoku, and Kyushu, the amount of erosion is relatively low. Oceanic type and population density in the watershed significantly contributed to dune changes. In the future, I would like to increase the number of target watersheds, and explanatory variables to identify the actual erosion and factors contributing to it in more detail.

T1.7 Collaborating for boreal forests futures

Assessing Collaborative Strategies for Boreal Forest Futures: Insights on Carbon, Biodiversity, and Economic Consequences

T1.7 Collaborating for boreal forests futures

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Abstract: Finland and the European Union aim for carbon neutrality by 2035 and 2050, respectively. Achieving these goals necessitates innovative measures from forests to decrease net greenhouse gas emissions. We examined carbon reduction potential in the forests of Ii municipality, Northern Finland, focusing on carbon storage in living trees, deadwood and soils. The future carbon storage capacity of forests heavily depends on their management. We evaluated several management alternatives, including traditional rotation forestry (BAU) and continuous cover forestry (CCF). We also assessed the impact of these alternatives on carbon storage, biodiversity and net present value (NPV) using available data and models. Using the SIMO simulation, we predicted forest stand characteristics, carbon storage, and biodiversity indicators and NPV for 100 years Our findings suggest that the CCF management regime were more cost-effective i.e., efficiently combines carbon storage, biodiversity, and economic performances compared to BAU management regime. This study also explores how alternative forest management approaches could inform planning and decision-making processes aimed at climate change mitigation.

Carbon residence time in forest ecosystems under climate change

T1.7 Collaborating for boreal forests futures

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Abstract: Carbon residence time in forest ecosystems is an essential determinant of vegetation-atmosphere carbon interactions, reflecting the ability of the forest ecosystems to sequester atmospheric carbon and retain it bound to vegetation and soil biomass. Model predictions of carbon residence time have therefore been of importance and subject to comparisons between models and measurements, especially in relation to the global vegetation models that inform climate models about atmospheric carbon.

Carbon residence times in forest ecosystems depend on the carbon fluxes between the atmosphere and the ecosystem, mainly photosynthesis and respiration. Both depend on carbon allocation within the ecosystem: photosynthesis depends on canopy leaf area, and mass-specific respiration on the component in question. Internal fluxes of carbon, especially allocation between fine roots and wood, which is an important trade-off determined by nutrient availability, and litter input from vegetation to the soil affect the carbon allocation. Litter input can be accelerated by increasing temperatures but also by increasing tree mortality caused by increasing rates of disturbance.

In this study, we aim to quantify the impacts of climate change on carbon residence time in boreal forests. We focus on making a distinction between the underlying impacts of long-term climate change on carbon residence time in the absence of disturbance versus the impacts with disturbances due to changes in extreme weather events, that are themselves also associated with changing climate. To accomplish this, we use a process-based stand growth model, PREBAS, combined with the Yasso soil carbon model to estimate the carbon residence times in boreal forests under climate change, considering climate and CO_2 impacts on process rates and including fire damage and bark beetle damage as examples of the impacts of increased disturbance rates. We analyse the relative impacts using Impact Response Surfaces (IRS) as a scenario-neutral tool for quantifying climate change effects. We also show how IRSs of carbon residence time can be evaluated with probabilistic projections of climate change derived from CMIP6 ensembles.

Changing disturbance regimes and forest landscapes in Fennoscandia

T1.7 Collaborating for boreal forests futures

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Abstract: Climate change, combined with past and present land-use, is altering the structure and composition of forests worldwide. In the boreal forests of Fennoscandia, forest management and past land-use practices have been the main disturbance agents influencing forest dynamics. In addition, the frequency, severity and size of natural disturbances are expected to change with climate warming. Here, we analyzed the past disturbance regimes and post-disturbance recovery using three different datasets. First, changes in pre-and post-disturbance forest dynamics were analyzed on regional scale using National Forest Inventory (NFI) data from Finland, Sweden and Norway. A 30-year time series of NFI was sampled by selecting plots identified as disturbed in the Landsat-derived European Disturbance Maps to analyze the post-disturbance reorganization of forest structure. Second, the dynamics of forest landscapes in Fennoscandia under different disturbance regimes were simulated using the landscape simulation model iLand. Specifically, we tested the effects of changing disturbance size and frequency on post-disturbance recovery in a changing climate using Neutral Landscape Models that controlled for landscape structure and environmental conditions. Third, the recovery and forest dynamics after large-scale disturbance events were studied by combining historical records, remote sensing data and field inventory data from case study sites in northern Finland, each with circa 20 000 ha of disturbance events in early 1960s. Here, the focus was on long-term recovery in different parts of the large, continuous disturbance area and the different natural disturbance interactions that followed these events. The results of the studies indicate that the recovery of forest structure is relatively fast towards pre-disturbance conditions in many parts of the boreal Fennoscandia due to intensive management. Natural disturbance regimes have historically been dominated by low-severity, high-frequency disturbance events, but this has changed with forest management and fire suppression. Site characteristics, climatic conditions, and recurring disturbances determine recovery time, rate and pathway, but the size and intensity of the initial disturbance also plays a role. Natural disturbance regimes have a major impact on forest dynamics, and accelerating climate change, together with forest management practices, will play a significant role in determining how boreal forest landscapes will look in the future.

Climate change adaption: Identifying climate refugia for retreating boreal forest species

T1.7 Collaborating for boreal forests futures

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Abstract: Climate change is shifting species ranges. Cold-adapted species are predicted to contract poleward at their warm range edge under climate change. One potentially important climate adaptation tool is to identify and locate places in the forest landscape where populations of these species currently occur and can continue to occur under climate change. Such places are buffered from climate change and are called climate refugia. The identification and protection of climate refugia allows time for species to persist under climate change, adapt and disperse should the climate become suitable again. However there are still a number of knowledge gaps that hamper the implementation of this climate adaption tool. The overarching goal of this project then is to understand the premises of climate refugia and fill these knowledge gaps. We investigate how cold-adapted species are distributed in relation to different microclimate gradients, what is the role of interaction between cold-adapted retreating species and warm-adapted expanding species and what is the generality of these patterns across species and communities. To answer these questions, we use miniature microclimate loggers installed across large areas of Sweden in combination with observational and experimental field studies to investigate and model the effect of microclimate on cold-adapted boreal forest plants. This project aims to provide a solid knowledge base on how to identify and use climate refugia as potentially important climate adaption tool.

Combining Active and Passive Spaceborne Measurements to Estimate Circumboreal Forest Growth

T1.7 Collaborating for boreal forests futures

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Abstract: Northern Hemisphere forests are currently subject to the most rapid warming on Earth from climate change. Since the last ice-age they have stored more atmospheric carbon than they have released, but their current fate is uncertain. Here, we estimate young boreal forest vertical growth as a baseline indicator of resilience to climate warming using ~49.7 million, 20 m height of canopy (hcan, 98% height profile) geo-segments collected at night from the Advanced Topographic Laser Altimeter System (ATLAS) onboard the Ice Cloud and Elevation Satellite 2 (ICESat-2) combined with Landsat stand age data from over 224,000 scenes spanning the period of 1985 – 2020 in a *space-for-time* substitution approach. Strong patterns of growth were apparent when calculated over a 0.5° × 0.5° grid. These empirically derived estimates provide a biome wide gridded reference to constrain estimates of boreal forest vertical growth which is important to provide a reference estimate of current above ground biomass accumulation.

Development of a Climate-Sensitive Matrix Growth Model for Larix gmelinii Mixed-Species Natural Forests and Prediction of Forest Dynamics

T1.7 Collaborating for boreal forests futures

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Abstract: *Larix gmelinii* natural forests, which are of great ecological and economic importance, are mainly distributed in northeast China. Sustainable management of these forests play a vital role in ecological security in northeast China, especially in the context of climate change. Forest growth models, which support forest management decision-making, are lacking for *Larix gmelinii* natural forests, hampering the prescription of forest management strategies. In this study, we produced a climate-sensitive, transition-matrix model (CM) for *Larix gmelinii* natural forests. For comparison, a variable transition model without including climate change effects (NCM) and a fifixed-parameter model (FM) were also built. We examined the performance of the CM, NCM, and FM by conducting short- (5 years) and long-term (100 years) simulations. The results showed that for short-term prediction, no signifificant difference was observed among the three predictive models. However, the long-term prediction ability of the CM under the three different RCPs was superior to that of the FM and NCM. The number of trees and basal area were predicted to increase under climate change, which might result in natural disasters, such as snow break, windthrow, and forest fire. Silvicultural practices, such as reducing the intermediate thinning interval and the enrichment planting of slow growing trees, should be implemented to mitigate the deleterious effects of climate change.

How does forest fertilization influence tree productivity of different boreal forests? An analysis of data from commercial forestry across Sweden

T1.7 Collaborating for boreal forests futures

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Abstract: Forest fertilization is a forest management technique that is often claimed to be the most effective to increase productivity in boreal forests. It is however also costly, can have negative effects on biodiversity, and may increase nitrogen leaching from the soil. To underpin the development of more cost-efficient forest fertilization regimes that encompass the goals of improved productivity while simultaneously limiting the negative impact on the environment, we conducted a study to better understand under which conditions forest fertilization stimulates tree growth the most. We used a dataset containing data from 24 839 recently harvested stands from the largest forest owner in Sweden and assessed the effect of fertilization on standing tree volume at harvest and how it varied depending on stand characteristics (stand index, stem density), climatic conditions (temperature sum) and management (thinning, stand age at harvest). We found that fertilization improved productivity, but the efficacy of fertilization was highly context-dependent. In pine-dominated stands, fertilization did not increase tree volumes in the coldest areas and in the least productive stands. In spruce-dominated stands, fertilization generally increased tree volumes in unthinned stands, but no fertilizer effect was found in thinned stands. And while the difference between fertilized and ambient stands that we found in pine-dominated stands (on average 15.8 and 17.3 m^3 ha^{-1} in respectively thinned and unthinned stands) was in line with previously reported growth responses to fertilization (13-20 m^3 ha^{-1}), fertilization responses in unthinned, spruce-dominated stands were lower (11.4 m^3 ha^{-1}). Standing tree volumes at harvest did not differ between thinned and unthinned stands when they were dominated by spruce, suggesting that in these stands, stimulated growth after thinning and/or higher natural mortality in the unthinned stands compensated for the extracted volume. Although our results are largely in accordance with current fertilization recommendations, they indicate that current practices can have economic and ecological costs that may outweigh limited benefits. Updated recommendations could both benefit forest owners and reduce potential negative side effects.

How water moves in boreal forests from snow/rainfall to tree under changing seasonal precipitation: in-situ water isotope and water flux measurements

T1.7 Collaborating for boreal forests futures

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Abstract: High latitude regions are warming more strongly than the global average with apparent changing precipitation seasonality. The latter includes warming-induced shifts from snowfall to rainfall, more frequent rain-on-snow events, and less summer rainfall. These do not only directly change the amount and the timing of regional water inputs by reduced winter snow and more variable summer rainfall, but could also alter how water goes through and exits boreal ecosystems, e.g., snowpack formation, sublimation, snowmelt, soil water movement, root water absorption, and tree water use. In boreal forests, c. 65% of the water being 'pumped' from soil to atmosphere (evapotranspiration) is done so through tree water use (transpiration). However, how boreal tree water use strategies and the affected northern ecohydrological processes respond to the ongoing rapid change in snow and rain is not well understood. Improving this understanding is critical as boreal forests are the second largest biome worldwide and have evolved under high precipitation seasonality. Currently, for tracing water movement and the water sources involved, the stable water isotope technique is the best tool available to researchers. Compared to the discrete, time-consuming, and destructive water isotope sampling method in snow, soils and plants, in-situ and high-resolution measurements are more needed than ever to investigate tree water use strategies, especially to understand the underlying mechanisms. Therefore, for the first time in northern environments, we are applying innovative in-situ continuous measurements of stable water isotopes (non-destructive Water Isotope Probes and Picarro L2140-i isotope analyzer) and water fluxes (bi-directional heat pulse sap flow sensors, soil water content, etc.) along the water movement pathway in boreal forests, i.e., snow (snowfall - snowpack - snowmelt), event-based rain (rainfall - throughfall), soil (vertical and horizontal), roots, and stems. These measurements are performed in typical boreal forests in Finland around the Arctic Circle (Oulanka Research Station and Pallas catchment).

Land-based Negative Emissions in the Boreal – Potentials and Challenges of Multi-Purpose Afforestation

T1.7 Collaborating for boreal forests futures

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Abstract: Climate warming is considered the major problem to date. The Paris Agreement aims at maintaining global warming well below 2 deg C by the end of the century. In its 1.5 deg special report, the IPCC projects a very limited window of opportunity to live up to the Paris Agreement. In order to do so, in addition to reaching zero net emissions by 2050 on a global scale, negative emissions (NEs) in the dimension of 600 Gt might need to be created between – latest between 2050 and 2100. To date, several greenhouse gas removal technologies (GGRs) or negative emissions technologies (NETs) exist including Enhanced Weathering (EW), Bioenergy with Carbon Capture and Sequestration (BECCS), Direct Air Capture (DAC), Biochar and Afforestation/Reforestation/Restoration. However, relevant parameters including the effectiveness, (both for climate and technology), energy and water demand, land availability, environmental sustainability, and public acceptance, as well as ramp-up time (to name a few) of NETs are investigated and understood at different levels and intensities. Moreover, these parameters are also discussed rather controversially.

This study aims at identifying the potential net negative emission contribution that can be achieved by large-scale and multi-purpose afforestation/reforestation in the boreal Ecotone inter alia on abandoned agricultural land and area burned from wild land fires. A combined remote sensing/GIS approach coupled with biophysical forest and forest fire modeling will be applied to identify potential afforestation locations in boreal forests.

Northern Eurasian forests in the face of global change

T1.7 Collaborating for boreal forests futures

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Abstract: Climate changes make Northern Eurasia (NE, limited here to territories of the Russian Federation) a hotspot of global meaning concerning problems of adaptation of forest ecosystems to, and mitigation of, environmental change. The beginning of 21st century highlighted the risks and challenges related to this giant region of the Earth because *inter alia*: 1) the rate of warming in 1976-2020 was about 2.5 time faster here than the global one; 2) the observed increase of precipitation in vast regions is not able to compensate the increase of temperature; 3) the thawing of permafrost may provide an explosive increase of C emissions because C stock only in permafrost of high latitudes from Ural to Pacific exceeds 500 Pg C, mostly in form of methane; 5) variability of weather, the long and intensive heatwaves and droughts, lead to weakening the resilience of forests and explosive increase of natural disturbances. The disturbance regimes in forests substantially intensified in 2000-2020s: the area of wildfire increased at 3 time; outbreaks of dangerous insects are shifting towards the north at 200-300 km; and carbon sink of forests declined.

The future conditions for NE forests are homogeneous, but mostly not favorable, and in some large regions – critical, where forest likely will reach tipping point. The favorable conditions will be only in regions have satisfactory precipitations, and the fertilization effect of e[CO2] here is also very likely. The major part of NE forest zone will suffer from water stress, dramatic intensification of disturbance regimes, and direct impact of increased temperature. Particularly heavy conditions are expected in southern parts of mid-latitude NE ecotone where basic climatic scenarios promise future climates of dry steppe up to the 60th degree of NL.

The future climates will critically aggravate the problems which NE forests are facing now. There is an urgent need of development of a national strategic program of forest sector's transition to sustainable forest management resilient to future regime of disturbances. The presentation outlines major directions and components of such a program and discusses possibilities of its implementation.

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

A Measure of Structural Complexity: its Mathematical Properties and Regional Patterns

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: In recent years, some authors have proposed using the ratio of the additive version of Reineke's Stand Density Index to the original version, or simple transformations of that ratio, as measures of stand structural complexity. We highlight some of the mathematical properties of this measure, including its relation to the shape parameters in a broad family of diameter distribution functions, and the connection with apparently dissimilar measures such as the coefficient of variation of the diameter distribution. The form of the complexity measure suggests that it could be generalized, within a family of similar measures that includes easier-to-calculate members. Finally, we illustrate the behavior and pattern of the structural complexity measure across the lower 48 United States. The results suggest that the measure does provide a useful, simple description of structural complexity. They also have strong implications for attempts to describe stand density quantitatively in landscapes where complex stands are surprisingly common.

Adapting production forests to climate change: The repercussions to biodiversity and ecosystem services of the resilience-path chosen

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Production forests provide humanity with essential ecosystem services ranging from wood products and carbon sequestration, to environments for recreation. In many countries production forests also provide the majority of forest area for biodiversity. The ecosystem services and habitats provided by production forests are however increasingly threatened by the impacts of anthropogenic climate change, which are expected to fundamentally alter forest characteristics over the coming century. Ensuring that production forests retain their desired development state despite climate change is often framed in terms of enhancing their 'resilience'. Whereas resilience has many definitions in the environmental sciences, it is usefully defined as "the capacity of a system to absorb disturbance and reorganize while undergoing change so as to retain essentially the same function, structure, identity, and feedbacks" (Walker, 2004). In complex forests systems, the source of resilience is frequently linked to the ecological processes and feedbacks – so called 'ecological resilience' - that arise from biological diversity and the regulatory services that result. Production forests are however not just ecological systems, but social-ecological systems, for which anthropogenic sources of resilience – so called 'coerced resilience' (sensu Rist et al., 2014) – may also be tapped into. This often becomes a necessity, as the ecological character of production forests can be heavily altered by human actions, often in an attempt to standardize and simplify natural variability and thereby ensure the predictable delivery of forest biomass. In such cases, highly modified production forests can via anthropogenic efforts rather than ecological processes, return to a pre-disturbance state and thereby mimic the response of resilient complex natural systems. The availability of these two sources of resilience has created a choice when adapting production forests to climate change: A choice which readily equivocates between fundamentally different sources of resilience, and fundamentally different outcomes with respect to resultant forest complexity. Here we highlight important distinctions between these two climate change adaptation and forest complexity pathways, and their potential ramifications for biodiversity, ecosystem services, and the sustainability of production forests this century.

Analyzing spatial distribution of crop trees in spruce-birch mixed stands before precommercial thinning

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Mixed forests provide a wider range of ecosystem services and are in many cases more resilient compared to single species forests. Thus, mixed forests increase the diversity of forests and may mitigate the effects of climate change. The distribution of the mixture affects the development of the trees, the competition between trees and their resource allocation. In addition, the distribution of the trees delineates the possible structures of mature stands. When moving from the random distribution of species towards a clustered pattern, the forest structure begins to resemble a single species forest. Thus, the benefits of admixture might be lesser in clustered stands. Therefore the structure of mixed birch-spruce sapling stands was analyzed.

Measurements were conducted at 9 managed juvenile mixed spruce-birch stands located in Central and Southern Finland. All stands were planted with Norway spruce, and birch admixture had emerged naturally. 2 circular plots of 0,05 ha were established on all stands totaling 18 measured plots. In each plot, all crop trees were charted and measured. The distribution of trees was analyzed using Ripley's L-function and patterns of intermixing of species were analyzed using Ripley's L_{12}-function. The trees were distributed dispersedly on short observation distances, but as distance increased, the distribution shifted to random. When examining the tree species separately, such behavior was observed only on Norway spruce. The distribution of birch was random on all observation distances. When examining the intermingling of different tree species using L_{12}-function, no patterns were found.

Findings suggest that utilizing naturally regenerating birch as admixture on spruce stands creates mixed stands where no apparent gaps are present. Slight differences of distribution between tree species are most likely explained mostly by regeneration methods. There were no sings of different tree species being clustered, suggesting random tree wise mixture. There is need for further research on how different mixing patterns affect the development of the stand.

Assessing emerging changes in functional characteristics of European forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: European forests cover more than one third of the continent, providing intimate linkages with the climate system, water, soil and biodiversity, ultimately playing a crucial role for Europeans' well-being. The services that forest provides to Europeans directly depends on the forest composition and structure. The way tree communities organize themselves in response to environmental conditions ultimately lies in their functional strategies. Tree functional strategies are the evolutionary adaptations that species developed in the way they use available resources, influencing biogeochemical cycles, ultimately affecting ecosystem functioning and stability. There is extensive evidence that the effects of global warming, the observed increase of forest natural disturbances, and their interactions are causing disruptions of forest ecosystem functioning by prompting tree mortality, which is the main driver of changes in forest community functional assemblages. Although knowledge on species functional traits increased, a lack of comprehensive species-specific data and temporal trends is hampering the understanding of forest functional dynamics response to environmental changes and its application in management decisions. Here we tested how functional composition (assessed using synthetic indexes of hyperdimensional niche occupancy) changed in European forests over the past ~20 years. We used more than 120.000 georeferenced trait observations to train models to predict a wall-to-wall dataset of 20 important functional traits for 150 European tree species. We combined this trait data with a unique dataset of >210.000 remeasured National Forest Inventory (NFI) plots in 13 countries to assess the temporal changes. Using such wide, ground-measured datasets we were able to assess with high accuracy European forest's functional changes. Those results highlight the regions where functional changes happened in Europe in the last decades, both in a positive and negative way. Moreover our findings allow for assessing further what are the drivers of change (e.g. climate, disturbance or management?), paving the way to design management alternatives based on the most intimate linkage between trees and ecosystem functioning in the era of climate-change.

Challenging Assumptions: A Comparative Analysis of Handheld and Unmanned Laser Scanners for Accurate Tree Height Measurements in Mixed Forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: This research examines methods for tree height measurements in mixed forests, with a particular focus on comparing handheld laser scanner (HLS) and unmanned laser scanner (ULS) techniques. We experimented with several scanning approaches, starting with a handheld laser scanner (HLS) and subsequently employing an unmanned laser scanner (ULS) at four varying altitudes (50, 70, 90, 110 m), performed with different scan frequency (dual and triple-echo). The investigation features a case study involving data obtained from a 1-hectare marteloscope situated in a complex, terraced mixed forest region in Portugal. The paper offers a detailed analysis concerning a frequent assumption cited in various studies, which postulates that height measurements from ground-based sensors show a systematic underestimation of heights, due to occlusions created by leaves and crowns. We aimed to provide a differentiated understanding of the results associated with different flight altitudes and ULS return numbers and the potential need to harmonize the HLS and ULS point cloud data, with the data obtained from the HLS alone. Our findings indicate that neither the flight altitude nor the number of returns from ULS significantly influence the tree height measurements obtained. The fusion of data led to an average height increase of 20 cm per tree, but it's important to note that this increase does not indicate a reduction in HLS-associated errors. Instead, it could beassociated with an increase in noise and variations in the alignment among point clouds. Contrary to common belief, our results demonstrate that HLS does not underestimate tree heights in this type of forestFurthermore, the ULS can operate effectively at heights up to 110 meters, expanding the coverage area without affecting the quality of results. Additionally, it became evident that merging point cloud data does not necessarily improve height measurements. Therefore, the choice of the sensor should primarily be driven by the unique objectives of a study, as each sensor provides distinctive characteristics and results.

Selected references

Climatic effects on the growth of Fagus sylvatica L. in mixed stands with Pinus sylvestris L. in Lithuania

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Climate change and warming will potentially have profound effects on forest growth and yield. However, climate change is not only a threat, but also an opportunity for tree species to be more productive or colonize new territories where previously they were fragmented or absent.

European beech (*Fagus sylvatica* L.) is a dominant and very important tree species in European forests with a pronounced ability to grow on a great variety of sites and to form mixtures with other tree species due to its shade tolerance. Only a few studies have analysed its growth to changing climatic conditions outside its natural gradient to the north.

The aim of this study was to clarify the main growth patterns and tree ring formation characteristics of beech in mixed stands with Scots pine (*Pinus sylvestris* L.) located outside its natural gradient. Analyses were carried out in six two-layered Pine-beech stands in the western part of Lithuania. The total area of the forest stands made more than 10 hectares. After shelter wood cuttings as well as gap formation, we collected more than six hundred cross cuts of the beech. Cross cuts were taken above the root collar. After thoroughly polishing the disks' surfaces, we measured the tree-ring widths of the sample trees in two directions (North and East). Measurements were done with the "LINTAB 6" system and the program package "TSAP-Win 0.30". Accordingly, from the closest meteorology station, located in Šilute we collected and tested the impact of following climatic data to tree ring formation: annual precipitation, mean annual, absolute minimal and absolute maximal temperatures, as well as effects solar radiation amounts.

Analyses of the changes in monthly meteorological parameters and their effect on radial increment showed that increasing temperature trends of summer months together with decreasing precipitation during the vegetation period could have stronger negative consequences growth and survival of the species. Therefore, recent climatic changes are prospectively not in favour for European beech. However, trees of this species successfully grow in the western part of the country and produced additional 200 m^3 per hectare in stand structures like the analysed mixed pine-beech stand.

Comparing natural disturbance and forest management parameters as a reference for multi-functional silviculture in Europe

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: In Europe, there has long been interest in natural dynamics silviculture (NDS) to provide a full spectrum of seral habitats and structural conditions required by forest biodiversity, including species that are poorly represented in intensively managed forests. NDS aims to emulate natural disturbance dynamics at stand and landscape scales through silvicultural manipulations of forest structure and landscape patterns. However, adoption of NDS has been limited by incomplete understanding of the ranges of variability in disturbance regimes, including frequencies, spatial attributes, and severities. Addressing this constraint in European forest management, we adapted a "comparability index" (CI) that was first developed in the US to compare natural disturbances and forest management effects. We extended the original concept that included spatial and temporal axes by adding disturbance severity (i.e. tree survivorship or retention) as a third dimension. We populated the model by compiling published data on disturbance dynamics for four major forest types (i.e. spruce, beech, oak, and pine-dominated). Data on silvicultural systems by country and

forest type were obtained through an expert-based process employing standardized estimation protocol. The data for both natural and harvest disturbances were visualized in three-dimensional plots indicating ranges for frequency, size, and severity. We developed an algorithim to calculate the index values for bivariate comparisons. The results indicated that natural disturbances are highly variable in size, frequency, and residual structure, but European forest management fails to encompass this complexity. The residual structure parameter proved crucial in the comparison of natural disturbances and silvicultural systems. The CI showed the highest congruence between uneven-aged silvicultural systems and key natural disturbance attributes. Even so, uneven-aged practices emulate only a portion of the complexity associated with natural disturbance effects. The remaining silvicultural systems perform poorly in terms of retention, especially, as compared to tree survivorship after natural disturbances. Our results and the CI will help European forest managers to expand their portfolio of silvicultural systems to manage for complexity and habitat diversity at multiple scales, while providing a broad array of ecosystem services. We suggest a holistic approach integrating natural dynamics silviculture with more conventional practices.

Comparison of horizontal forest structure between virgin and managed forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Horizontal forest structure can be defined as the mosaic of forest patches. In virgin forests horizontal structure is as a result of i) processes of growth, regeneration, and tree mortality, and ii) natural disturbances influencing those processes. In managed forests patch pattern depends in great extent on the silvicultural system applied. Close-to-nature silviculture (CTNS) is characterized by natural regeneration and mimicking natural stand dynamics. The main aim of our study was to compare the horizontal structure of virgin forest (VF) and managed forest (MF) in which CTNS, combining elements of the irregular shelterwood and partly of the selection silvicultural system, has been applied for more than a century. We hypothesized that in the MF i) the patchiness and ii) vertical heterogeneity of patches are higher, iii) while the top height of patches in MF is lower in comparison to that in the VF. The study was performed in the Dinaric Mountains (Slovenia, the Rog areas, 22,776 ha, silver fir-European beech forest type with three virgin forest remnants). We used a TBk toolkit developed at the BFH to automate stand map creation based on LiDAR data. The objective delineation of stand patches enabled comparison of the size of patches and their structural characteristics (e.g. top height, coverage of four canopy layers, tree species composition) between the VF and MF. In the VF the average patch size is significantly larger, and top height of patches is significantly higher in comparison to that in the MF. In both objects small patches (0.05-0.5) prevail. However, the relative frequency of very small patches (<0.05 ha) and very large patches (>20.0 ha) is much larger in the VF, while the opposite is true for the medium sized patches (2-20 ha). In the final model of patch size, the variables describing coverage per canopy strata, dominant height of patches, index of vertical heterogeneity and the management treatment (VF, MF) – the latter as a dummy variable – were included. Current studies of horizontal structure were based on field mapping. The novel approach can contribute to the objective study of horizontal structure, enabling comparison of results between various forest types.

Dependence of broadleaf tree diversity on stand age and landscape structure: lesson from long-rotation and uneven-aged sugi plantations

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Conifer plantation forestry in Japan has partly been recommended to shift from short-rotation forestry (ca.40 years) of even-aged monoculture to uneven-aged forestry with small-scale clearcutting or long-rotation forestry for sustainable forest management. However, it is still unclear how these alternative forest management can contribute to promote the complexity of stand structure and the tree species diversity. We investigated broadleaf tree population in an old sugi plantation (137-year-old) and uneven-aged sugi (*Cryptomeria japonica*) plantations (including 4 to 80-year-old patches) in southern Japan, and evaluated the contributions and its limitations of long-rotation and small-scale clearcutting to the diversification of stand structure. The old sugi plantation had high richness of tree species equivalent to that of old-growth natural forests of the region. The size structure of broadleaf trees was also similar to the old-growth natural forests even growing beneath the sugi canopy layer, indicating that the canopy height as well as stand age is the key factor of promoting high structural diversity. However, species composition of the old plantation was not same as old-growth natural forests because of limited recolonization of trees with gravity-dispersal seeds (such as acorns) even under the canopy gaps created by natural disturbance. Uneven-aged patches also demonstrated a clear age dependence of the broadleaf trees colonizing in understory; older patches contain higher richness and abundance of trees those originally inhabit in natural forests rather than in disturbed sites. Forest edges created by small-scale logging mitigated the “stem exclusion” of colonized trees by improving the light condition under the thick canopy of the younger patches. Further, several shade tolerant species were thought to be maintained as metapopulations in the uneven-aged patch mosaics. However, the colonization of gravity-dispersed species was limited even in the older patches with improved light conditions. We concluded these case analyses that the long-rotation and uneven-aged forestry by small-scale clearcutting is effective for diversifying size structure and composition of broadleaf tree population in conifer plantations, and that the retention or restoration of effective seed sources at the landscape level is crucial for maintaining the population of gravity-dispersed trees even under in the uneven-aged forestry.

Does thinning intensity modify soil carbon stocks in a Mediterranean mixed forest?

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Mixed-species forests are reported to be more productive and can better provide ecosystem services than monocultures, which is of great importance for climate change mitigation. Management by thinning to reduce the stocking density is required to control competitive conditions and avoid the expected high mortality rates in mixed forests, while maintaining species proportion and the benefits of the admixing. Thinning is becoming one important measure for adapting forests to climate change, since it can mitigate the effect of extreme drought events. In this context, where soil carbon sequestration is one of the ecosystem services that may benefit from mixing due to the above and below-ground niche complementarity of tree species and their different type of litter inputs, practitioners should be clear about the effect of forest management. Thinning was expected to reduce the soil carbon stocks, with the most significant impacts in the forest floor and generally non-significant effects in the mineral soil, although the effects were usually dependent on forest and soil type, thinning intensity and time after treatment. In order to gain insight into the effects of forest management on soil carbon stocks, a thinning trial on a common Mediterranean mixture found in the Spanish mountains (Maritime pine – *Pinus pinaster* Ait.- and Pyrenean oak –*Quercus pyrenaica* Willd.-) was studied. In this trial, pine trees come from plantation in the 70's, while oak trees are sprouts from a previous coppice forest cleared in the soil preparation process. Two thinning intensities from below (moderate and heavy) and a control were compared. In 2010, thinning was applied only to pine trees. Forest floor were collected considering organic material until 2 cm of diameter, and mineral soil were sampled in the same place to a 30-cm depth. As main results, we didn't find any significant reduction in soil carbon stock at the mid-term after thinning, hypothesizing that since there was not a great stocking reduction, litter inputs have been recovered in a few years, and the modification of soil microclimate conditions or those soil affections by management were not so important to accelerate organic matter decomposition.

Does tree species mixture shift intra-annual growth response

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Species mixture is frequently studied at the stand level and mixed stands have been reported to have a higher productivity, to reduce risk and to be beneficial for biodiversity and to be able to mitigate climate change impact. Species mixture is less frequently studied at the individual tree level and here studies of intra-annual growth have the highest temporal resolution and the closest relation to climate explaining most of the variation. Band dendrometer data of six tree species namely (*Picea abies* (L.) Karst., *Pinus sylvestris* L., *Larix decidua* Mill., *Abies alba* Mill., *Fagus sylvatica* L., *Quercus spp. (Quercus petrea* (Matt.) Liebl. *Quercus robur* L.) were sampled on five sites in mixture and in the respective pure stands for 6 to 10 years. The elevations of the sites varied between 400 and 1530 m above sea level, and the mean annual temperature of sites varied between 6.0 and 10.1 °Celsius, with annual precipitation sums of 490-1580 mm. Sites were not only very diverse in elevation and climate, but also with respect to soils and geology encompassing Planosols on flysch, Cambisols on granite and rendzic soils. Generalized additive mixed models were fit to the data encompassing a component for intra-annual growth, shrinkage and swelling and daily water uptake from the plant. The growing season was longer on the cooler and more humid sites and the highest growth rates were observed earlier for the deciduous species. Species effects however differed between years and so did mixture effects, which could be positive or negative. Mixture also shifted the seasonal growth pattern but only by few days.

Effects of forest structure on insect community assemblages in a large-scale experiment – a trait-based approach

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Structural diverse forests with the shading and buffering function of the canopy provide a heterogeneity of local microclimates, which is especially important for insects operating on small spatial scales and directly depending on external heat sources. However, forests shaped by human needs are usually focused on maximizing timber production and therefore very homogeneous in age, structure, and consequently microclimatic conditions. Trait-based approaches explaining the connection between functional traits and climatic parameters have earned attention in past decades. We aim to gain a more mechanistic understanding of how insect species assemble in and respond to variation in forest structure, which is essential in the context of ongoing loss of biodiversity. We tested the response of coleopteran, heteropteran and lepidopteran insect communities from 503 temperate forest sites throughout Germany to mean annual temperature, canopy openness and direct solar radiation. Further, we systematically enhanced the forest heterogeneity by creating gaps in four forestry regions in Germany and investigated their effects on nocturnal Lepidoptera in a large-scale experiment over two to four years. Subsequently, we analysed the whole moth community and also measured several individuals belonging to four species to also enlighten within-species responses to canopy openness, which is often neglected in the field of species community analyses. Linear mixed effect models reveal in forest insect communities a decrease in body size but an increase in colour lightness with increasing annual mean temperature. However, both traits decreased with increasing canopy openness. Further, there were no consistent coherences between the traits and canopy openness between moth families, which indicates that the composition of insect communities in forests is shaped by diverse processes. Our results indicate that canopy cover is strongly affecting insect communities by altering local climates. Influenced by climate change e.g., due to more frequent disturbance processes, canopy cover should seize more consideration in climate-biodiversity studies. Increased attention should be paid to forests' structural heterogeneity, for example by creating forest gaps, promoting forest biodiversity through an increased supply of resources and variability in microclimate.

Effects of neighbourhood tree species diversity and stand density on drought-induced mortality in European forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Unprecedented tree mortality occurred in recent years (2018-2020) in Central European forests as a consequence of drought and heat waves. Forest scientists and practitioners are seeking for strategies to mitigate further mortality in existing forest stands. One frequently mentioned option is the promotion of tree species richness in forests. When compared to monocultures, mixing tree species can promote resistance and resilience of growth in relation to droughts. However, it is unclear if there is also a positive effect on tree survival.

Here, we investigated how plot and neighbourhood tree species richness, species composition and stand density affected tree mortality and also growth performance prior to death. For this purpose, we made use of the FunDivEurope exploratory platform, which consists of a plot network of mature forests in six European countries with diversity gradients from monocultures to six tree species, covering boreal, temperate and Mediterranean forest types. To reconstruct whether death occurred as a sudden event or was already indicated by a long period of declining growth performances, we analysed tree rings from dead trees and related the growth performance of dead individuals to their neighbourhood diversity and competition. Tree species richness, species composition and stand density served as main variables predicting mortality rate in our mixed model analysis.

The design of our study is suited to disentangle tree diversity and stand density effects on tree mortality. Accordingly, our results will allow us to elucidate how drought-induced mortality can be mediated by steering stand density in mixed forests. In addition, we provide information on which species combinations are most suitable to reduce drought-induced mortality in mature forests.

Enhancing tree species diversity in boreal forests: a large-scale simulation study in Sweden and Finland

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Species diversification is an effective strategy to mitigate risks posed by climate change and natural disturbances as well as can benefit biodiversity. It can be implemented at both the stand level, where forest stands consist of multiple tree species, and at the landscape level, which includes mixed species stands and monocultures of different species. However, in boreal Sweden and Finland, there are limited options for native species with high biomass production potential. Scotch pine (*Pinus Sylvestris)* and Norway Spruce *(Picea Abies)* dominate the growing stock, followed by birch species *(Betula spp.)* in third place with a smaller share.

This study examines the potential for increasing species diversity by substantially increasing the share of birch both through monospecific plantations and mixed spruce-birch stands, as well as the share of mixed pine-spruce stands in Gävleborg and Västerbotten counties (Sweden) and Päijät-Häme and Kainuu regions (Finland). The Swedish Heureka and the Finnish Motti decision support systems are used to simulate forest development under various scenarios, including species diversification and different management intensities.

The study utilizes plot-based data from the National Forest Inventory of each country as the initial state. It focuses on the speed of species composition change and the impact on timber harvests, including species composition, total volume, and financial value. The results indicate that achieving substantial species composition change without premature harvesting requires a significant amount of time. The production and economic impacts show a moderate reduction in growth, harvests, and financial value. These negative impacts should be weighed against the multiple direct and indirect benefits of mixed forests, such as enhanced resilience and improved biodiversity conditions. In addition, future tree improvement programs are expected to enhance the growth of birch and its competitiveness compared to spruce.

Evaluation of growth models for mixed forests used in Swedish and Finnish decision support systems

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Interest in mixed forests is increasing since they could provide higher benefits and positive externalities compared to monocultures, although their management is more complex and silvicultural prescriptions for them are still scarce. Growth simulations are a powerful tool for developing useful guidelines for mixed stands. Heureka and Motti are two decision support systems commonly used for forest management in Sweden and Finland respectively. They were developed mostly with data from pure stands, so how they would perform in mixed stands is currently uncertain. We compiled a large and updated common database of well-replicated experimental research sites and monitoring networks composed by 218 and 1,160 plot-level observations of mixed stands from Sweden and Finland, respectively. We aimed to evaluated the accuracy of Heureka and Motti basal area growth models in those mixed-species stands and to detect any bias in their short-term predictions. Basal area growth simulations (excluding mortality models) were compared to observed stand-level values in a period-wise process with update of the start values in each period. The residual plots were visually examined for different stand mixtures: Norway spruce (*Picea abies* Karst.)-birch (*Betula* spp), Scots pine (*Pinus sylvestris* L.)-birch and Scots pine-Norway spruce. We observed that the basal area growth models in both decision support systems performed quite well for all mixtures regardless of the proportion of species. Motti simulations overestimated growth in Scots pine-Norway spruce mixtures by 0.063 $m^2 \cdot ha^{-1} \cdot year^{-1}$ which may be acceptable for practical use. Therefore, we corroborated that both decision support systems can be currently utilized for short-term forest growth simulation of mixed boreal forests.

Exploring complexity: Integrating experimental and observational infrastructures to enhance forests understanding and inform management strategies

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Changes in forests are spatial and temporal dependent so a careful experimental and observational design is crucial in forest research. Long-term experimental and observational plots' networks provide unique insights into forest dynamics both in trends and quantitative level. Such research facilities provide information on forests stand that cannot obtained in small temporary plots. However, strategical, tactical, and operational forest inventories may effectively complement data from observational experiments collected over long time periods. The combination of the casual relationships uncovered with observational plots with experimental site generates key knowledge. Such insights under current global change situation are essential for understanding the long-term effects on stand dynamics and for developing adaptive forest management strategies at different spatial and temporal scales. Different challenges are faced by researchers that want to establish and maintain observational and experimental plots' networks to foster forest research. Examples of such challenges are (1) long term maintenance of plots' network securing enough funding, social engagement (stakeholders, public opinion,…) during long term periods, (2) use data from facilities deployed for old objectives and research question several years (if not decades) after its establishment, (3) effective collaboration with other scientists and data sharing policies development, (4) maintain representativeness of the facilities while environmental conditions and managerial schemas are changing. Different types of observational and experimental facilities have been used in the past. Examples of such facilities are plots (temporary, interval and permanent) networks across forest types, paired and triplet plots networks, Nelder wheels, structural modification (thinning and pruning) experiments, diversification plantations and natural regeneration experiments. Examples of observational and experimental facilities from different ecosystem types, research questions address, and managerial approaches are presented, and its trade-off discussed. Finally, challenges related with data analysis on these facilities on large spatial and temporal scales are discussed.

Exploring Intra- and Interspecific Interactions in Forest Ecosystems through Triplets: A Global Initiative

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Research on mixed forests vs monospecific species has consistently highlighted the importance of mixed forests in providing greater stability and higher productivity compared to pure stands. Different triplets' networks have been deployed in temperate forest ecosystems during the last decades for insight into mixture development. Based on our experience studying intra- and interspecific interactions in mixed stands using triplets' networks, we are currently developing a global triplet network. The plots within our triplets' networks are meticulously defined. In pure stands, the main species should account for a minimum of 80-90% of the basal area, while in mixed stands, one species should not exceed 70% and the other species should remain below 30%.

To expand the current knowledge and increase globally the awareness of developing and sustaining mixed forests we are analyzing intra and interspecific interactions in different forest ecosystems, based on species functional traits such as shade tolerance, wood density, or drought tolerance. Our network seeks to address key questions related to stand productivity, stress resilience, and the annual mixing effect. Currently, we have selected triplets of pure and mixed forests globally, consisting of shade tolerant and intolerant species. Triplets are in Europe, America, Africa and Asia covering different boreal, tropical and temperate forests. Triplets' data obtained are statics (no growth measurements) or dynamics (growth obtained by extracting increment cores or, in other cases, conducted multiple inventories over time)

We invite researchers to join our collaborative Triple Network aimed at investigating the dynamics of mixed and pure forest stands worldwide. By joining our Triple Network, researchers can contribute their expertise and contribute to a comprehensive understanding of the dynamics and ecological implications of mixed and pure forest stands.

From energy to species diversity: A mechanistic investigation

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: The distribution of species richness across the globe, particularly the gradient from the tropics to the poles, has been a longstanding interest of ecologists, especially concerning the mechanisms behind this distribution. This project focuses on the mechanisms relating to ecosystem energy availability and the corresponding abundance and species diversity at various trophic levels. We investigate the intermediate processes and patterns that contribute to the relationship between energy availability and species diversity at multiple trophic levels. To determine the constraints on energy flow between trophic levels, this project uses ecological efficiencies found from various literature sources to estimate the biomass potential for trophic guilds, following a bottom-up approach. Using an energy budget approach, we connect the estimated biomass values to richness estimates using species accumulation curves as well as determined correlations between richness at different trophic levels. In the process of creating this multitrophic energy and richness budget, this project collects and organizes data from numerous sources relating to trophic interactions of various organisms as well as quantified relationships between energy availability, abundance, and richness that will prove to be a useful compilation of data to researchers interested in investigating, modeling, and understanding complex forest trophic webs. This research also provides a quantitative approach to a theoretically dominated research field by using the theoretically developed pathways and relationships from species-energy theory approaches and overlaying values collected empirically to investigate and quantify these relationships.

Functionally dominant species and species richness mediate the effect of structural diversity on aboveground biomass in tropical forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Despite mounting empirical evidence regarding the positive effects of forest structural diversity (STR_{DIV}) on forest functioning, the underlying biotic mechanisms and controlling abiotic factors remain poorly understood. We provide the first assessment of the interactive effects of S_{DIV} and diversity in species and species functional traits on aboveground biomass (AGB) in various types of natural forests in West and East Africa. Using data from 276 plots and 7993 trees of 207 species distributed across major climatic zones of Africa and structural equation modeling, we evaluated how taxonomic and functional diversity attributes mediate the relationship between STR_{DIV} and AGB, while accounting for the effects of environmental covariates. We found that STR_{DIV} had a strong and positive effect on AGB. The positive effect of STR_{DIV} on AGB was underpinned by both the community-weighted mean of trait values (selection effects) and species richness (niche complementarity and competitive exclusion). Across floristically and environmentally homogenous forest units defined based on aridity index and stand development stage, STR_{DIV} primarily mediated the effects of CWM of traits and species richness on AGB. We also showed that water availability and soil fertility are crucial for maintaining positive STR_{DIV}–AGB relationships. Our findings highlight the importance of promoting high structural diversity to increase AGB production in tropical forests. Moreover, management and mitigation strategies aimed at fostering biomass production through increased STR_{DIV} should focus on maintaining high levels of functionally dominant species while also increasing tree species diversity.

Growth resilience of trees: Interactions between changing climatic conditions and the structural and trait composition of tree neighborhoods

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Small scale disturbances in forest stands caused by humans through silvicultural interventions or by natural drivers such as windthrow, insects or pathogens are affecting the structure of the remaining stand. The growth response of the remaining trees to a sudden release event will largely determine the future development of a forest stand. We present results about the response of growth resilience of trees after disturbances to climatic conditions and the structural and trait composition of tree neighborhoods.

Trees that react with a growth increase due to reduced competition may contribute to the resilience of forest stands. However, older trees and tree species that have a low growth plasticity may react neutrally to release events or even with declined growth. Additional to effects of individual tree traits, the capacity of individual trees to respond to release events in a plastic way may be impaired in the future by changing climatic conditions. Structurally diverse tree neighborhoods with multiple species may increase resistance and resilience to disturbances than monospecific even-aged stands and thereby mitigate climate change impacts, whereas high competition pressure may lead to additional stress and a further decrease of forest resilience. Our objectives are to demonstrate driving factors of the growth response of different tree species to release events and how potential effects of a changing climate may be mediated or amplified by diverse tree neighborhoods and competition intensity.

We present results from the Swiss long-term forest growth monitoring network. Tree traits and coordinates from stands covering a broad range of Central European tree species, silvicultural management types and climatic conditions were monitored in 5-to-10-year intervals mostly since the 1980s, individual plots since the 1930s.

Our results are important for a better understanding of the biodiversity – ecosystem stability relationship in forests during climate change. For an adaptive management of forests, it is important to be aware about stand structural features that increase or decrease the resilience of trees and stands.

Higher tree water deficit under intra- vs. interspecific competition – insights from mature stands of European beech, Norway spruce and Douglas fir

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Mixed forests are, for multiple reasons, a promising option for forest management in Central Europe. However, it is not clear to what extent interspecific competition affects tree hydrological processes. High-resolution dendrometers capture sub-daily variations in stem diameter, presenting a valuable tool to monitor growth and water status of individual trees at the same time.

To evaluate the effect of intra- vs. interspecific neighborhood on tree growth and water status, we deployed >100 sensors in pure and mixed forest stands of European beech, Norway spruce and Douglas fir on four different sites in north-western Germany, measuring stem diameter at 10-minute resolution for a period of four years (2019-2022). Using normalized minimum tree water deficit as a daily indicator for water stress, we found that throughout the growing season, beech trees growing in pure stands exhibited higher water deficit than those in mixed stands. An exception was 2021, the wettest year of the study period, where all trees showed low water deficits, while the largest differences were observed during the driest year (2022).

We assume that these differences may arise from belowground complementarity in interspecific neighborhoods, since results from water stable isotope analysis on a subset of plots show small but consistent differences in water uptake depth of the tree species in the mixed stands, suggesting a broader access to belowground resources. Still, environmental variables (mainly VPD and soil matric potential) were the strongest predictors of tree water deficit, and annual growth was substantially impaired by drought on all plots.

Overall, our data suggests that mixed beech-conifer stands seem to be less affected by severe droughts than pure stands, making them indeed a valid option for the adaptation of forests to climate change.

Impacts of diversity across a range of scales: evidence of tree species diversity effects on the structure and function of forests in North America

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: This presentation highlights results from three studies of tree species and genetic diversity effects on forest function and structure. The first study is an experiment comparing the productivity of polyclonal and monoclonal plantings of *Populus spp.* plantations in southeastern US. The second study is observational, comparing monocultures and mixed-species structure and function in ~35-year-old plantation forests in the Pacific Northwest, US. The third study leverages national forest inventory plot data to assess regional impacts of species and functional diversity on forest productivity in the southern US. We synthesize results from these three studies and discuss how investigating impacts of tree species diversity at different scales can help advance our understanding of the biodiversity-ecosystem function relationship in forests. First, how short-rotation *Populus* plantations can serve as a model system for testing and developing hypotheses about diversity effects on ecosystem functions using approaches that would be infeasible in natural forests. As an example, I will highlight results from a study showing overyielding in polyclonal plantings is associated with differential expression of stress response genes, suggesting water and heat stress response as a possible underlying mechanism for increased productivity in mixtures. Second, field studies in plantation forests as found in the Pacific Northwest can provide semi-controlled conditions for observational studies to evaluate impacts of species composition at temporal and spatial scales larger than what is feasible for designed experiments. As an example, I will highlight results showing how tree-species composition affects productivity at the individual tree and plot level and may be explained by species characteristics that potentially contribute to increased canopy packing in mixtures. Third, these types of results help interpret large trends observed across regions, including how the positive relationship between tree species richness and productivity is mediated by stand density according to model results using national forest inventory data. In conclusion, generalizing trends, understanding specific mechanisms, and advancing ecological theory on biodiversity ecosystem function relationships in forests cannot be feasibly achieved by working at a single scale. Rather, integrated studies at multiple scales are needed.

Influence of different silvicultural practices on forest structure and genetic diversity of forest tree populations

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Genetic variation enables populations, species, and consecutively ecosystems to adapt to new environmental conditions. Functioning forest trees communities, also a consequence of their forest genetic resources, are key for the maintenance of biodiversity. However, forest genetic resources face a large number of increasing threats, such as climate change and unsuitable forest management practices, threatening future adaptive potential of forest trees and forest ecosystems. To assess an ecosystem's genetic resources and the system's ability to adapt, it is fundamental to analyze hypothetical changes in the population's genetic diversity and the consequences of these changes. Forest management can impact both structural characteristics and genetic variability of forests. Considering this, selection of suitable silvicultural practices is crucial for conservation of diverse genetic structure, including the maximization of population size and selection for specific adaptive characteristics. Different research results show that old-growth forests may have a more complex structure and higher genetic diversity than managed forests. Close(r)-to-nature forestry, that mimics natural processes in virgin and old growth forests, may positively impact biodiversity, including genetic diversity of forest tree populations and improve the adaptive potential of forests. The impact of different forest management practices on forest structure and spatial genetic diversity in 13 European forest types was analysed within the Life Systemic project. Species composition, stand density and age structure, site conditions, genetic structure, and soil biodiversity, as well as historical overview of the forest management practices, are being evaluated in 30 different sites across Italy, Croatia and Slovenia. These sites comprise different intensities of management, from unmanaged forest reserves to clear cutting management system, with the aim to evaluate the role of different forest management regimes to secure forest genetic structure important for the potential adaptability of forests to climate change in given European forest types.

Influence of tree species composition and of stand density on epiphytic diversity in mixed and pure pine and oak forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: The effects of mixed stands on biodiversity are increasingly being studied. Nevertheless, among the few studies dealing with epiphyte taxa, even fewer compare mixed stands with the pure stands of each tree species. We evaluated the diversity of tree-dwelling cryptogamic communities (bryophytes, lichens) in mixed and pure oak-pine stands (Quercus petraea (Matt.) Liebl., Pinus sylvestris L.) in French lowland forests. The main explanatory variables were the phorophyte species and the stand type (pure versus mixed) at tree level, the stand composition (pure oak, pure pine and mixed) at plot level. In addition, we investigated the role of the stand density (low vs high). Data were analyzed using Generalized Linear Models under Bayesian statistics. Richness and abundance of cryptogams were significantly and strongly higher on oak. Pine cryptogamic diversity at tree level was higher in mixed compared to pure stands, whereas mixed stands did not enhance oak bryophyte richness. Epiphytic bryophyte richness decreased with increasing tree density, this was the only strong effect of tree density. Bryophytes and lichens showed similar relationships with the phorophyte tree species, the stand composition and density.

Influence of tree species diversity and competition on drought sensitivity of silver fir, Norway spruce and European beech in uneven-aged forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Promoting tree species diversity and structural diversity are two commonly advocated forest management strategies for adapting forests to climate change and the projected increase in drought frequency and severity. Still, mixing and structural effects on the drought response of trees can vary substantially with site conditions and tree species identity. To investigate the influence of species-specific neighborhood environment (species richness, competition, stand structure) on the drought response of silver fir (*Abies alba*), Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*), we combined annually resolved tree-ring data with repeated forest inventory data spanning the past century at three long-term experimental plots in Switzerland. Our study focused on six drought events that occurred since the 1970s. Our findings indicate that neighborhood competition and tree species diversity effects are generally weak, with significant interspecific influences observed primarily in the growth resistance and recovery of European beech to drought. These effects, however, were overshadowed by the effects of tree age and size. While tree size consistently negatively affected all species, age effects depended on species identity. Our results highlight the fact that the effects of diversity can differ for each combination of species and vary along tree ontogeny, making it challenging to draw broad conclusions. This is because species interact through their specific traits, and interactions vary as trees' neighborhood structural complexity changes over time. Adaptive management strategies in mixed uneven-aged mountain forests are more likely to succeed if they promote drought-tolerant species and the reduction of stand density. Despite the lack of clear evidence supporting the advantage of tree diversity in enhancing drought resilience, the pursuit of species-rich forests still offers benefits such as risk distribution among multiple species and the provision of numerous ecosystem services.

Managing for Complexity in Western Coniferous Forests of North America

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Managers and scientists are engaged in a collaborative effort to establish a series of experimental silvicultural trials across a network of different forest ecosystem types throughout the United States and Canada called the Adaptive Silviculture for Climate Change (ASCC) project. Partners in Colorado, USA have co-developed locally-specific adaptation actions for three complex, fire-adapted forest ecosystems across Rocky Mountain elevational gradients to research long-term ecosystem response to a range of climate change adaptation approaches, manage for changing fire regimes, and protect the valuable ecosystem services they provide. These three forest types include: 1) high-elevation, spruce-fir forests at the Colorado State Forest, which is the source of an estimated 75% of annual water in Colorado that flows to an array of downstream consumers from agriculture to municipalities, and crossing state lines; 2) lodgepole pine forests located in the north-central portion of the Taylor Basin of the Gunnison National Forest which are threatened by mountain pine beetle outbreaks and extreme fire and drought events; and 3) dry mixed-conifer forests on the San Juan National Forest established on Jackson Mountain in Southwestern Colorado, ranging in elevation from 2,250 to 2,620 meters and surrounded by communities in the wildland-urban interface.

To promote adaptive response of these forest ecosystems to drought, insects and disease, and changing wildfire regimes, treatments were developed to approximate a gradient of climate-adaptive management approaches including resistance, resilience, transition, and a no action control. Site-specific treatments were collaboratively designed by local managers and researchers using ecosystem vulnerability assessments. The range of treatments involve a combination of intermediate treatments, regeneration silviculture, forest assisted migration using natural and artificial regeneration, and increasing species and structural complexity and heterogeneity at the stand and landscape levels. This presentation will cover climate change impacts for these fire-adapted forests, key silvicultural considerations for achieving sustainable management of multiple species, forest structure and ecosystem services, and lessons learned from implementing adaptive silviculture treatments through this collaborative effort to steward forested watersheds and communities into the future under climate uncertainty.

Mixed pine forest effect on organic matter topsoil and their relation with understory vegetation.

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: The more efficient supply of ecosystem services by mixed *versus* monospecific forests has already been shown in many studies. But many of the mechanisms that implement this more efficient supply have yet to be discerned, especially when the mixtures combine two coniferous tree species. We assessed the effects of mixed *versus* monospecific stands of *Pinus sylvestris* and *P. pinaste*r on topsoil and their relationship whit under- and overstory in a triplet's essay in northern Spain Thus, in 180 plots [6 triplets x 3 forest stands (1 *P. sylvestris* monospecific stand + 1 *P. pinaster* monospecific stand + 1 Mixed stand if both *Pinus* species) x 10 plots/stand] were analyzed the quantity (Total organic carbon) and quality (C:N ratio) of topsoil organic matter, the % cover and richness of understory species and the % basal area of both *Pinus* species. *P. sylvestris* monospecific stands presented higher quantity and quality topsoil organic matter, in contrast to *P. pinaster* monospecific stands which presented lower quantity and quality topsoil organic matter. Mixed stands showed an intermediate quantity of topsoil organic matter but a quality of topsoil organic matter similar to *P. sylvestris* monospecific stand. We conclude that the similar species richness in mixtures to *P. sylvestris* monospecific stands is linked to the high quality of topsoil organic matter.

Quantifying maximum size-density relationships in mixed-species and monospecific stands of the southeastern United States

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Maximum size-density relationships have been quantified in single species stands for nearly a century. Quantifying size-density relationships in mixed-species stands, however, is a relatively new endeavor. Species specific functional traits and their interaction with climate have been demonstrated to influence maximum size-density relationships in mixed stands. However, these relationships have primarily been documented in temperate forests where at least one component of growing space is limiting. Mixed-species management is less common in the Southeast compared to other regions of the United States, however, the impact of climate change and a transition away from vertically integrated forest companies may increase the importance of mixed-species management in the future. Here, we evaluate maximum size density relationships across a range of monospecific and mixed-species stands in the southeastern United States. Specifically, we examine the role of functional traits and climate on maximum size-density relationships in a region characterized by long, warm, growing seasons and an abundance of precipitation. We used quantile regression to predict maximum size-density across 103,884 United States Department of Agriculture Forest Inventory and Analysis plot observations with 2,013,326 trees across 186 different species. Using the selected equation, we examined the role of climate, site, and species-level functional traits in predicting maximum size density for both monospecific and mixed-species stands. We will present results, discuss modelling challenges, and examine management implications. As climate change may already be altering maximum-size density relationships in the Southeast, understanding variation in maximum size-density relationships across a commercially and ecologically important region will allow for targeted management to optimize a wide range of ecosystem services.

Restoring complexity in plantations: mission impossible?

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: The importance of plantations in the landscape of the mixed forests of eastern Canada has increased over the last five decades. Although the plantations have some natural regeneration ingrowth (~ 40% in stocking), the biggest difference with pre-industrial forests are due to changes in the age structure, and to a lesser extent composition. The irregular and uneven-aged mixed wood stands have been replaced by even-aged stands, of which plantations can cover over 20% of a management unit. Over the last 15 years, efforts have been made to reintroduce complexity in some of these plantations by instigating a transition to irregular stands. But how is complexity measured? And how is it influenced by silvicultural treatments? These questions have been explored using the data from trials established in the last two decades. Within the trials, several thinning modalities were tested: thinning from below, neutral thinning and crop tree release. The latter is seen as the first step in converting the even-aged plantations to uneven-aged or irregular stands. Using traditional structural metrics, such as diameter distribution, plantations were found to be very resistant to anthropogenic disturbances. Even the spatial distribution of the trees in the stand changes only slightly after thinning unless gaps are created. We therefore hypothesized that canopy opening through partial harvesting may not influence the spatial and size distribution of the trees but could affect canopy and understory structure. Results from data obtained with a terrestrial laser scanner also showed that the structure of plantations is very resistant to thinnings, where even the "chainsaw effect" (i.e., the change between pre- and post-harvest conditions) is very limited. Understory composition, measured by specific and functional trait diversity, only changes when gaps are present. These results thus indicate that introducing complexity into plantations is a lengthy process and will mostly likely rest on the success of establishing natural regeneration. In this perspective, thinning, by opening the canopy, has increased the presence of natural regeneration under cover but not in the gaps. More fundamentally, silviculturists must ask the question: what is the time frame to restore complexity through silviculture in these plantations?

Silviculture of multi-aged temperate mixedwood forests in Eastern Canada

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: The temperate mixedwood forest of Québec, Eastern Canada, has been used for decades for wood production, fishing, hunting and other recreational activities, given its proximity to inhabited areas. In this forest, temperate and boreal species coexist through complex interactions of light, moderate and severe disturbances that create diversified landscapes. Since 2010, ecosystem management is the main tool to achieve sustainable forest management on public land, because of its capacity to address multiple economical, ecological, and social objectives. Using natural forests as reference, ecosystem management aims at maintaining ecosystem functions and resilience by reducing the gap between managed and natural forests.

This talk will present the natural developmental model for yellow birch-conifer ecosystems and the associated ecological silviculture. Since natural dynamics for mixedwood ecosystems result in an increase of conifers, late-successional species, and structural complexity over time, silvicultural systems aim at enhancing these attributes. In young and intermediate age stands, the goal is to facilitate natural development by increasing the proportion of conifers and late-successional species. In mature and old-growth stands, actions aim at promoting diversity and structural complexity by ensuring the establishment of a regenerating cohort at each intervention, and by retaining biological legacies with silvicultural systems such as irregular shelterwood and hybrid selection cutting.

Even though ecological silviculture is based on past and current natural dynamics, the overall approach to promote structural complexity and species diversity can help fostering stand resistance and resilience, two adaptation strategies to help forests face climate change in a context of uncertainty.

Size heterogeneity – productivity relationship in pine forests across an environmental gradient

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Structural complexity is a key characteristic of forests stands, as it is related to many forest functions and services. Many efforts have been done to identify the effects of species diversity on productivity, showing a general positive effect that is mediated by climate conditions. However, results on the effect of other structural traits such as size heterogeneity on productivity are less conclusive, with findings suggesting positive, neutral and negative effects. This relationship is driven by growth partitioning among trees, which depends on development phase, species composition and environmental conditions. For forest management, it is of great relevance to understand the relationships between size heterogeneity, growth partitioning and stand productivity, as size structure can be modified by silvicultural interventions.

Pinewoods occupy a large area of forest land in Spain, having a great importance from ecological and socio-economical point of view, including their role in carbon sequestration. In this study, we analyse the relationship between size heterogeneity, growth partitioning, and productivity in pine forest stands across an environmental gradient in Spain. We use the network of long-term experimental plots from the ICIFOR-INIA (CSIC), which covers stands of different pine species (*Pinus halepensis* Mill., *P. nigra* Arnold, *P. pinaster* Ait., and *P. sylvestris* L.), ages and site conditions. We select the plots and surveys that represent full growing stock (unthinned or slightly thinned plots). To describe environmental site conditions, we will use climatic and topographic variables, as well as site index derived from existing models for the different species. We estimate size heterogeneity through the Gini coefficient and the growth partitioning between trees in a stand through the growth dominance coefficient. For each species, we explore the effect of site conditions on size heterogeneity and growth partitioning, and their effect on stand productivity, taking also into account the possible effect of stand age. Finally, we compare and discuss the results of the different species and their implications for promoting complex structures through forest management.

Spatial pattern analysis of trees of Re-growth forest in International Institute of Tropical Agriculture, IITA, Nigeria

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Inter-and intra-specific interaction contributes to coexistence of tree species alpha diversity. Exclusion and coexistence of tree species are dependent on competition intensity. However, failure of conservation efforts in most tropical natural forests is due to lack of understanding of relationship between competition and coexistence mechanisms among tree species. Therefore, the objective of this study was to quantify inter-tree spatial pattern in Re-growth forest of International Institute of Tropical Agriculture, IITA, Nigeria. Five (5) parallel line transects of 400m long and 50m width were demarcated in the IITA re-growth forest. Six (6) sample plots (30m x 30m) were demarcated alternatively with 30m intervals on a line transect of 400m long. A total of 30 sample plots (30m x 30m) were used for the study. Trees with diameter-at-breast height (dbh≥5cm) were enumerated and identified to species level and measured for stem circumference. Two reference trees maximum (Dominant) and minimum (Suppressed) dbh were selected in each plot. A circular sub-plot (Area=314.2 m^2; radius=10m) was demarcated around Dominant and Suppressed trees within a plot. Distances between reference and individual trees within a sub-plot were measured. Data collected were analysed using descriptive statistics, Correlation analysis, Clark-Evan index, C-E (Cluster stand <1.0, Regular stand; <2.14), diameter differentiation (D-D) and Mingling indices of dispersion. Dominant trees showed few significant negative correlations ($r = -0.873$; $n= 10$, $p \leq 0.027$) while Suppress expressed few significant positive and negative correlations ($r = 0.820$; $n=10$, $p \leq 0.013$) between sum of diameters of neighbouring trees and distances. Significant correlation occurred mostly at 7m to the reference trees. Ninety six percent of sub-plots expressed random pattern for communities of Suppress and Dominant trees, while three percent of sub-plots expressed cluster pattern for communities of Dominant and Suppress trees. Mingling index expressed J-shaped curve for tree communities of Dominant and Suppressed trees, respectively. Competition among trees was relatively weak and interference was more in tree communities of Suppressed than Dominant trees. Most trees were surrounded by neighbours of different species rather than same species. Spatial analysis should be limited to 7m around the reference trees.

Spatial Patterns of Eco-efficiency and Spillover Effects in the Life Community of Mountains-Rivers-Forests-Farmlands-Lakes-Grasslands Life Community

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Eco-efficiency as a measure of sustainability that can be improved is receiving increasingly widespread attention globally. Under the concept of integrated conservation and system governance in China, the measurement of eco-efficiency in mountains, water, forests, fields, lakes and grasses and the identification of the spatial distribution and spillover effects of eco-efficiency levels in a spatial and temporal pattern are of great significance in improving the quality and stability of China's ecosystems.Heilongjiang Province, situated in northeast China and serving as a significant natural ecological barrier in the region, encompasses diverse natural ecosystem features representative of the aforementioned systems.This study employs the super-efficiency Slacks-Based Measure (SBM) model to quantify the ecological efficiency of the Mountains-Rivers-Forests-Farmlands-Lakes-Grasslands Life Community in Heilongjiang Province from 2006 to 2019. The results indicate a relatively low overall ecological efficiency in Heilongjiang Province during the study period, classifying it as an inefficient ecological efficiency region. Spatial heterogeneity is observed among different cities within the study area.Moreover, this study utilizes GIS spatial tools and exploratory spatial econometric models to analyze the spatiotemporal patterns of ecological efficiency. The findings suggest a trade-off relationship between ecological efficiency and ecosystem services, rather than a synergistic one. Additionally, a significant negative spatial autocorrelation pattern is detected.

Structural Complexity is a Better Predictor than Single Habitat Attributes for Understory Bird Densities in Southern Andean Temperate Forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: The simplification of forest structural complexity, caused by anthropogenic land-use practices, is one of the main threats to understory specialist birds. We examined the association of forest habitat attributes and structural complexity with the density of four understory bird species in a Global Biodiversity Hotspot in South America. Between 2011 and 2013, we surveyed habitat attributes and conducted understory bird point counts in 505 plots in Andean temperate ecosystems in Chile. In each plot, we measured understory density, coarse woody debris (CWD) volume, number of snags, diameter at breast height (DBH) of trees, and litter depth. With these attributes, we developed an index of stand structural complexity (ISC). On average, old-growth forests had higher values for understory density, CWD volume, DBH, and litter depth than secondary forests and open fields. The density of understory species was positively correlated with the ISC for the Rhinocryptidae *Pteroptochos tarnii*, *Scelorchilus rubecula*, and *Scytalopus magellanicus*. We also found a positive association between understory density and litter depth with the density of the Furnariidae *Sylviorthorhynchus desmursii*. However, this latter species showed a negative association with the density of standing dead trees.

Our results suggest rhynocryptids as good indicators of structural complexity of temperate forest ecosystems. Also suggest the utility of an index of structural complexity, rather than single habitat attributes, for determining the density of understory specialist birds. We recommend that management plans should promote the retention of habitat legacies that contribute to the structural complexity of forest ecosystems.

Synergies between structural diversity and economic value in mixed forests of European beech with spruce and Douglas fir

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Forest management in Germany is based on mixed forests with the underlying goal of providing several services and functions, both ecological and economical. This might be related to a more complex three-dimensional distribution pattern of tree elements, resulting in a higher overall structural diversity of mixtures. Structural diversity can present economic benefits over time, e.g. through income diversification; however, there is a lack of research on the relationships between structural diversity and economic outcomes in mixed forests. We hypothesize that there are synergies between economic value and structural stand complexity (from laser scanning data), while they differ between forest types (mixture or pure stands). We analyzed 40 plots of 0.25ha of pure and mixed stands of beech, Douglas fir and spruce throughout Lower Saxony, Germany. We scanned the plots using a mobile laser scanner with leaf-on conditions in July 2021. Scan data were processed with the Geoslam Hub software to produce 3D point clouds. The raw point cloud was first subsampled by removing points closer than 0.5 cm to each other. Then, we obtained the structural diversity indicators of box dimension, the effective number of layers (ENL) of dimensions 0, 1, and 2, and the vertical diversity ratio (VDR). As a simplified indicator of an economic value, we used the value of standing timber (stumpage value) based on inventory data. We modeled the relationships between the structural diversity indicators with economic value using either generalized linear mixed models or linear models. We noticed that the relationship between stumpage value and structural diversity was positive for most of the indicators, and this relationship is mediated by forest type in some of them (ENL0 and ENL1). In general, either Douglas fir or its mixtures with beech performed better in both structural diversity indicators and economic value. Thus, admixing beech forests with Douglas fir could be a nature-based solution to increase structural diversity as well as the economic value of the forests.

The illusion of heterogeneity: unveiling the impact on biodiversity and the need to embrace biodiversity as a dynamic process

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Forest management often aims to improve biodiversity by increasing forest structure heterogeneity using indicators such as tree species richness, deadwood diversity, and natural regeneration indices. However, existing research report contradictory results on how biodiversity responds to these variables, particularly at large spatial and temporal scales. Our study examined the effect of forest management on forest structure heterogeneity and its biodiversity implications in temperate forests. We performed a systematic review of peer-reviewed studies examining the impact of forest structure indicators on the species richness of four taxa (beetles, vegetation, fungi and lichens). Then, we evaluated the effect of forest management and local environmental conditions on forest structure heterogeneity in Germany's Black Forest using a Structural Equation Model (SEM). We also analyzed the effect of forest structures and heterogeneity on species diversity and community composition of seven taxa using Generalized Additive Models (GAM) in managed stands in Germany's Black Forest. Lastly, using a partition tree algorithm, we assessed the transition point for the biodiversity of three taxa (lichens, mosses and fungi) resulting from forest structure variables in protected Scandinavian areas. We found that management-influenced forest structures had no significant direct effect on species richness. While forest management actively shapes forest structure heterogeneity, the response of local environmental variables is taxa-specific, and we didn't find any clear pattern to suggest using a forest structure variable as a biodiversity indicator. Deadwood diversity significantly affected the biodiversity of lichens, mosses, and fungi in protected areas. Still, observed values were far from those that can be found in managed forests, making such transition points impractical for forest management. Our findings challenge the idea of using forest structures as biodiversity indicators and suggest a taxa-specific approach based on common triggers for conservation and management goals.

The trade-offs between timber production and forest grouse occupancy become harsher at larger spatial scale in the boreal production forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Forest management affects the viability of forest biodiversity causing alterations to habitat quality. Sustainable forest management aims to find win-win solutions for economy and biodiversity, ensuring that timber flow is maintained while minimizing degradation of forest characteristics increasing habitat quality. As species are related to different forest characteristics at different spatial scales, the impact of forest management on their habitat can also be different. In this context, the aim of our study was analysing the spatial trade-offs between timber production and grouse occupancy at multiple spatial scales.

We simulated and optimized a Finnish forest holding for a typical rotation horizon under several management options with a forestry dynamics model. We compiled production possibility frontiers to reveal the tradeoff between the forest economic (Net Present Value of timber) and ecological value (grouse occupancy). Occupancy for four forest grouse species (hazel grouse, black grouse, capercaillie and willow grouse) was modeled using nationwide wildlife triangle census data with variables related to forest structure and composition at local (stand), home-range (1-km) and regional (5-km) scales.

Our results show that the trade-offs between timber production and forest grouse occupancy were species- and scale-specific. An increase in the economic value of the landscape highly reduced the landscape occupancy of capercaillie, related to undisturbed contiguous forests, intermediately for black grouse and hazel grouse, both preferring a mosaic of mixed young forests and marginally for willow grouse, related with open regeneration or poorly productive forests. The slope of the trade-off curves was steeper when species occupancy was estimated with predictors at regional than at local and home-range scales, as at this scale the explanatory power of the forest characteristics was larger and larger the impact of timber harvesting on grouse habitat.

In conclusion, our research demonstrates that the evaluation of the trade-offs between timber harvesting and species occupancy at multiple spatial scales can better inform forest managers about the species' potential use of the landscape and help target management at the relevant scale. The evidence that the conflicts are expected to be harsher at large spatial scales calls for better integration of forest planning among small forest owners.

Transformation methods of pine monocultures to mixed-species in the Mediterranean. The COMFOR network.

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: The need to maintain and increase species- and structure-rich forests has increased in recent decades. This type of forest has positive effects on the regulation of biogeochemical cycles, the conservation of biodiversity and the mitigation of global warming. This need clashes with current forest landscape in many regions, which it is populated with monospecific and regular stands. With the turn of the century, the idea of increasing the area of structurally heterogeneous forests like mixed forests or the implementation of closer-to-nature management has been gaining attention. Although these principles have been recurrent in the history of forestry, almost since its origins (Gayer 1898), it is in the context of Global Change that a definitive move forward can be given to its large-scale implementation. Among the silvicultural options to maintain or increase structural complexity the irregular shelterwood system (ISS) has been proposed. This silvicultural system has been applied in boreal and temperate forests whereas, to our knowledge, its implementation on more semi-arid conditions, like the Mediterranean, is non-existing. Here, we present the first results of a broad scale implementation of the expanding gap variant of the irregular shelterwood system in southwest Europe. The implementation consisted of opening small and large gaps according to different site specific objectives. For example, in one of the sites the objective was to replace the monospecific pinewood plantation into a mixed oak Mediterranean forest. In this case, the gap size should prevent the establishment of pine seedlings while allow for a good development of planted Mediterranean oaks (*Quercus suber, Q. ilex and Q. faginea*). The analyses after three years of implementation showed that opening very small gaps (gap diameter = 0.5 times the dominant height) controlled the regeneration of *Pinus pinaster* (a light demanding species). However, larger gaps increased the survival rate of saplings indicating that a trade-off between controlling for pine regeneration and oak plantation performance must be considered. We discuss the appropriateness of the method and recommend guidelines for its correct implementation in Mediterranean forests.

Tree diversity increases forest temperature buffering

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: The rising frequency and intensity of climate extremes make the stable provision of ecosystem functions and services a priority for forest management. One crucial but often overlooked forest function is the buffering of temperature extremes, that is, the cooling of hot and insulation against cold macroclimate temperatures beneath the tree canopy. Tree diversity may play a significant role in enhancing this temperature buffering, which may itself maintain forest biodiversity and functioning, for example, by stabilizing functions like photosynthesis that respond non-linearly to temperature. Despite its significance, the effect of tree diversity on temperature buffering remains largely unknown. Here, we leverage hourly measurements of microclimate temperatures over six years from a large-scale forest diversity experiment covering a species richness gradient of 1 to 24 tree species. We show that tree species richness consistently increased forest temperature buffering across daily, monthly, and annual time scales. We found that species richness strengthened both components of forest temperature buffering, the cooling of hot and the insulation against cold macroclimate temperatures, with the cooling effect being more pronounced. By disentangling the forest properties responsible for the buffering effect, we show that species richness effects are mediated by vegetation density and structural diversity, assessed as leaf area index and stand structural complexity, respectively. Our results demonstrate that forests with high diversity in tree species and structure have a stronger buffering effect on temperature fluctuations than forests with low tree diversity. This buffering effect of tree diversity may have important implications for temperature-sensitive forest functions, the diversity of forest-dwelling species, and

the thermal stress release humans experience in forests. Due to their temperature buffering capacity, species-rich and structurally diverse forests may foster the stable provision of ecosystem functions and services under global warming and climate extremes.

Tree Growth at Gap Edges. Insights From Long Term Research Plots in Mixed Mountain Forests

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: The structure and dynamics of Central Europe's forests are increasingly characterized by canopy gaps which either result from disturbances or from planned silvicultural actions. It remains, however, unclear, whether the neighborhood to a gap has effects on tree growth which cannot be sufficiently covered by existing standard models so far. In order to test for such effects, we used data from a series of long term experiments in Southern German mixed mountain forests, where silviculture has been traditionally working with gaps in order to steer forest structure and species shares. In parallel, we developed a method for an automatized detection of canopy gaps and gap edge trees given such data. We found that the basal area growth of such trees amounted to about 15–30% more compared to what could be covered by a classic spatial competition index, with a plausible ranking of the main species. Our results suggest, in addition, that an exposition to a gap has a longer lasting effect on tree growth, even after the gap has closed again. With regard to such long-term effects, we found that tree size at the first exposition matters, with strong species-specific differentiation. We concluded that gap exposition effects on tree growth, given their order of magnitude, require being included in tree growth models which are used for planning purposes.

Understanding the competition between different species in mixed forests: The impact of European Beech on the morphology of Scots Pine

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Mixed forests can have higher levels of resilience and resistance to environmental risk, and a more diverse portfolio of ecosystem services. The challenge now is to properly understand the interaction between species to adequately plan for future forests. Our research investigates how direct competition between European beech (Fagus sylvatica) affects the morphological characteristics of Scots pine (Pinus sylvestris L.). For this purpose, high-resolution terrestrial laser scanning (TLS) was performed, combined with quantitative structure modeling (QSM) allowed us to obtain an accurate and non-destructive representation of tree structures, especially at the thin branch level. This methodology allowed accurate estimates of tree structural parameters, such as crown and trunk variables, and to determine crown competition indices. Our study was conducted on two long-term permanent plots in the Bavarian region, examining 31 Scots pines, 14 of which were in direct competition with Beech. We obtained seventeen crown characteristics, four trunk variables, and the competition between individuals was defined by the KKL index at 60% of the height of the tree in question. The trees were felled, and measurements were validated on the ground. The findings indicated significant differences in the crown and trunk structures of Scots pine trees due to direct competition with European beech. As such, this study supports the value of using advanced technologies like TLS and QSM for understanding inter-species competition and managing complex forest structures in the context of climate change. Furthermore, the evidence provided emphasizes the need for a nuanced approach to forest management practices, taking into consideration the distinct responses of different species to competition.

Selected references

Understanding the role of crown biomass allocation patterns in species interactions in a temperate forest mixture

T1.8 Complex forests: Understanding and management of multiple species, structures and ecosystem services.

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Abstract: Mixed-species forests are common in natural environments, and recent findings of their benefits led to increased forest planting areas with mixed species worldwide. Recent studies suggest that mixed-species stands can overyield mono-specific stands. A more detailed understanding of how an inter-specific neighborhood affects tree growth, i.e., whether overyielding is mainly an effect of higher space-use-efficiency and packing density or higher efficiency of resource use (e.g., water, light, nutrient), may improve the knowledge-based design of resource-efficient forest ecosystems. For a common mixture in temperate forests (European beech (*Fagus sylvatica* L.) and Scots pine (*Pinus silvestris* L.)) for which overyielding have been reported, we here provide further insight into tree neighborhood diversity – crown structure - growth efficiency relationship. Based on 128 individual felled trees, we show that in mixed compared to mono-specific stands, (i) the tree crown and its components follow different allometric relationships, and (ii) the branch and leaf biomass allocation along the vertical structure are different, especially for E. beech. We (iii) show that an interspecific neighborhood can significantly increase the growth efficiency of E. beech. Our findings reveal that the overyielding in mixed stands is partially due to heightened space-use efficiency and packing density, attributed to distinct allometric relationships and biomass distribution within crowns. Furthermore, we posit that this overyielding is not solely dependent on spatial dynamics but is also enhanced by superior efficiency in resource use, with both effects coexisting. Our results are essential for individual tree modeling using potential-modifier approaches. They suggest that both potential growth and its reduction by local competition require an adjustment before models for mono-specific stands can be successfully applied to mixed stands.

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

400 years of fire history hidden at the bottom of our lakes

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Forest fires are getting more intense and frequent. In Canada, the surface burnt in the first 6 months of 2023 was 8 times greater than the mean of the last 30 years. Will this become our new reality? What does the future hold for our forests? To answer these questions and predict the fire dynamics under climate change, reconstructing past fire dynamics is essential. However, a major knowledge gap regarding past disturbance regimes in preindustrial forests remains, and past fire proxies are sparse, especially in Canadian boreal forests. So, how can we reconstruct fires?

At the beginning of forest exploitation, waterways were used as the main wood transportation. Since around 15% of log-driven logs sank during their transport, this accumulation of subfossil wood can serve as a proxy for reconstructing the fire dynamics of preindustrial forests. In Québec (Eastern Canada), eastern white pine stands used to dominate the landscape until 1800 and are now very sparse owing to intensive forest exploitation. Because of their high ecological and monetary value, efforts to preserve these stands and improve managing methods are necessary. However, little is known about the natural occurrence of fires in these stands and how it has changed with anthropization and climate.

The aim of this study was to reconstruct fire regimes in white pine stands of Eastern Canada forests from the preindustrial period to present using subfossil log-driven logs. We extracted 1000 logs from the bottom of lake Tee (Québec) and dated 90 fire scars.

We were able to reconstruct the fire dynamics of the last 400 years and revealed that surface fires occurred naturally in white pine stands. However, forest exploitation and climate change led to an increase in fire frequency (one fire every 10-50 years) since the middle of the 19th century. This study is the first to reconstruct fire regime of the preindustrial pine forests of Québec and demonstrates how human activities have interfered with this disturbance in the past. Our results are essential for the sustainable management of pine forests in Québec and to predict how fire regimes will be modified in a warming world.

Algorithms for multi-pith and tree-ring detections of stem images – a preliminary research on fresh stem discs

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Mixed forests have gained attention due to their better resistance to threats of climate change. To understand their growth patterns for in-depth ecological insights, dendrochronology is often used by analyzing stem cores and discs. However, stems in mixtures are often eccentric and may have multiple piths, so that the two directional cores typically extracted might not be sufficient to represent complex internal patterns.

In recent years, studies that employ automatic detections to reduce the burden of manual employments and produce reproducible measurements have emerged.

In this study, we have developed algorithms capable of extracting the pith and the tree ring data that are also able to handle detections under multi-pith and irregular discs conditions. Using X-ray images from 25 discs of conifer and broadleaf species, the hypothesis has been drawn that the application of our method on whole disc images can produce results that are identical to those detected manually.

The findings show that the algorithms obtained an average error of 4.0 and 1.57 pixels (equivalent to 0.60 mm and 0.24 mm) in comparison with human-eye detections for the pith and the tree ring detections, respectively. These offered sufficient multi-pith targeting capability, and considerably reduced the subjective error from manually determined ring width detection tracks.

The work offered insights into capturing irregular stem patterns and steps to reduce the burden of manual work. However, the distinguishment of the outer bark, a better edge detection method, and the trade-offs between the resolution and the computation difficulties remain open.

To conclude, the detection of ring patterns can help to extract precise patterns from irregular discs with relatively low manual efforts. Additionally, with this methodology, scientists can have access to more representative ring widths and growth patterns for a better analysis of structurally heterogeneous stands, such as the resilience to draught stress.

Assessing the growth response of silver birch (Betula pendula Roth.) to climate change

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: In Europe, forest owners and managers have favoured a little number of species for a long time (e.g., Norway spruce, common beech), that are now threatened by the current extreme climatic events weakening trees and leading to forest dieback. This phenomenon raises the critical need for diversifying forests with a wider range of species to look towards a sustainable adaptive management.

Among the potential species, some native species were once neglected but should recover their rightful place in the forest ecosystem. In this context, silver birch (*Betula pendula* Roth.) could play a key role in the future forest diversification: its large ecological amplitude goes with a remarkable capacity to colonise diversified environments, even the most constraining.

Despite such interesting characteristics, the climatic sensitivity of silver birch has been barely studied in Europe. This issue has motivated my PhD project that combines complementary approaches, namely dendrometry, dendroecology and dendroanatomy.

The assessment of long-term growth response of silver birch to past climatic events will be performed at the regional scale of Wallonia (Belgium) through a dendroecological approach. Then, I will link tree structure to tree function by studying the impact of extreme climatic events on xylem anatomical traits and more specifically, the wood intra-density fluctuations using x-ray CT scan method and quantitative wood anatomy. Finally, the influence of soil water availability on growth daily variations will be assessed along contrasted forest sites using automatic radius dendrometers.

Biotic and abiotic factors in shaping variation of tree radial growth along topographic gradients in northwestern Yunnan, China

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Stem radial growth is known to be highly responsive to varying weather and offers a comprehensive record of tree inter-annual growth patterns. In mountain ecosystems, the diverse range of environmental conditions generated by topographic gradients provides an excellent opportunity to examine the influence of abiotic factors on tree radial growth. However, only 31 out of 110 articles reviewed, found significant relationship between tree radial growth and climate, meanwhile, only 16 of 31 studies found a significant relationship of radial growth with climate in elevation gradients (Cuapio-Hernández et al., 2023). This indicates other factors, e.g., biotic ones, and climate mutually influencing radial growth. Since specific influences of biotic factors, and their relative contributions with abiotic factors, in influencing the variation in tree radial growth, are not well understood. The aims of this research are to study how forest structure and composition, climatic conditions and soil nutrients in shaping tree radial growth variation along topographic gradients (elevation, mountain aspect and slope degree). We set inventory plot systematically in four cardinal directions at 100-m elevational intervals from one peak in the Hengduan Mountains, southwestern China. We measured and analyzed species composition, maximum height, basal area, number of trees per hectare, tree species richness, soil organic matter, soil nitrogen and soil phosphorus of each plot. We cored all trees with diameter at breast height larger than 10cm in the plots. We estimated the air temperature of each plot from 1958- 2021 based on the closest meteorological station and plot-based measurements for nearly a year. We calculated Standardized Precipitation Evapotranspiration Index (SPEI) of the closest meteorological station. We developed ring-width chronologies of each species in each plot, and analyzed the relationship between the radial growth with temperature, precipitation, SPEI, and soil nutrients change along topographic gradients. We also explored to what degree forest structure and species composition can explain tree radial growth, by examining the correlation between vegetation attributes with growth-climate/soil relationship. Our study will highlight the influences of biotic and abiotic factors in determining relationship between tree radial growth along topographic gradients and improve the comprehensive understanding of forests growth under climate change.

Carbon and oxygen dual-isotopes in tree rings indicate alternative physiological responses opted by European beech trees to survive drought stress

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Poor drought tolerance of European beech trees raised concerns in Europe. We hypothesized that beech could show an opposite physiological response to the same level of climatic drought with a change in edaphic drought. We performed a combined analysis of $\delta^{13}C$ and $\delta^{18}O$ in tree rings to reveal retrospective temporal physiological responses of trees to drought. The edaphic drought was assessed by quantifying the capacity of soil to store water in plots (classified as “dry” and “less-dry”) near the drought limit of the species in three near-natural oak-beech ecotones in Germany and Switzerland. Neighbourhood competition was quantified. A climatic drought index was calculated from meteorological records and related to the $\delta^{13}C$ and $\delta^{18}O$ values of the trees. Trees from dry plots showed a higher response to drought and climatic dependency than less-dry plots. Neighbourhood competetion increased $\delta^{18}O$ values significantly. Dual isotope analysis shows a tendency of greater stomatal resistance in dry plots and higher stomatal conductance in less-dry plots. We conclude that beech trees belonging to the same population under changing soil water availability can show different physiological responses under climatic drought stress. Our finding indicates the high plasticity of the beech trees to survive drought stress with varying site conditions.

Climate change effects on Mediterranean beech forests: new insight from dendro-ecological analysis and continuous monitoring system

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Forests provide an increasing array of ecosystem services to our society. At the same time, forest ecosystems are put under pressure by climate change with increasing trends in disturbance size, frequency, and severity. Although trees are able to survive the impact of extreme events thanks to their adaptive traits, is crucial to identify the most resilient species capable of countering future rates of climate change.

In this study we monitored two *Fagus sylvatica* stands located in the Matese Regional Park and subject to different microclimatic conditions, with the aim to unravel the responses of this widespread and important species to the environmental drivers and to climate stressors, such as drought. The adopted approach integrates dendroecological analysis with real-time monitoring data. Each monitored tree is equipped with a TreeTalker devices that transmit high-frequency data on the WEB cloud with a unique IoT identifier. Such technology has been demonstrated to be helpful in monitoring tree-level ecophysiological processes and their relation to environmental drivers.

Tree ring data and ^{13}C -derived intrinsic Water use efficiency (WUEi) of the two stands showed how the same species responds differently to microclimatic fluctuations, in terms of productivity and water use. The monitored trees during the 2021 and 2022 growing season, increased their transpiration with vapor pressure deficit (VPD) when the water deficit index was moderate, while the transpiration was lowered at high water deficit values, indicating a reduction in transpiration during the most droughty periods. In 2022 sap flux was generally lower, even if the response to VPD and water deficit appears to be the same. The contribution of incoming radiation was significant in 2022, while not in 2021. The transpiration of the Fagus trees in the beech forests appears to be limited by the low water availability, when in summer there is shortage of water resources.

We will discuss how our approach, showing the long-term trends in the hydraulic behaviour of Mediterranean *Fagus* forests and potential implications of it on the plant health and growth, help identifying proper "climate-smart" management strategies.

Climate effects on the growth of Pinus caribaea Morelet at the Intakin Silvicultural Research Station, Chiang Mai Province, Thailand

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: The relationship between the growth of *Pinus caribaea,* an exotic pine species in Thailand*,* and historical climatic variables was studied. Standard dendrochronological techniques were employed on a total of 40 core samples obtained from 20 trees to cross-date tree-ring width and establish the growth patterns of each sample. Over the period of 1985-2019, the calculated mean annual ring-width value was determined to be 1.008 cm per year. Additional statistical parameters derived from the COFECHA program, including mean series intercorrelation, average mean sensitivity, standard deviation, and autocorrelation, were found to be 0.679, 0.423, 3.534, and 0.585, respectively. An analysis of the relationship between the tree-ring widths of P. *caribaea* and climatic data indicated a strongly significant and negative correlation ($P<0.01$) with mean temperature in April ($r = -0.442$). The chronology also exhibited a significant and positive correlation ($P<0.05$) with mean relative humidity in April and rainfall in October ($r = 0.422$ and 0.370), respectively. Conversely, a negative correlation ($P<0.05$) was identified with the total rainfall in November ($r = -0.350$). Among the climatic factors analyzed, the temperature in April emerged as the main limiting factor for the growth of *P. caribaea* ($r^2=0.195$; $P<0.01$). This investigation emphasizes the significance of scrutinizing growth-restricting factors and establishing meaningful associations between climate variables and the growth of P. caribaea via the analysis of tree-ring widths using dendrochronology. These findings can be effectively employed to inform forest plantation management strategies and facilitate the identification of suitable areas for cultivating exotic pine species in Thailand.

Climate sensitivity of Norway spruce and Scots pine radial growth in a warming Norway, 1960-2020

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Boreal forests are considered among the most vulnerable forest ecosystems to climate change, yet it is still unclear whether the warming trend of the past decades has triggered a change in the long-term growth dynamics. Since 1960, climate change has brought a mean temperature increase of 1.3°C during the growing season in the forested parts of Norway, accompanied with changes in precipitation patterns. Using the National Forest Inventory (NFI) plot network, we analysed the long-term relationship between radial growth and climate for the two dominant conifer species of Norway - Norway spruce and Scots pine - over a 60 years period (from 1960 to 2020). Despite the significant warming trend, the linear growth-climate relationship recorded in tree rings was relatively unchanged between the two sub-periods 1960-1990 and 1990-2020 in both species. We could confirm findings from earlier studies that shifts between temperature-limited and water-limited radial growth are tightly related to mean June temperature with water-limitation dominating under higher June temperatures. The temperature threshold between the two groups did not shift between the two 30-year periods. We subsequently examined growth-climate relationships at decadal time scales using moving windows. This analysis revealed important temporal shifts in the sensitivity of radial growth to temperature and water availability for spruce and pine. This study shows a relatively stable long-term relationship between growth and climate for Norway spruce and Scots pine based on the NFI network. However, it encourages discussion around updating drought indices to increase their relevance to boreal forests as well as additional tree-ring analysis, for example by including the specific response to individual climatic events.

Coherent but different climate responses of dominant and codominant trees in a Taiwan Cryptomeria japonica plantation

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Deciphering the climate signals embedded in trees is the first and pivotal step in assessing the impacts of climate change on forests. Trees record complex biotic and abiotic environmental signals, and different frequencies of radial growth variability may correspond to various climate factors. Extracting climatic signals embedded in radial growth is thus a crucial but nontrivial task. Furthermore, dominant and codominant trees may exhibit differential sensitivities to various climatic factors. This study analyzed tree-ring series of 37 dominant trees (DBH ³ 55 cm) and 26 trees codominant trees (DBH < 55 cm) from a 96-year-old *Cryptomeria japonica* plantation in central Taiwan. We used ensemble empirical mode decomposition to filter radial growth into different frequency bands. Between 1940 and 2020, radial growths were positively correlated with the growing season average daily minimum temperature (Tmin) and the early spring precipitation of the previous year, but negatively correlated with the annual average of daily sunshine hours (SSHr) and the diurnal temperature range (DTR). The detrended radial growth series were negatively correlated with the annual average of daily maximum temperature (Tmax) and the potential evapotranspiration (PET) in the early growing season. The highest frequency variations in radial growth were positively correlated with the average daily dew point temperature (DPT) of early spring between 1961 and 2021. The dominant and codominant trees responded coherently to various climate variables, although with differential sensitivities. The dominant trees responded stronger to Tmin, precipitation, and PET. In contrast, the codominant trees were more sensitive to Tmax, SSHr, and DPT. The study suggests that to understand how trees respond to climate using tree-ring analysis, we should include trees of different social statuses and separate radial growth variations into frequency bands. Otherwise, results may underestimate or overestimate the impacts of climate change, if not misleading.

Combining tree-ring growth and carbon isotope data enhances the understanding of climate sensitivity and physiological responses for Chinese fir

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Chinese fir(*Cunninghamia lanceolata* (Lamb.) Hook) is one of the most important forest tree species in China; hence possible adverse factors affecting its growth and physiology can have strong ecological and economic impacts. Hence, we investigated the tree growth and physiological response of 30 Chinese fir provenances in relation to changes in atmospheric CO_2 concentration(c_a) and climate in southern China during 1987-2013. Trees(a total of 354 trees) were sampled at a long-term common garden, encompassing the majority of Chinese fir's distribution range. Combined dendrochronology with carbon isotope analysis ($\delta^{13}C$), the 30 provenances were compared in terms of climate-growth relationships, growth trends and growth response to drought stress. The present analysis suggests that temperature and relative humidity is crucial for determining the growth and physiology of Chinese fir trees in our study. $\delta^{13}C$ in tree rings provide complementary information on eco-physiological responses to environmental changes and have been shown to be more sensitive to current growing-season climate than radial growth and wood density. We found that intrinsic water-use efficiency (iWUE) increased significantly over the last 27 year by 12.71 – 33.56%, but radial growth has significantly declined (--− 63.38% ~ − 88.93%). Strong growth decreases reflected increasing water stress as a result of drought events, which was not offset by greater iWUE. Our results highlight the important role of provenance temperature in growth rate and water use efficiency. Seed sources experiencing slightly warmer and more humid climates from the middle region grew faster and had higher water use efficiency (inferred from lower $\Delta^{13}C$) than provenances from drier climate conditions. However, provenances from drier climates had slower growth, higher wood density and higher carbon isotope discrimination ($\Delta^{13}C$) than those provenances. These results provide a better understanding of the climate sensitivity and physiological responses of Chinese fir under long-term drought conditions. Increasing the number of tree ring studies linked with eco-physiological parameters of tree growth is recommended to better visualize the level of stresses on the Chinese fir provenances.

Comparing methods for estimating gross primary production in a Norway spruce forest in SW Sweden

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Forests are both affected by and affecting global climate change. In the Anthropocene, the era of human dominance on the Earth System, forests need to adapt to climate change, and at the same time, there is a need to optimize forest management for contributing to climate change mitigation by enhanced ecosystem carbon (C) storage.

Gross Primary Production (GPP) is a key flux in terrestrial ecosystems and roughly equivalent to stand level photosynthesis. We will present estimations of GPP for a 60-year-old Norway spruce forest at the SITES station Skogaryd Research Catchment comparing different approaches. First, we will use sap-flow measurements of transpiration conducted during 2015-21 combined with tree-ring isotope data ($\delta^{13}C$) at annual resolution from the rings to of the same trees. The GPP calculation is based on the well-established physiological relationship between GPP and transpiration, termed water use efficiency (WUE), the latter derived from the tree-ring $\delta^{13}C$. Second, GPP is assessed by eddy covariance (EC), the current state-of-the-art method. The EC approach is based on measurements of Net Ecosystem Production (NEP) and estimates for ecosystem respiration (Reco) and have been conducted since 2015, i.e. spanning the same years as approach one and including the drought year 2018, in which EC data suggest no change in GPP at the site.

In addition, we will present preliminary data on GPP estimates, stated in 2023, using a recently developed alternative method, which combines measurements of sap flow and the $\delta^{13}C$ of phloem, using the same physiological principles as above. Those measurements started immediately after a selection harvest and cover both, a selective cut stand and an un-harvested control. This method, in contrast to the EC approach, provides tree-scale information on GPP, which is critical to the assessment of selection harvest conducted at the site.

Coupling tree-rings and carbon isotope discrimination to forecast early warning of dieback on beech forest along a latitudinal gradient in Italy

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: The impact of extreme climatic events such as dry spells accompanied by warmer temperatures has caused forest dieback and increased tree decline worldwide. Nonetheless, the physiological mechanisms to cope droughts and how forests will be able to survive under extreme climatic conditions are scarcely understood. In this study, we conducted a retrospective analysis of the period 1965-4, using tree-rings, basal area increment (BAI) trends, and ^{13}C derived intrinsic water use efficiency ($_i$WUE) to assess forest growth performance under droughts and disentangle the hydraulic strategies adopted by European beeches (*Fagus sylvatica* L.) by using generalized additive mixed models (GAMM). To investigate the temporal variations in forest resilience, we performed first-order autocorrelation (AR1) analysis, to detect any early warning signals of tree dieback, to identify sites that are more to withstands future extreme events.

We selected four stands of beech forest along a latitudinal gradient in Italy. The sites were: Trentino (TRE), Lazio (LAZ), Matese (MAT) and Calabria (CAL). The GAMM analysis revealed a drastic reduction in BAI trends in TRE, LAZ and CAL in the last decades, and this pattern was more noticeable in the northernmost site. On the contrary, MAT (the oldest site) exhibited a consistent increase of BAI.

The results of the AR1 indicated that TRE presented the highest increased in synchrony and autocorrelation following the drought event of 1995, indicating a reduction in resilience, thus more vulnerable to future droughts. Interestingly, $_i$WUE in TRE showed the highest increased over the last decades, suggesting that trees have responded closing their stomata to minimize water loss, reducing the photosynthesis rates, as observed by the decline in BAI.

Overall, multi-proxy, retrospective quantifications of tree-rings, BAI, iWUE and resilience assessments provide a robust and complementary tool for differentiate water use strategies and forecasting the growth decline and tree dieback, as well as identifying those that have the potential to survive in a hotter future and under drier conditions

Current and future drought vulnerability for three dominant boreal tree species

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Climate change is projected to increase the frequency and severity of droughts, possibly causing sudden and elevated tree mortality. Better understanding and predictions of forest responses to climate change are needed to efficiently adapt forest management. We used tree-ring width chronologies from the Swedish National Forest Inventory, sampled between 2010-2018, and a random forest machine-learning algorithm to identify the tree, stand and site variables that determine drought damage risk, and to predict their future spatial-temporal evolution. The dataset consisted of 16,455 tree cores of Norway spruce, Scots pine and birch from all over Sweden. The risk of drought damage was calculated as the probability of growth anomaly occurrence caused by past drought events during the period 1960-2010. We used the block cross validation method to compute model predictions for drought damage risk under current climate and climate predicted for 2041-2070 under the RCP.2.6, RCP.4.5 and RCP.8.5 emissions scenarios. We found local climatic variables to be the most important predictors, although stand competition also affects drought damage risk. Norway spruce is currently the most susceptible species to drought in southern Sweden. This species currently faces high vulnerability in 28% of the country and future increases in spring temperatures would greatly increase this area to almost half of the total area of Sweden. Warmer annual temperatures will also increase the current forested area where birch suffers from drought, especially in northern and central Sweden. In contrast, for Scots pine we were only able to identify drought damage associated with low early-spring temperatures. Consequently, the current area with high drought damage risk would decrease in a future warmer climate for Scots pine. We suggest an active selection of tree species, promoting mixtures and thinning to reduce tree competition as promising strategies for adapting northern-European forests to future droughts.

Dendroanatomy under an Eddy covariance tower. New perspectives for a better understanding of the link between climate, C uptake and biomass growth

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: A better understanding of the forest carbon (C) cycle is essential to address climate change challenges. However, there is great uncertainty on the different effects of climate variability on photosynthesis (C uptake) and woody biomass growth (increment of C stock in long-term pool). Recent studies have investigated climate effects on both primary productivity (GPP) and biomass growth within the same site, evidencing different responses of C sink and C source to climate variability and, in most cases, scarce connections among them. Most of these studies have used ring width to estimate tree annual growth variability, and seasonal or annual eddy covariance (EC) measurements to estimate tree C uptake. We present different study cases in boreal, temperate and mountain conifer forests. Here, tree-ring quantitative wood anatomy (QWA) was used to assess intra- and inter-annual variability of woody biomass, and daily EC and climate data to investigate short-term variability of C uptake.

In *Pinus banksiana* boreal forest in Saskatchewan, Canada, and temperate *Pinus strobus* stand in Ontario, Canada, we observed complex associations between climate variability, C uptake and woody biomass growth. Our results warn against a simplified view of temperature limitation in boreal forests and drought limitation in temperate forests. Interestingly, strong correlations between GPP and cell and ring biomass suggest a direct linkage between C fluxes and the accumulation of carbon in woody biomass at the two pine stands. On the other hand, in a *Picea abies* stand in central Italian Alps, we found a clear influence of climate on xylem formation, but weak associations between C uptake and woody biomass production as compared to the pine stands.

Our study demonstrates that high-resolution of QWA data allows a deeper understanding of the mechanisms underlying the influence of climate on C uptake and biomass growth than the classical annual (tree-ring) approach. Integrating QWA with other sources of information operating at different scales can improve the understanding of the C cycle in forests.

Dendrochronological Potential of Native Species for Ecological Studies in Colombia

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Dendrochronology is the study of annual growth rings, which provides valuable insights into species growth and the environmental conditions they experience. Despite recent advances in dendrochronology in tropical regions, there is a need to expand the number of species with the potential to develop growth chronologies. At the Laboratory of Ecology and Forest Management of the Universidad del Cauca in Popayán, Colombia, we are assessing the feasibility of using dendrochronological methods for ecological studies in the northern tropical Andes. Our goal is to extend hydroclimatological records and establish growth models that enable the implementation of sustainable management practices for commonly harvested species. We are investigating the dendrochronological potential of *Retrophyllum rospigliosii* and *Podocarpus oleifolius*, which are native conifers of ecological importance in the Andean forests. These slow-growing species exhibit annual growth rings that allow cross-dating. Additionally, we are studying the dendrochronology of *Colombobalanus excelsa*, an endemic and endangered species of the Fagaceae family found on the eastern slope of the Andes due to its annual rings. We examined the growth patterns of commonly harvested timber species on the western slope of the Eastern Mountain Range of the Andes, including *Cedrelinga cateniformis*, *Erisma uncinatum*, and *Hymenaea* spp. Remarkably, we have identified individuals over 250 years old with annual growth rings among these species. Identifying tree rings in the Andes, particularly in the Colombian massif, will enable us to reconstruct and establish climate trends in an area that accounts for 70% of the country's freshwater supply. Additionally, the presence of growth rings in timber species will allow the development of growth models necessary for implementing measures aimed to their sustainable management and conservation. Overall, our study highlights the potential of dendrochronology in Colombia for ecological research and provides valuable insights into climate trends, species growth, and sustainable forest management practices.

Dendroecological demonstration of the adaptive value of phenotypic plasticity

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Dendroecology allows to fit very efficiently response curves associating average time-series of annual tree-ring variables and of climatic variables. When applied on an individual basis, this method enables the adjustment of reaction norms, which are direct measures of phenotypic plasticity. The application of this approach to different annual ring variables and species demonstrates that phenotypic plasticity is not only highly variable between pairs of annual ring traits and environmental variables, but also is environmentally and genetically determined.

The application in common garden experiments is especially relevant in the frame of the climate change. The provenance trials installed in the second half of the 20th century experienced the full impact of climate change. The phenotypic plasticity estimated on these trees makes it possible to quantify, with a single value, several decades of response of an individual to local climate change.

Here we present results obtained from a common garden experiment of Douglas-fir provenances from Washington, Oregon and California (USA), planted in two sites in Southern France.

Our results show that the ability to estimate plasticity varies from almost 0% to over 90% from one ring variable to another. We also show that the ability to adjust reaction norms increases with the number of annual rings present in the time series. This is a direct consequence of the rise in statistical power that accompanies the increase in the number of rings.

But even in cases where the number of rings is as low as 20, we could sometimes estimate significant plasticity on more than 50% of the trees, which allow to comfortably use the statistical power of the common garden experiment.

In particular, we show that phenotypic plasticities associated with certain tree-ring variables are adaptive traits involved in resistance to drought: the provenances have evolved in their natural range under the effect of climatic pressures to become locally adapted.

The fact that the provenances in this common garden experiment have been established in regions hotter and drier than those in their natural range enables us to anticipate the effect of climate change when they are introduced into cooler, wetter regions.

Drought resilience in mixed forest plantations: interactive effects of functional trait diversity, tree size and competition

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Mixing tree species has been proposed as a potential solution to mitigate the impacts of rising drought stress in forest ecosystems while providing a wider range of ecosystem functions and services than dominant monocultures. However, it is still unclear how increasing tree diversity improves tree resilience to drought across different species and biotic and abiotic contexts (e.g. mixture composition, climate or degree of soil drought). Here, we investigated how the diversity of tree species and functional traits affects the drought responses of tree radial growth, wood density, and carbon isotope composition ($\Delta\delta^{13}C$, as a proxy for water use efficiency). We collected wood increment cores of 21 tree species growing in monocultures and mixtures (2- and 4-species) in nine experimental sites across Europe, belonging to the global network of forest biodiversity experiments (TreeDivNet). These experiments cover a wide gradient in climatic conditions, reflected in the forest types they represent (from boreal to temperate and Mediterranean). We determined the intensity of recent drought events based on the Standardized Precipitation Evapotranspiration Index (SPEI) and water availability outputs of the soil-plant-atmosphere hydraulic model SurEau. We obtained wood density and tree-ring width series using X-ray micro-Computed Tomography (μCT) and assessed the drought-induced responses of radial tree growth in terms of resistance, recovery, and resilience. We investigated how tree drought responses and water use efficiency varied depending on the tree species identity, the diversity of functional traits in the neighbourhood and the local climate. In addition, we analysed how the effect of tree diversity on the individual tree responses and community responses was mediated by drought intensity, tree size, and neighbourhood competition index. Our results indicate that selecting appropriate combinations of tree species is crucial for improving forest resilience to drought events. The identified mechanisms emphasize the importance

of increasing the diversity and complementarity of functional traits to adapt forests to drought risks and thus provide more robust restoration approaches in the face of climate change.

Effects of extreme weather scenarios on vitality and productivity of beech-, oak-, spruce and pine stands in northwest Germany

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Changing climatic conditions will increase extreme weather events in the future. Especially higher summer temperatures and decreased precipitation during the growing season, leading to more severe drought events, take their toll on forest vitality. Within the last years the national forest condition survey in Germany documented a decrease in vitality in all main tree species. Forest management now faces the task of developing a more climate adapted concept.

It is generally assumed that especially more frequent drought stress increases trees vulnerability on specific sites. This leads to a decrease in vitality, resulting in a reduced productivity and overall higher risk of other abiotic and biotic stressors. To establish tree specific drought limits as a reference for forest management we calculate the site water budget, being the sum of the climatic water availability in the growing season and the field capacity. On that basis tree specific thresholds for drought stress risk are defined based on literature, inventory assessments and expert knowledge.

In our project we evaluate the impact of extreme weather events of recent years on vitality and productivity on Forests in Northwest Germany through tree ring analysis (tree-ring width). We sample increment cores on plots of the forest condition survey, where concurrently soil survey data is available. To also evaluate the current drought risk thresholds for each tree species (European beech, Scots pine, Norway spruce, sessile oak and pedunculate oak) the plots were selected along a site water budget gradient. For each plot a comprehensive amount of data is available describing site and individual tree characteristics. In this study we correlate inventory data of 38 years, describing tree vitality with tree ring analysis on overall 672 sampled trees.

Our special interest is to combine growth reaction with climatic extreme events and vitality factors like defoliation and fructification to better understand tree species specific limits and to better advise forest management for the future.

Ensuring the sustainability of wood harvesting from Dry Afromontane forest in Ethiopia

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Accurate information on the structure, volume, and diameter growth rate of a tree is an essential element to ensure wood harvesting from a forest. Unfortunately, such information is lacking from Dry Afromontane forests in Ethiopia. Thus, in this study, we aimed to quantify the stand characteristics in the Chilimo Dry Afromontane forest and assess the sustainability of wood harvesting from *Juniperus procera* Hochst. ex Endl. trees. We established 163 plots (400 m^2) in the forest and collected vegetation data. We also conducted growth ring measurements on 12-disc samples. We determined the diameter growth rate, the current and mean annual increments, the minimum logging diameter, and the cutting cycle. We estimated the harvestable volume of wood by combining four minimum logging diameters and five cutting cycles using a stand projection table. The findings revealed that *J. procera* trees have an average density of 183 stems ha^{-1}, a total basal area of 12.1 m^2 ha^{-1}, and a standing volume of 98.9 m^3 ha^{-1}. The mean annual diameter growth rate ranges between 0.50 and 0.65 cm $year^{-1}$ with an overall mean of 0.59 cm $year^{-1}$. The population followed a reverse J-shape diameter distribution pattern. The current annual increment (CAI) occurred at 49 years, and trees reached 30 cm in diameter. The mean annual increment (MAI) occurred at 91 years. and trees attained 50 cm in diameter. Among the evaluated scenarios, the minimum logging diameter of 40 cm and a cutting cycle of 15 years provided the highest harvestable volume of wood (21 m^3 ha^{-1}) and volume increments (1.42 m^3 ha^{-1} $year^{-1}$). In addition, this scenario will enable us to preserve 82 % of the initial tree density and ensures the sustainable extraction of wood from the forest. We concluded that the forest is well stocked and has a substantial amount of harvestable volume of wood. This will enable Ethiopia to meet the growing wood demand. The study generated valuable information for policymakers to formulate a regulation for the sustainable harvesting of wood from *J. procera* trees from a well-stocked Dry Afromontane forest in Ethiopia.

Keywords: Logging, modeling, dendrochronology, cutting cycle, minimum logging diameter

Exploring the Influence of Climate and Soil Properties on Tree Ring Formation: Insights from a Multispecies Tree Ring Analysis in Central Europe

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Tree ring data is a valuable signal when it comes to growth reactions of trees due to varying environmental factors, in particular under a changing climate. Drought susceptibility and limits of different species has been the focus of many tree ring studies. However, the role of soil properties is not yet well understood due to limited data availability. To address this gap, we explored the influence of climate as well as soil compensating effects on tree ring formation.

We used a comprehensive dataset of 6 tree species (*Picea abies, Abies alba, Larix decidua, Pinus sylvestris, Fagus sylvatica, Quercus petrea* and *Quercus robur*) consisting of increment cores collected from mature stands at ~2,500 forest sites distributed over 2 Mio. hectares of forest in Austria with steep climatic and environmental gradients (mean annual temperature: 2.1°C to 11°C; mean annual precipitation: 450 mm to 2000 mm). The dataset includes detailed plot-specific climate, stand, and soil information. Soil data was obtained through a morphological description of 80 cm soil pits excavated at each forest site, laboratory analyses on a subset of ca. 20 % of the plots and upscaling of physical and chemical properties via pedo-transfer-functions for the remaining sites.

Generalized additive mixed models were fit to the data incorporating tree and stand attributes (e.g. age, competition), topographic factors (e.g. slope, aspect, irradiances), climatic factors (mean annual temperature, climatic water balance and drought indices) and detailed soil parameters (soil type, soil nutrients, plant available water capacity).

The model based on 2/3 of the data explains over 80 % of the variation in tree ring data and is currently being extended to include the climatically drier forest sites, where data collection was finished by the end of 2022. Tree growth depended on age, topographic factors, mean annual temperature, climatic water balance and plant available water capacity of the current and previous year and soil nutrient status and interactions thereof. Maximum growth was found on sites with sufficient soil moisture and nutrients and declined with a lack or surplus of water and nutrients. Species specific growth reaction were in line with the tree species auto-ecology.

Identifying proxies for drought tolerance in Sitka spruce to enhance forest resilience

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Extreme drought events across the UK are expected to increase in the future, both in intensity and frequency. Droughts can have an impact on tree growth and are a possible cause of wood defects in trees, causing cracking which can impact the structural integrity of timber. Wood density has been linked to predisposition to cracking and is also considered a potential heritable trait. Understanding the heritability of wood density and its link to drought resilience and resistance could make wood density an important proxy for resilience. With Sitka spruce (*Picea sitchensis* Bong. Carr.) being the most common and commercially important tree species in the UK, determining whether we can screen and select families of Sitka spruce showing higher resilience against drought would be of great value to tree breeding and forest management.

To answer this question, we measured tree-ring width and wood density in X-ray densitometry scans of samples taken from over 600 trees originating from 29 full-sibling Sitka spruce families growing on two sites in the UK. Individual nonlinear mixed-effects growth models were developed for both sites to remove non-climatic effects on growth. Drought events were identified using the standardised precipitation evapotranspiration index. The reaction of individual trees and families to a specific drought event (2003 to 2006) was measured using established resilience, resistance and recovery indices which compare growth before, during and after the drought event. Heritability calculations were performed to estimate the hereditary potential of the trait of wood density. Preliminary analysis suggests that although families do differ in resilience and mean density, their relative ranking in these traits is inconsistent between the two sites.

Life after recovery: post-drought compensatory growth and forest recovery dynamics

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Large scale losses in forest productivity and widespread tree mortality linked to extreme drought have now been documented on every forested continent on earth. With climate change set to increase the frequency, intensity, and duration of future extreme drought events, understanding the impact of drought on forest productivity and the post-drought recovery dynamics of these systems is increasingly important. However, the way we quantify the resistance, recovery, and resilience of tree growth to drought constrains and simplifies the temporal scale and resolution of our assessments. In turn, this limits our understanding of how forests respond and recover by partially obscuring a more complete understanding of drought legacies. To build on one of the most commonly used approaches to estimating resilience, we first demonstrated how our understanding of the drought resilience for *Pinus sylvestris* is dependent on the way in which resilience indices are calculated, using different pre- and post-drought time scales. We then developed an alternative approach using dynamic regression to capture each individual tree's relationship between climate and growth, which was then used to forecast tree growth annually for the drought year and nine subsequent years, in a scenario where no drought had occurred. This approach allowed us to increase the temporal scale and resolution of resilience assessment by comparing observed growth with forecasted growth in a 'no-drought' scenario and follow tree and stand level growth response throughout recovery and into a post-recovery phase, where we find evidence for significant compensatory growth. The existence of compensatory growth post-recovery reduced estimates of drought linked losses of radial growth, indicating that current approaches to quantifying drought impact risk underestimating tree and stand resilience and may overestimate losses in above-ground biomass. Our results have wide reaching implications for forest management targeted at increasing resilience, carbon budgeting and our understanding of drought legacy.

Long- and short-term impact of climatic conditions on mountain forest growth in the Alps along an elevation transect

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Climate change is increasingly affecting mountain forests by an increasing frequency and intensity of extreme events such as drought or storms, but also by increasing growth conditions at high elevations due to higher temperatures and longer growing seasons. To investigate the long- and short-term growth responses of five conifer (*Larix decidua, Pinus cembra, Picea abies, Pinus nigra, Pinus sylvestris*) species to different and changing climate conditions, we combined tree ring analysis with dendrometer and sap-flow measurements starting in 2012 along an elevation gradient from the valley floor at 1000 m to the forest line at 2300 m above sea level within the LTSER platform Matsch|Mazia in the province of Bolzano/Bozen, Italy. We found a strong limitation of tree growth and transpiration by water availability at low elevations independent of species. At mid-elevations growth responses to precipitation were strongest for *Picea abies* and increasing in recent decades. Temperature responses at high elevation differed between *P. cembra* and *L. decidua* leading to growth increases of larch in recent decades. In a current project we are now adding xylogenesis and wood anatomy analysis to dig deeper into climatic impacts on wood formation and its influence on carbon storage and tree hydraulics. Given the location of the study area in the inner Alps and the resulting dry climate conditions, our measurements results could be a preview of conditions relevant to larger regions of the Alps in the future.

Pre-monsoon moisture sensitivity determines growth resilience of four Asian pine species

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: The increasing frequency of drought events poses a threat to forest stability, and the resilience of trees to extreme drought is directly related to trees and forests safety. However, the growth resilience of trees is affected by many factors, characteristic with regional and species specificity. Focusing on southwest China and Indochina Peninsula, this study used four widely distributed pine species (*Pinus densata, Pinus yunnanensis, Pinus kesiya, Pinus lattrei*) tree ring data, aiming to explore the resilience of trees to extreme drought events and reveal the influencing factors of growth resilience. The results showed that all species tree growth was markedly limited by pre-monsoon water conditions. We used pre-monsoon season 3-month standardized precipitation-evapotranspiration index (SPEI3) to identify the extreme drought events and then calculated resistance, recovery, and resilience for the quantification of tree growth resilience. We fund significant differences in drought resilience between species of our study pine, *P. densata* and *P. latteri* had highest resistance, *P. yunnanensis* had highest recovery. There was a tradeoff between resilience index, and growth recovery decreased with resistance increased, high resilience related to high recovery but was not relative to resistance. Trees growth rate and tree size effected growth resilience. Drought severity influenced trees recovery and resilience but not resistance. The sites which sensitive to pre-monsoon drought declined more in drought events but had higher recovery. However, there was no significant difference in the factors affecting drought resilience among different species. The results of our study will help to understand the adaptability of coniferous forest ecosystems to global climate change, and provide theoretical basis for management measures of coniferous forest resources in tropical and subtropical Southeast Asia regions.

Keywords: extreme drought, tree ring, growth resilience, pine, drought sensitivity

Quantifying drought impact on tree growth and wood formation: observations along an elevation transect in a dry alpine valley

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Drought is increasingly affecting forest health and mortality, even in mountain areas. The Matsch valley (province of Bolzano/Bozen, Italy), one of the driest areas in the Alps, has been strongly affected by the 2015 and 2018 summer droughts and could be considered as an example of future scenario for larger areas in the Alps.

We expect drought to differently impact the timing and duration of wood formation processes along the elevation gradient and species. In particular, the lower elevation sites should be more affected by drought due to the combined effect of higher temperatures and lower precipitation. At lower elevation site, warm temperature in spring can lead to an earlier start of the wood formation process but then low water availability may lead to a premature cessation of xylogenesis or a dormant period. In contrast, climate warming can lead to a longer growing season at higher elevation due to earlier snow melt. We expect a difference between species as Pinus are less susceptible to drought than spruce and larch. Additionally, we hypothesize that deciduous larch might start xylogenesis later than evergreen spruce or pine.

Since 2012 we are monitoring tree growth along an elevational transect from 1160 to 2250 m a.s.l. that includes four plots with 4 species (40 trees total): 20 *Larix decidua* Mill., 10 *Pinus cembra* L., 5 *Pinus nigra* Arnold and 5 *Picea abies* L using dendrometers. These useful measurements to estimate both growth and water stress, have now been complemented by observations of wood formation (xylogenesis) by performing weekly micro-coring of xylem-cambium-phloem tissue during the growing season 2023. Xylogenetic analysis can directly determine climatic aspect on wood formation. Drought can impact the kinetics of wood formation, causing a lower number of cells produced, smaller and thinner cell walls and a longer duration of the formation phases.

To provide a better understanding of the impact of drought on wood formation, our contribution will provide original quantifications of the impact of drought on wood growth phenology of trees at different elevation and species within the Match valley monitored sites.

Rapid beech decline under recurrent drought stress. Findings & perspectives.

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: During the summer of 2022, an acute drought once more afflicted central and southern Europe. This marked the third episode (after 2015 and 2018) of severe aridity in large parts of Germany within the last decade, leading to increased soil water depletion. Consequently, from July 2022 onward, European beech trees (*Fagus sylvatica* L.) exhibited early withering and pronounced premature defoliation. Nevertheless, crown defoliation exhibited substantial variation among trees within the same forest stands, prompting questions regarding the causal factors. In our study, we scrutinized twelve major drought-impacted, beech-dominated forest stands in northern Bavaria, arranged along a gradient of different nutrient regime levels (base-rich, intermediate, base-poor), with co-occurring vital (≤ 40% crown defoliation) and declining (≥ 60% crown defoliation) trees. Within each stand, we selected an equal number of vital and declining trees, culminating in a total of 332 target trees. Dendrochronological patterns were analysed to identify a potential timing of growth separation between vitality classes. Moreover, we used a Bayesian modelling framework to discern whether disparities in tree vitality hinged on competition, structure, small-scale differences in plant-available water, and competitor vitality. We further explored the factors influencing the magnitude of recent growth decline and how these were modulated by the site's nutrient regime. Our study unveiled that (i) vital and declining trees exhibited strikingly similar growth trajectories in the past, which underwent a drastic shift in recent years, indicating a potential for a rapid vitality and growth decline under recurrent severe drought stress; (ii) low and asymmetric competition bolstered tree vitality; (iii) declining trees were spatially aggregated; (iv) plant-available water emerged as a crucial determinant of tree vitality disparities within the same forest stand; (v) growth decline was most pronounced at base-poor sites. Our findings underscore the importance of accommodating small-scale differences in soil and stand characteristics and advocate for silvicultural guidance towards reduced stand densities in combination with a more heterogenous structure to mitigate European beech dieback in drought-prone forest stands.

Upscaling dendroecological studies at different spatial sampling designs: a case study on sessile oaks along a climatic gradient

T1.9 Dendroecology for Evidence- based solutions and Resilient Forest landscapes

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Abstract: Tree-rings provide the longest available quantitative records of tree and forest growth conditions, even in forests with extensive management history. Although dendroecological sampling designs are typically planned for local representativity without a comprehensive collection of tree cores along a greater region, the integration of different sampling designs could facilitate the upscaling of findings, conforming the information needs of large-scale forest planning.

Sessile oak (*Quercus petraea*) is an ecologically and economically important forest tree species in Central Europe, experiencing a potential renaissance of forest management interest, due to its wide but sometimes debated limits of drought tolerance. Within the frame of a forest site classification project in Northern and Eastern Austria over a forest area of ca. 800,000 ha, single tree core sampling at 1020 stratified sampling sites was carried out, with about a 25% share of oak stands significant for the region. In addition, seven monitoring sites have been established for the species with 15 trees sampled at each, spanning along a climatic gradient between 550 to 1250 mm annual precipitation and 7.7 to 10.8 ° C mean annual temperature. This gradient represents the entire climatic range of the species in Austria, while also approaching the xeric edge of its distribution.

Along this wide climatic gradient, the sensitivity of growth to the climatic drivers, drought induced growth anomalies, and the variability of individual tree response are tested in common multivariate statistical tools and machine learning algorithms at the different sampling scales. The statistical models are built and cross-validated on the complementing sampling designs. Mean climatological differences and other site and stand attributes are also included as predictors with lower frequency of temporal change to account for the (shifting) climatic gradient.

While previous data from similar single core sampling in the neighboring southern regions of Austria yielded promising results when modeling radial growth, the extension of the monitoring sites along the climatic gradient further reveals differences in growth patterns and their individual variability. This sets an interesting scene for the evaluation of findings at different scales, allowing also for a spatially explicit comparison of the climatic sensitivity of the selected species.

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

Assessing adaptability and resilience of pure species and hybrid clones of Eucalyptus grandis and Eucalyptus camaldulensis in Kenya.

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract:
Hybrid crosses between the fast-growing *Eucalyptus grandis,* for high potential sites and *Eucalyptus camaldulensis*, for low potential sites are important for addressing challenges of commercial forest productivity brought about by climate change through adaptation initiatives. This study was initiated to demonstrate options for increasing productivity and quality of timber from planted forests amid the ravaging effects of climate change. The objective of the study was to determine the resilience of the Eucalyptus hybrid crosses and the pure species in terms of survival and growth in a medium potential site in Kenya. A Randomised Block designed (RBD), experiment was established with 34 treatments consisting of 15 clones of crosses between E. grandis and E. camaldulensis (GC), 18 pure E. grandis clones, all developed in South Africa, and one local E. grandis clone. Survival after establishment and growth parameters of height, and diameter at breast height (DBH) were assessed annually for seven years. Wood volume of the clones was determined from the growth parameters against weather components. Results show higher survival of pure species of *Eucalyptus grandis* clones with more than 50% trees surviving in each treatment. At age seven, the best performing clone showed growth in volume of 3,875.1m^3. Overall, there was a significant difference in volume growth among the clones, with hybrid clones consistently showing higher volumes compared to the germplasm of the pure species. The results confirms the potential of hybrid crosses as a viable option to increase productivity of forests in medium potential zones as well as a means of mitigating against the vagaries of climate change.

Key words: *Eucalyptus grandis* clones, Eucalyptus hybrids clones, resilience, climate adaptability.

Ecosystem Services Modelling of Ecologically Degraded Forested Wetland (Montreux Site)

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Forested wetlands provide essential ecosystem services. Anthropogenic activities such as agriculture have increased the degradation and conversion of privately held wetland regions. The Montreux sites are the Ramsar sites of international importance where ecological changes have occurred, are occurring, or are projected to occur as a result of technological advancements, pollution, or other human influence. Ecosystem service valuation can guide restoration decisions. Therefore, the objective of the current study is to evaluate ecosystem services provided by ecologically degraded wetland ecosystems with a view to proper restoration and management practices. The study includes InVEST model for the valuation of ecosystem services. In this research, we discuss how such findings could influence local policy for environmentally responsible management and set a baseline for the vast wetlands networks. The study concluded that forested wetland plays a significant role even after the ecological conversion. The areas with high ecological degradation have shown low ecosystem services in terms of water storage, vegetation covers as well as carbon storage. These hotspot areas should be prioritized for the ecological restoration of the Montreux site. Keoladeo National Park, Montreux site, has recovered its ecological disturbances in several parts being a protected area. This is a positive sign for the study site that is an indication for its improving ecological condition.

Effects of forest harvesting technologies on the hydrology of compaction-prone soils

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Forest soils usually show high infiltration rates and thus, compared to other landuses, a quick recharge of the soil water storage, a reduced peak flow and a prolonged base flow.Soil structure is crucial for both, the infiltration rate as well as the plant available soil water storage capacity.

Different mechanical stresses caused by different harvesting technologies as well as biological remediation measures have, however, a short- and long-term impact on the infiltration rate and the water storage capacity of forest soils. Analysing the effects of fully and highly mechanized timber harvesting practices on the hydrology of compaction prone soilsis one of the objectives of a project, funded in the framework of the Austrian *Waldfonds*. The project focusses, in general, on how to secure the sustainability of forest soil functions in hardwood forests. In course of this project, water infiltration, surface runoff, water storage as well as water availability are being investigated on different scales, before and after the timber harvesting intervention using two harvester-forwarder (HF) configurations‘(w/wo bogie tracks) or cable-yarding with motor-manual-felling (CCM)‘. This includes rainfall simulation experiments and continuous as well as discontinuous soil moisture measurements.

Preliminary results, considering surface runoff, indicate a strong change in rainfall-runoff behaviour following timber harvesting operations. Rainfall events on recent, highly compacted skidtrails suggest a significant increase surface runoff. We further observe higher soil water content as a result of the lack of vegetation activity and the changed soil structure after harvesting. By linking the direct hydrological effects of timber harvesting with other affected soil functions, a holistic perspective is created, which will lead to recommendations for soil-conserving timber harvesting on soils at risk of compaction.

EFFECTS OF FOREST RESTORATION ON THE HYDROLOGICAL REGIME

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Changes in land use has generated several consequences in ecosystem services and/or functions supported by forests, including water services. In this context, the United Nations Decade of Ecosystem Restoration 2021-2030 was established, and therefore more forest restoration projects worldwide have been occurring. The vegetation biomass affects the partition of precipitation in flow and evapotranspiration. Thus, the forest succession promoted by restoration also affects the quantity, quality, and regulation of the flow at the local scale. Despite this well-known relationship between forest and water, the implications of restoration forests in tropical region in water dynamics are an ongoing study and there are some knowledge gaps. In this study, the objective was to evaluate the effect of forest restoration on the hydrological dynamic at local scale using three paired catchments with 5- and 10-year-old restoration (RF10, RF5), and pastures (PA) considered the zero age in a semideciduous forest in the southeast of Brazil. Our results show that the base flow index (BFI) is higher in the catchment under PA (0.852), while the difference between the restoration catchments is low, with a BFI slightly higher in RF10 (0.655) than FR5 (0.503). The water yield was lower in the RF5 catchment (3.45%), which can be explained by the higher water consumption in the first years of establishment, while the RF10 and PA catchments had almost the same value (8.37% and 8.30%). In RF10, the higher value can be explained possibly due to the improvement in soil porosity, infiltration, and protection from the impact of rain. Regarding the flashness index, the RF5 catchment had the highest value (0.309) followed by RF10 (0.215), showing that with greater age of the vegetation, there is an improvement in the regulation of flows in the catchments, making them more stable; Contrary to expectations, PA (0.068) had the lowest value, with the most stable flow. We can conclude that even 5 and 10 years after the restoration, the establishment of vegetation can improve the flow regulation function, however, the water consumption throughout its development must be evaluated, in addition to studying better the soil properties in PA catchment.

Enhancing forest resilience for water-related ecosystem services in a changing environment

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: To meeting organizers:
I am invited as a member of the panel discussion, so I don't know what I could say here.

Enhancing water resources through restoring resilient forests in the U.S.

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: About 30% of the U.S. is covered by forests which provide a myriad of ecosystem services locally (e.g., clean water and air, aquatic habitat) and globally (timber supply and carbon sequestration). For example, it is estimated that 50% of the national total water yield is derived from forests and over 150 million or half of the US population benefit from forestlands for drinking water supply. However, these forests are increasingly stressed by climate change, urbanization, wildfire, biological invasion, and insects and disease outbreaks. For example, due to climate warming and fire suppression, the southern forests have experienced "mesophication" - forests have become too dense and plant species have shifted, resulting in decline in water yield and rise of wildfire risks even in a humid region. Similarly, meeting demands of timber productions during the past century in the region has favored fast growing pines (e.g., loblolly pine, *Pinus taeda*) have resulted in tremendous loss of 'open forest' ecosystems such as longleaf pine (*Pinus palustris*) forests. Restoring longleaf pine ecosystems with frequent prescribed fires is being considered as one approach towards enhancing regional forest resilience and improving water yield and other ecosystem services. This paper presents results from recent case studies that show forest management has the potential to improve forest ecosystem resilience and benefit ecosystem services in the U.S.

Forest disturbance thresholds for cumulative hydrological impacts in the Montane forests in British Columbia, Canada

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: The forest disturbance threshold is defined as a critical disturbance level in forested landscapes above which cumulative and significant hydrological impacts are detected. Determining disturbance thresholds is critically important for supporting forest management to ensure sustaining of ecological and hydrological functions and services. However, there is no quantitative evaluation of forest disturbance thresholds regionally or globally. In this study, we applied the modified double mass curve, MDMC, to derive the long-term, continuous hydrological response curves and to quantify forest disturbance thresholds on annual streamflow in 42 Montane forested landscapes in British Columbia, Canada. We find that the average forest disturbance threshold for significant and cumulative hydrological impacts is 17.28% of cumulative equivalent clear-cut area (CECA) ranging from 7.20 to 51.67%. We also find that climate (inter-annual and intra-annual) and watershed properties exert critical controls on forest disturbance thresholds. Watersheds with greater snowfall proportions, more desynchronization of energy demand and water supply, lower ecosystem diversity, larger watershed sizes, lower water retention capacities, and steeper slopes have lower forest disturbance thresholds. These results have important implications for managing water supply and other hydrological functions under increasing forest disturbance and climate change impacts in the region.

Forest Landscape Restoration through multi-pronged approach in catchment of Yamuna river

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Water and forests are intimately associated and dependent on each other as forests are important part of hydrological cycle. Majority of the areas that are facing severe water scarcity are those where forests and trees are currently scarce. The predicted shift in suitable climatic conditions for forest trees and ecosystems under climate change presents a challenge for large-scale restoration of deforested and degraded forest ecosystems. So the need is to evolve and practice climate-smart forestry to maintain a synergy between carbon sequestration and water usage by species. Under Indian government's programme on Greening India Mission and rejuvenation of the major Indian rivers, large-scale forest restoration activities alongwith soil and moisture conservation inputs are being taken up in degraded forest areas and river catchments. The study presents such approaches being practiced and envisaged for future, in the catchment of river Yamuna which is the largest tributary of the Ganga. The drainage basin of Yamuna is 366,223 km^2 in size which comprises areas of seven states, viz., Uttarakhand, Himachal Pradesh, Uttar Pradesh, Haryana, Delhi, Rajasthan and Madhya Pradesh. The major portion of the basin lies in semi-arid climatic region. Forest department regularly undertakes afforestation, soil and moisture conservation, wetland management and other forestry activities in the Yamuna basin.

The width of treatment zone (riverscape) was taken as 5 km on both sides of Yamuna and 2 km on both sides of its tributaries in plains. The entire catchment area of Yamuna was included in the riverscape in Uttarakhand and Himachal Pradesh, as well as untreated watershed area identified by Rajasthan forest department. The riverscape has three landscape classes viz. natural, agriculture and urban/peri-urban, and plantation activities are proposed for all. Activities commonly carried out in forest areas are planting of trees (oaks, fir, spruce, birch, maples, etc. in Himalayan area), shrubs, grasses, medicinal plants, enrichment plantation and low-cost soil and moisture conservation. In riverfront development, trees, shrubs and grasses have been planted to stabilize the riverbank and control soil erosion. Thus, with these measures it is hoped that forest landscape restoration in the river catchment will enhance its ecological and economic resilience.

Groundwater resource dynamics post plantation forestry in quaternary catchment K30C in the Southern Cape region of South Africa

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

Tatenda Mapeto

Abstract: Intensively and sustainably managed plantation forests are an important land use in South Africa. They supply the bulk of the country's timber, fibre, pulp and paper requirements while generating local and export income, providing jobs and ensuring the conservation of natural landscapes that are mosaiced within plantations. These benefits of the commercial forestry sector are clear, yet they do come at considerable environmental costs, particularly the impact on water resources. Numerous studies have now conclusively indicated that plantations of introduced tree species consume more water than grasslands, shrublands or indigenous forests that they replace and thus they reduce water yield (stream flow) from afforested catchments. Additionally, while the hydrological cycle is well documented, the links between the interdependent components of ground water and surface water interactions as a function of land use and land use change are less understood. There are currently limited studies that have monitored groundwater resources during a rotation of plantation forestry stands and a few years after the formerly afforested land is cleared and currently in transition back to the natural or baseline vegetation landscape. This study quantified the groundwater resource dynamics after previously afforested land was fallowed and transitioned to natural vegetation within a mosaic of introduced species natural regeneration resulting from the seedbank of the previously planted introduced species stands. A comparative analysis of groundwater level dynamics monitored when the catchment had fully stocked plantation stands versus when the plantations have now been phased out is presented. The study therefore quantified, extrapolated, and compared groundwater resource dynamics in a quaternary catchment with stands that were previously afforested with introduced species and intensively managed for timber production. The work complements progressing scientific efforts to understand eco-hydrological patterns in tree production systems in a country where the best possible use of water is sought.

How light and atmospheric demand modulate tree transpiration in a mixed boreal forest

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Trees are pivotal regulators of water balance in boreal forests. Through evapotranspiration, they are key drivers of mass and energy transfer. Evapotranspiration can be partitioned into 50% evaporation (including interception) and 50% transpiration during the growing season. Yet, transpiration is a dynamic, species-specific process that can vary considerably according to climatic conditions and vegetation type. In general, trees at high latitudes experience contrasting light availability and temperature conditions during the growing season. Day length can be more than 20 h in summer and just above 10 h in early spring, and during this period temperatures can fluctuate from below freezing to 30°C. Under these circumstances, it is essential to make efficient use of the available resources, while responding promptly to the current environmental conditions.

Under non-limiting soil moisture conditions, the main environmental drivers for tree transpiration are light (Photosynthetically active radiation, PAR) and atmospheric demand (vapor pressure deficit, VPD). However, it is not clearly understood how tree transpiration responds to these factors throughout the season, and what the species-specific patterns are.

To elucidate this, we deployed sap flow sensors in a boreal forest in northern Sweden, on the three most dominant tree species: Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* (L.) H. Karst), and Silver birch (*Betula pendula* Roth). For a period of three years (2019-2021), we monitored daily tree transpiration and environmental variables. We separately analyzed transpiration response to PAR and VPD to identify seasonal differences and species-specific patterns. Our data suggest that PAR and VPD are indeed strong drivers of transpiration, but the tree's response to them is not constant throughout the growing season.

Overall, light conditions tend to be set for a given latitude, however VPD and species composition in high-latitude boreal forests is projected to change in the upcoming decades. To estimate how the water and energy balances will be influenced, it is crucial to understand how the interaction between light and VPD can regulate tree and forest transpiration and evaporation rates.

Hydrological resilience indicator: understanding how forest management can mitigate water scarcity effects

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Forest plantation areas are increasing in Brazil, reaching more than 9,9 million hectares. Suzano SA are an important part of this movement once the company has an important portion and a key role in the Brazilian forestry sector. The expansion frontier of forest plantation in Brazil has moving to humid subtropical and tropical climate, in a landscape predominantly covered by Savanna biome. Therefore, understanding forest-water relation is fundamental to enhance forest resilience and support water ecosystem services in this biome. In this context, the goal of our study is to understand the relation of climate effects on water supply in forest occupied catchments. Based on this knowledge, we established environmental indicators to determine the level of hydrological sensitivity in these catchments. Firstly, we delimited watershed boundaries for study area (Midwest of Brazil) and developed two indicators in each watershed: hydrological sensitivity indicator and forest management indicator. The hydrological sensitivity can be defined as local intrinsic hydrological characteristic and it was obtained as a function of four variables: water availability, annual precipitation seasonality, digital model of terrain and curve number (CN-SCS). The sum of these variables was further classified into five classes from lower to higher hydrological sensitivity. The indicator that represents forest management intensity is the sum of three variables: forest coverage percentage, forest plantation density and forest age mosaic. This indicator was classified into five classes from lower to higher management intensity. The ratio between watershed hydrological sensitivity and forest management intensity provided the hydrological resilience indicator, but they can be used separately to identify where the natural conditions afford management flexibility and where the best practices of management are essential. Our results showed that areas with higher hydrological sensitivity represents 6,2% of total watershed analyzed, trending to concentrate in Midwest of Brazil. The indicators allow us to understand which are the watersheds with highest hydrological sensitivity, where forest management can mitigate the effects of water scarcity, making forests more resilient, especially in the face of climate change.

Improving ecohydrological resilience of forest plantations in Brazil by landscape management

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Forest plantations in Brazil are increasing in last years reaching more than 9 million of hectares in 2022, due to internal and external demand growth for fiber and wood. Forest management plans are seeking environmental sustainability of those planted areas, guided by crescent restrictions enforced by government, environmental certification and society pressure. Landscape indicators commonly reflects environmental management, and the development of tools for landscape analysis and monitoring could be an opportunity to improve forest management in order to conserve biodiversity, water and ecological processes. Based on long-term stream monitoring data of several experimental catchments installed on forest plantation landscapes along Brazil and Uruguay, field data collection regarding biodiversity and insect damage, we analyzed the relationship between landscape indicators and ecosystem services related to biodiversity, water, soil and pest management. Landscape indicators were calculated based on climate, soil, terrain and landscape composition and structure related to different components of forest plantation ecosystem: eucalyptus plantations (genetic material diversity, age diversity, roads design, watershed composition) and natural areas (vegetal typology diversity, landscape proportion, edge density, proximity and core area). Data used for indicators calculation was extracted of land-use maps including forest stands, roads, and natural vegetation. Our results show that many field observations were related to landscape characteristics (natural or anthropogenic) like pest damage frequency, natural areas biodiversity, suspended sediments and stream flow regime. Based on results, we suggest a framework with landscape management alternatives to improve ecohydrological resilience on forest plantation ecosystem.

Landholders leverage over moisture flows and forest resilience in South America

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Moisture originating (i.e., evaporation) from the Amazon rainforest contributes to the rainfall over the forest and human-influenced land systems in South America. However, the alarming rate of land-use change by landholders in the Amazon – mostly due to agricultural expansion – poses serious threats to regional water cycling. On the one hand, this loss of moisture over forests reduces their resilience to future hydroclimatic perturbations (e.g., droughts). Loss of moisture over human-influenced land systems, on the other, threatens rainfed agricultural yields. However, the leverage these landholders have over the downwind rainfall is uncertain. Understanding their influence will help us realise the potential of land-use-change impact on the regional water cycle. In this study, we analyse landholders' leverage over atmospheric moisture flows and the resilience of forest ecosystems in South America. Using the remotely sensed MapBiomas land-use dataset and the output of an atmospheric moisture tracking model - UTrack, we analyse moisture flows from different spatial explicit landholder-dominated regions to natural and anthropogenic land systems. We find that of all the moisture originating from small (3.0×10^3 $km^3\ yr^{-1}$), medium (0.6×10^3 $km^3\ yr^{-1}$) and large (4.7×10^3 $km^3\ yr^{-1}$) landholders, contributes to the rainfall over the forests. Furthermore, nearly half originates from the forests within these landholder-dominated regions. We also find that all landholders' equally influence the rainfall over nearby land systems and those situated further downwind. Among them, smallholders have a disproportionately larger influence over forests' rainfall (19-39% more than other landholders). Despite this, large landholders strongly influence forest resilience in South America, along with their disproportionately larger influence over the agricultural land systems (29-116% more than other landholders). The results from this study emphasise the need for more stringent forest policies to factor in the influence of deforestation on downwind landholders and promote effective ecosystem stewardship.

Light at the end of the tunnel or will-o‘-the-wisp? Best practices in integrated forest and water management in Germany beyond sector fragmentation

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: The drought years in Germany since 2018 have highlighted the close relationship and interdependencies of forest and water resources and raised awareness about the negative effects of lacking precipitation and declining groundwater levels for forests. While water resources have turned into a prime concern on the agenda of forest actors, water resource management is only beginning to perceive forests as relevant for its area of responsibility. This fragmentation seems to prevail despite numerous disturbances affecting both forest and water resources and management. To successfully adapt to changing circumstances, however, joint efforts will be necessary in order to advance integrative management practices. These practices must aim at increasing water retention capacities to buffer droughts and floods, improving forest soil infiltration capacities and optimizing tree species composition to maintain forest cover under crisis conditions. In our research we contribute to both policy as well as management practices necessary to improve resilience of water forest ecosystems. Based on expert interviews and focus group discussions, we identify best practices in forest and water management, including the development of institutionalized policy integration across sectors. Data was collected in five highly affected local regions of Germany, which were selected according to maximum range sampling concerning type of disturbances and landscapes. Overall, our results contribute empirical evidence on best practices in integrated resource management policies and measures and their transferability to different regions and countries, while at the same time they provide valuable insights into the conditions for successful cooperation, the potential for integration and possible indications for limited benefit.

Management for forest multi-functionality with special emphasis on water

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Forest management and forest operations have the potential to impose large negative effects both at the site in question and in neighbouring ecosystems. These effects can include abiotic as well as biotic disturbances and can vary depending on climate, soil properties, forest operation systems, and forest management strategies. Decisions on forest management should account for carbon balance, biodiversity, wood supply, and other ecosystem services, especially those related to hydrology and water quality.

This presentation will focus on the ways forest harvesting can affect both water quantity and water quality and will include aspects of forest management, technical solutions, and knowledge exchange/transfer to reduce forestry impacts. Some of the negative effects of forestry on water flows, water quality and aquatic ecology could be counteracted by improved management and logging planning, use of technical aids, and knowledge transfer between involved parties. The development of best management practices (BMPs) such as the use of forest buffers, protecting discharge areas, water sensitive driving and other low impact techniques could in some cases prevent impacts on water quality. Technical adjustments to machines, e.g., high flotation tires, use of extra bogie axle, lower inflation pressure, and use of steel flexibles tracks. Driving damage can be reduced using techniques to reduce soil compaction along the trails, e.g., brush mats, together with improved route planning. By implementing a small number of relatively low cost changes and adaptations, forestry can take greater concern for water related ecosystem services, which will contribute to more resilient forest ecosystems.

Managing forest hydrological services: Integration into forest management plans and applied implications in Aegean region

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Forests act as natural sponges, absorbing rainfall and reducing surface runoff, thus preventing soil erosion and flooding downstream. The intricate root systems of trees enhance infiltration and groundwater recharge, ensuring a reliable water supply. However, forest management practices often face a conflict between erosion prevention and water provision. Logging and other forest activities can boost surface runoff, but also lead to soil erosion, water quality degradation, and harm groundwater. In some cases, in order to provide more water to dams, more trees are removed compared to standard silvicultural practices, and deciduous trees are more preferred over mixed or coniferous ones. Balancing and enhancing hydrological services for forest resilience and incorporating them into forest management require evaluating spatial information and local knowledge.

Our study focused on three dam watersheds in the Aegean region of Türkiye, assessing forest hydrological services beyond administrative district boundaries. We evaluated erosion prevention and quantified water yield by determining runoff coefficients for different land-uses, forest types, and hydrological soil groups, we modelled these services and validated through field surveys and stakeholder workshops. Slopes above 59% are considered severe in Türkiye. Forest conservation practices are carried out to prevent erosion with a slope of 60% to 79%, and to protect nature in forests with a slope of more than 80%. However, both models and field analyses have revealed that slopes starting from 40% are also significant for these services. For the study area, less than 35% of runoff occurs in forest stands, leading to soil loss below 0.5 tons/ha/year.

Collaborating with the General Directorate of Forestry in Türkiye, management practices have been developed for the forest management plans to enhance forest resilience, increase water efficiency, and minimize soil loss based on abovementioned thresholds for forest stands that fall outside the specified values. These practices involved different silvicultural options at the stand level. Our study serves as an example of successful integration of watershed considerations through water-related ecosystem services and multi-scale approach. It incorporates diverse mapping and modelling tools, proper monitoring, and the implementation of best management practices to minimize adverse impacts on these crucial ecosystem services.

Managing forests for water - lessons and challenges from implementation

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: This presentation will focus on the lessons and challenges during the implementation of projects that aim to improve the management of forests for water-related services as part of FAO's work. Over the past decade, FAO has been implementing projects, developing tools, advocating for and increasing the capacity of actors to improve the management of forests for water-related services, especially in the context of climate change. This presentation will include a brief overview of this work and will draw on examples from recent projects highlighting the lessons learned and challenges as well as the research gaps and priorities that have been identified. Examples will also cover different countries and geographies as well also allowing for discussion of governance considerations.

Managing forests for water-related ecosystem services under a changing environment

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Water-related ecosystem services such as water supply, flood control, flow regulation, soil erosion control, and climate regulation provided by forests are vital for human well-being. Frequent natural forest disturbances (e.g., wildfire, insect outbreak) and anthropogenic activities (e.g., deforestation, reforestation, and afforestation) can have profound impact on the provision of water-related ecosystem services by forests under a changing environment. This talk will share a world-wide synthesized work on the state of water-related ecosystem services of major forest ecosystems under changing climate, and the possible impacts of forest disturbances and anthropogenic activities on water-related ecosystem services of forested watersheds across different biomes. Forest management strategies for sustaining or improving water-related ecosystem services for different biomes will be recommended accordingly to mitigate negative impact of climate change and meet the growing human need for water-related ecosystem services of forests.

Mycorrhiza communities in a hybrid aspen plantation: first results

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Mycorrhiza is a crucial for water and nutrient absorption and hence tree growth, particularly under widely intensifying drought conditions. Though, mycorrhizal communities vary locally, as well as depending on the host genotypes implying uneven efficiency of the symbiotic interactions. Furthermore, mycorrhizae are presumed to largely participate in plant communication, thus facilitating tree defense against pests and pathogens. Hybrid aspens, which are highly productive due to heterotic gene interactions favouring growth over defence, are sensitive to herbivores and, due to intensive similariton, also to water deficit and hence droughts. Though there are explicit clonal differences in growth and sensitivity. In this study, mycorrhizal communities on fine roots of two clones with contrasting productivity growing in a clonal trial established in 2008 on former agricultural land in the mid-part of Latvia were assessed using classical microbiological (isolation and propagation) and molecular genetic methods (genomic analysis; ITS sequencing and OTU identification). The clonal differences in mycorrhizal communities between clones considering the local variation were assessed using the permutational analysis of variance (ANOSIM) which compare difference with and between groups. The results are discussed in regarding the functional ecology of mycorrhiza species.

Keywords: Populus tremula × Populus tremuloides; fungal communities; functional ecology; diversity-productivity relationships.

Role of plantation forest in hydrology : a short review

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: This presentation is made on behalf of the IUFRO task force on planted forests, this will review publication related to plantation forest role on hydrology. Many aspects will be addressed, some of them are listed bellow.

- After the storm occurred in France in 1999, the reduction of forest areas induced a lower precipitation regime in the following years that has been recovered one forest has been replanted.

- In Portugal, the effect of afforestation with eucalyptus plantations compared with pine plantation did not show significant changes of fluxes in the mediterranean headwater catchment

- In FORSEE project, looking for indicator on water quality in relation to forest, scientists concluded on a very simple proxy to estimate water quality.

- In Bresil a study confirmed that depending on the management intensity, the dryness index and the ratio of eucalyptus in the landscape, we can evaluate eucalyptus plantation impact on water catchments.

The effect of forest disturbances on hydrology in karst aquifers

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Mitja Ferlan[1], Janez Kermavnar[1], Blaž Kogovšek[2, 3], Erika Kozamernik[1], Aleksander Marinšek[1], Janez Mulec[2, 3], Cyril Mayaud[2, 3], Magdalena Năpăruş - Aljančič[2, 3], Metka Petrič[2, 3], Tanja Pipan[2, 3], David Štefanič[1], Daniel Žlindra[1], Lara Valentić[2, 3], Nataša Ravbar[2, 3]
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Abstract: Forest disturbances are an essential component of forest ecosystem dynamics. The effects of rapid loss of forest cover and other changes in forest ecosystems are inextricably linked to hydrologic processes such as evapotranspiration, soil and recharge processes. Among all hydrogeological systems, karst aquifers are important because of their rich and unique biodiversity, heterogeneity, and drinking water resources. At the same time, they are characterised by specific hydrological processes that make them highly vulnerable to environmental changes.

The effects of large-scale forest disturbances in karst aquifers have been only marginally addressed, although evaporation of water from the soil and epikarst is recognized as an important process affecting the hydrologic cycle in karst regions. In this study we present a holistic approach to infiltration processes research in Dinaric silver fir – beech forest after ice storm in 2014. To better understand infiltration in different compartments of the karst aquifer, an *in-situ* environmental monitoring network of the atmosphere-vegetation-soil-unsaturated zone was designed. Special attention is given to the different stages of forest development following large-scale disturbances and to the morphology of the karst terrain. The amount of precipitation in the open, canopy interception in mature forest and in canopy gaps with different stages of forest development, soil moisture content, and soil temperature are measured at the surface and subsurface. These measurements are performed in the area of the eLTER site Postojna-Planina cave system, i.e., on the top and bottom of karst depressions, while in the underground water discharge, temperature, and electrical conductivity are measured in cave drips. By observing the time lag of the measured parameters to recharge events, the effective infiltration of precipitation into the aquifer is evaluated and quantified.

The results allow us to distinguish recharge conditions at different forest development stages following large-scale disturbances and under different geomorphologic conditions. In addition, vegetation-hydrologic modelling of recharge conditions is presented and further upscaling of the modelling results from the local scale to the catchment-wide scale is preformed to evaluate the effects of large-scale forest disturbance on the water balance of the entire karst aquifer system.

The effects of forests on precipitation

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Whether forests influence precipitation patterns has been a matter of enquiry and debate for hundreds of years. A considerable body of conflicting research evidence has been presented by those who claim that forests do influence the amount and timing of rainfall, and those that think it does not. After a lull in scientific enquiry on the subject in the 20th Century, a revival has taken place partly driven by the intense interest generated by concerns over global warming and climate change. This renewed interest has led not only to new theories (e.g. the Biotic Pump) and ways of thinking about the subject (e.g. supply-side and demand-side), but also new research.

Recent studies have tried to shed light on the issue by utilising satellite data and long-term meteorological records, often combined with numerical models. These studies have been useful and many support the view that forests influence rainfall amounts, but empirical data is still lacking. This is partly due to the general increase in desk based studies relative to field based enquiry, but also some of the difficulties presented by the latter, such as the complexity of separating background climatic effects from the forest effect.

If forests do influence precipitation patterns there are wide-ranging implications for water supply, drought, ecological flows and flooding, to name but a few.

Here, we present some of the issues, knowledge gaps and solutions to addressing this key research question. We finish by introducing new research that aims to fill some of the knowledge gaps through both desk and field based approaches; the former utilises satellite and historical meteorological data whilst the latter is a field based empirical study.

Understanding the Relationship of Forest and Water Dynamics in a Changing Climate Regime: Insights from a Tropical Deciduous Watershed

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: Understanding the interlinkages between forest, water, and climate is vital for sustaining essential ecosystem services, ecological proliferation, and economic development. Furthermore, forests function as water and climate regulators while ensuring water security (quality and quantity), a major challenge globally. This necessitates the need for designing policies and strategies for effective management of forest and water resources. However, in the Indian context, policy and planning for natural resource management lack synergy and seldom consider the intricate feedback loops among forest, water and climate change. Forests in India (21.71%) are under pressure due to over-exploitation, climate change and deforestation, diluting the benefits and ecosystem services for forest-dependent communities (275 million rural and 88 million tribal people). India has the highest population (17.7% of the global population), with only 4% of the global freshwater resources, creating extremely high-water stress conditions (54%). The changing climate is catastrophic for both water security and ecosystem services linked to forests, especially water regulation, and there is a gap in research focusing on integration of climate variability with forest-water interlinkages in India. Our study attempts to understand the impact of climate change on forest disturbance and water quantity in the Dindori watershed (2313 km^2), a tropical deciduous forested watershed of the Narmada River in Madhya Pradesh. Long-term datasets of climate variables (rainfall, maximum and minimum temperature), observed streamflow, and land use & land cover change have been used as proxies for changing climate, water quantity and forest disturbance, respectively. Annual, monthly and seasonal trends for climate and water are assessed using time series analysis, non-parametric tests and change point detection. Multiple regression and sensitivity analysis is conducted to understand the integrated influence of climate on forest disturbance and water quantity. There has been a significant increase in minimum and maximum temperature, while rainfall patterns depicted no significant change from 1951 to 2020. Streamflow was more sensitive to changes in precipitation than LULC, as large watersheds are more resilient to forest disturbances. We further discuss the results in the context of existing forest-water policies and schemes for holistic forest-water management, focusing on ecosystem services and adaptation to climate change.

Water regulation on Amazonian streams depends on forest cover conservation

T1.10 Enhancing forest resilience for water-related ecosystem services in a changing environment

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Abstract: The Amazon rainforest is crucial for climate regulation worldwide and water supply to South America. The intensification of deforestation in recent decades may have altered the hydrological dynamics of its rivers, but few studies address this issue. In this work, we assessed the influence of forest cover loss in Amazon basins over the last three decades on the regulation of water flow in their rivers. Four indicators were used: high flows (Q10), low flows (Q90), RB-Flashiness Index (RBI), and Base Flow Index (BFI). We compared these indicators from 1985 to 2018 in 12 intact forest watersheds and 12 deforested watersheds, using Mapbiomas Panamazonia data. Daily discharge and precipitation data came from the CAMELS-BR dataset. To test the effect of the dry season, we categorized basins as dry season absent (average monthly precipitation consistently above 100 mm) or present (other basins). Results showed that deforested watersheds had higher Q10, therefore the loss of forest cover leads to an increase in high flows, regardless of the dry season. In the same direction, the RBI was higher in deforested basins, meaning greater flow oscillations. So, deforestation increased Q10 and RBI in all deforested watersheds, threatening flood protection services regardless of climate. In addition, deforested basins had higher low flows (Q90), probably due to lower evapotranspiration or increased runoff. On the other hand, the lower BFI in deforested basins suggests decreased baseflow, probably due to lower infiltration. The most prominent effect of deforestation was in dry season watersheds, decreasing the base flow (BFI) and increasing flow fluctuations (RBI). Thus, our findings provide evidence that deforestation significantly impacts water regulation in the Amazon, potentially leading to detrimental effects on crucial water services, such as flood protection and water supply, particularly in watersheds experiencing both deforestation and the occurrence of the dry season. These results underscore the urgent need for proactive conservation measures as deforestation and climate change continue to pose significant threats to the Amazon's hydrological dynamics.

T1.11 Forest Fires in Mountain Regions

A comparative study on characteristics of the fuel flammability of forest ecosystems in the Alpine region

T1.11 Forest Fires in Mountain Regions

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Abstract: As a consequence of drier and warmer conditions, the intensity and frequency of forest fires are increasing and is becoming a major threat for protective forests in Alpine regions. The long-term impacts result in a higher number of avalanches, rockfalls, erosion, carbon and smoke release putting human lives and infrastructures in danger. The suppression of fires in mountain areas are difficult and costly, due to steep terrains and high elevations. Therefore, it is crucial to understand the flammability of forest fuels in such mountain environments as one of the important components that influences fire ignition and fire behavior, in order to plan and perform preventive measures to reduce the fire risk. Fuel flammability describes how well a species burns (sustainability), how fast it burns (combustibility) and how long it burns (ignitability). The aim of this research has been to assess and compare flammability parameters of surface fuels collected between 2009 and 2023 in several study areas in Austria. More than 150 litter samples were collected during fuel measurements in the field, immediately oven-dried at 60°C for 48 hours in the lab, classified in 8 groups (needles, leaves, seeds and fruits, woody material < 6 mm, woody material from 6 -20mm, woody material > 20mm, bark and others) and weighed. Experimental burning was performed in a laboratory, under control conditions, using an indirect ignition source and three humidity levels. Our findings indicate that the variables 'time of ignition' and 'burning time' are positively correlated to fuel moisture content. The size and structure of the fuel has an important influence as well, as woody materials with larger diameter size took longer to ignite at all different levels of humidity in comparison to others. The findings will help to improve our knowledge about the assessment of the fire danger based on the fuel moisture of different fuel types in the early warning systems.

An integrated fire danger assessment system for mountain forests with high resolution vegetation data

T1.11 Forest Fires in Mountain Regions

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Abstract: In the face of climate change, the European Alps experience higher temperatures, more heatwaves, and severe wildfires in recent years. Improved fire danger assessments become a key element of a holistic fire management strategy. An integrated fire danger assessment system was designed for the Alpine country of Austria considering i) daily fire weather index data, ii) high resolution topographic information, iii) a hazard map for fire ignition by human and lightning and iv) information about fuels, mainly regarding forest types. The expert-driven modelling approach was implemented as an online Web-GIS prototype, which produces daily forecasts of fire danger with a spatial resolution of 100 m x 100 m. To improve the information quality on fuel data, additional vegetation parameters were derived through field investigations, sampling of fuel data, by analysing high-resolution LiDAR data, aerial images, and by extracting information from Sentinel 2 data. Several new data layers were added to the online portal www.waldbrand.at, e.g. a map of forest gaps, a solar irradiance map, a layer on fire ladders, information about fuel loads and a classification of tree species. These layers were combined in order to improve the prediction quality of the ignition danger, fire spread and expected fire intensity based on vegetation parameters. In this contribution we demonstrate, how the inclusion of these new vegetation data in combination with topographical information and meteorological conditions can improve the daily fire danger assessments in mountainous areas.

Comparison of post-fire forest recovery and silvicultural interventions under different forest management regimes in the Western Himalayan Eco-region

T1.11 Forest Fires in Mountain Regions

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Abstract: The Western Himalayan Eco-region (WHER) represents a complex, socio-environmentally vulnerable mountain landscape. Historically, human activities and socio-economic reforms have shaped the structure and quality of forests in the region. The middle Himalayan zone, spread between 800 - 2000 meters, is an acutely fire-prone zone due to current forest composition, topography, ongoing climate change, and anthropogenic disturbances. In the WHER, forest fire has historically been used to generate ecosystem services and support socio-economic and political goals. With the shifts in climate patterns, demography, agricultural practices, and values in forest management and conservation, the incidences of forest fires have been changing in the WHER. Often, controlled fires for resource management have spread to larger areas due to topographical, weather and poor fire management practices. The recovery and health of disturbed forest ecosystems can be impacted by various active and passive forest management approaches. The impact of different forest management approaches on the structural and functional attributes of forest and fire-focused silvicultural intervention is understudied in WHER. This study aims to explore and compare different fire-focused management interventions, post-fire vegetation structure, and ecosystem health in passively and actively managed fire-prone forests. The study will be focused in Uttarakhand, a fire-prone Indian state in the WHER. Forest management in Uttarakhand is governed by decentralized community forest management groups (*Van Panchayats*), forest, wildlife, and revenue departments, and private entities. Further, citizen groups and NGOs support these major forest stakeholders in managing forests for different socio-ecological goals. The sites will be identified based on remote sensing-based analysis of historical fire distribution and key-stakeholder interviews. The primary data will be collected through intensive ecological survey in the post-fire and fire season of the 2023 and 2024, respectively. First results are expected within June of 2024 and will reflect upon the existing condition of post-fire landscapes and fire-focused silvicultural treatments in Uttarakhand. The outcomes could provide recommendations for fire-focused forest management policies in the fragile mountain landscapes of the WHER.

Controlled or Uncontrolled; Effectiveness of Landscape Approach to Fire Management in Ghana.

T1.11 Forest Fires in Mountain Regions

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Abstract: Evidence abounds on approaches to fire use and management in most parts of Sub-Saharan Africa, but often characterized as poor and less effective. In Ghana, fire use and management practices are less effective coupled with increasing warmer conditions; resulting in widespread wildfires, and associated risks. Landscape approach to fire management bridges this gap at scale by dwelling on locally owned, inclusive and participatory landscape governance for planning, and managing how best to live with fire within a given location. Though with marked potentials, effectiveness of landscape approach in addressing wildfire issues at scale, and sustenance of same especially in the tropics is least explored. This paper examined the nature and effectiveness of landscape approach to fire management, and to proffer options for improvements and upscale. This was done through extensive literature review and information gathering through interviews, focus group discussion, PRA techniques, etc. on landscape approach to fire management in the Juaboso-Bia/Sefwi Wiawso cocoa-forest landscape, and Kintampo/Atebubu landscape in the transition zone of Ghana. Indications are that, the approach addresses fire issues at scale by a composite of local actors, their resources, and interrelations that encompasses individual interests, sectors and activities; thus, making it comprehensive, and intersectoral. As a consequent, stakeholder inclusiveness and participation in fire discourse across the landscape is guaranteed which makes many fire users and actors more responsible towards effective fire use. Locals' leadership and ownership of processes at scale, enhanced capacity, improved sense of responsibility among stakeholders, adaptability and flexibility are key strengths of the approach. This imbues landscape actors with capacity to effectively engage and/or be engaged by other actors in fire use and management discourse, and have practically demonstrated this by successfully safeguarding some 252 hectares of restored forest lands, river buffers and agroforestry park lands. This hints that, with requisite capacity, resources and incentives, landscape actors can effectively and efficiently make use, and manage fires sustainably. This however requires enhanced capacity in contemporary fire management practices for all relevant actors, coupled with requisite policy and regulatory reforms that stresses multi-stakeholder inclusiveness in fire management at scale.

Disturbances and ecosystem carbon in a fire-prone human-impacted mountain in northwestern Yunnan, China

T1.11 Forest Fires in Mountain Regions

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Abstract: Ecosystem carbon is largely determined by climate, soil and past disturbances. In a human-impacted mountain ecosystem, the disturbance regimes are largely influenced by people. Feedbacks between woody vegetation attributes and disturbance regimes are critical for shaping ecosystem carbon along topographic gradients in mountain ecosystem. The aim of this research was to explore the effects of disturbances, especially fire, on ecosystem carbon in a fire-prone human-impacted mountain. We set woody vegetation and soil inventory plots systematically in four cardinal directions at 100-m elevational intervals from a 4200m peak in the Hengduan mountains in northwestern Yunnan, China. We used records from local authorities, interviews with villagers, remotely sensed data and dendrochronological wood samples to describe past disturbances. Based on these, we (1) quantified the effects of these disturbance regimes on woody vegetation structure, composition, and on tree species richness and radial growth, and then (2) established links between disturbance regimes and ecosystem carbon. This research is crucial for advancing our understanding of how disturbances affect carbon stocks in fire-prone human-impacted subtropical highland forests.

Effects of thinning and prescribed burning on future forest productivity and composition in southwest US

T1.11 Forest Fires in Mountain Regions

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Abstract: In the southwestern US mountains, ongoing climate change is exacerbating a legacy of fire-exclusion that has altered forest structure and increased high-severity wildfire risk. Management can mitigate this risk by reducing forest density and restoring frequent surface fires, but at which cost in terms of carbon stocks and habitat diversity? We sought to quantify the impact of management on the carbon storage capacity and potential tree composition changes along an elevation gradient comprising pinyon-juniper woodlands, ponderosa pine forests, and mixed-conifer forests. We simulated carbon and vegetation dynamics under projected climate and wildfires with and without management scenario. This scenario involved thinning and prescribed burning in areas with high probability of high-severity wildfires. At multidecadal scale, management significantly increased net photosynthesis relative to no-management, especially in ponderosa pine and mixed-conifer forests. Furthermore, management allowed to better maintain tree species diversity. Given the increasing climatic and disturbance pressures impacting southwestern US mountains, management will play a critical ensuring the continued provision of ecosystem services.

Engaging citizen science in gathering data related to forest fire risk in mountain regions: A case study in Central Vietnam

T1.11 Forest Fires in Mountain Regions

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Abstract: Negative consequences from forest fires are becoming increasingly severe for human life, destroying natural ecosystems and bringing enormous economic losses. Fire management planning requires regularly updated data about forest fuels and forest fires to adapt the plans and mitigate related risks. However, the current methods to collect such empirical information have limitations in terms of workforce, real-time and related costs, especially in mountainous areas.

This study aims to explore the potential of engaging citizen science in providing data on forest fires and fuels in mountain regions, leveraging a mobile phone application as a tool for data collection, and evaluating the suitability of the voluntarily collected data from citizens. Through a citizen science approach, different representatives of authorities, action forces, and scientists were engaged in discussing an initial set of questions for collecting forest fire data in a workshop in the study area of Hue province, Vietnam. The workshop outcome provided feedback on the questions and helped to ensure a user-friendly design of a mobile application for the collection of forest fire-related data suitable for the needs and capabilities of volunteers. For example, the mobile app can automatically record the date, time, and coordinates of each observation, and the volunteers can answer the question about forest fuel, including uploading photos of the observation, estimating surface vegetation conditions and continuity of large woody debris as well as the probability of fire ignitions of the observation.

The study outcomes reveal that citizen science might close the gap in needing more real-time information on forest fuel data to facilitate an assessment of ignition potential. In addition, a key aspect identified through this collaborative process was providing and integrating comprehensive information into documents on forest fire events is crucial in reducing forest fire risk and improving fire prevention measures in mountainous areas.

Furthermore, the research findings are promising for future exploration and application of citizen science projects, including ensuring reliable quality data generated. These are expected to strengthen community involvement, raise public awareness, and enhance and mitigate forest fire impacts in mountain regions.

Exploring the Potential of using Sentinel-2 Satellite Data in Mapping Burn Severity in Aberdare Ranges Afromontane Forest, Kenya

T1.11 Forest Fires in Mountain Regions

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Abstract: In Kenya, most of the reported wildfires in mountains and ranges mostly occurs in inaccessible areas with difficult terrain causing high destruction of water catchment and biodiversity. Studies using moderate or high-resolution satellite images to understand the spatial and temporal occurrence in mountains covered with Afromontane forests are limited. This study aimed to evaluate commonly used Normalized Burn Ratio (NBR) and Burned Area Index for sentinel-2 (BAIS2) in mapping burn severity using sentinel-2 satellite data and to compare the relationships of Field Based Index (FBI) and sentinel derived severity indices. The study was carried out in Aberdare Ranges, which represent tropical Eastern Afromontane forests and also a designated world heritage site with a rich diversity of fauna and flora but frequently affected by wildfires. The sentinel data during the 2022 fire season was processed for NBR and BAIS2 using Google earth engine. After processing the burn severity classes, a separability index (M) was used to estimate the effectiveness of spectral indices to discriminate among the burn severity classes. Fifty-nine plots distributed in high (21), moderate (9), and low (15) burn severity classes and unburnt areas (14) were established about 2-3 weeks after the wildfires to develop FBI guided by affected ground vegetation. Our results indicated that NBR performed better with a mean separability index (M) of 1.10 compared to BAIS2 (M=0.75) in all severity classes. Separability index for NBR was good during discriminating low and moderate severity classes (M=1.31) but rather weak between moderate and high severity classes (M=0.84). The separability index for BAIS2 was good when discriminating low severity and unburnt areas (M=1.13) but poor in all other burn severity classes. The best model to explain the relationship between the sentinel derived spectral indices and the FBI was best described by a nonlinear equation for NBR (R^2= 0.89) and BAIS2 (R^2=0.62). Our studies demonstrates the usefulness of sentinel-2 satellite images and the superiority of NBR spectral indices in mapping burn severity within Afromontane forests. We recommend further studies in various vegetation types of Kenya to support wildfire management.

Key words; Wildfires, Sentinel-2, Burn severity, Aberdares, Afromontane forests.

Forest fire management and post fire forest restoration in mountainous part of Slovenia

T1.11 Forest Fires in Mountain Regions

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Abstract: In recent decades, fires do not significantly disturb the development of forests in the mountainous parts of Slovenia. However, with upcoming climate change reflecting in further rising of average annual temperatures, unevenly distributed annual precipitation, lengthening of spring and summer draughts period the fire risk in the mountainous parts of Slovenia will increase. Knowledge of the occurrence and severity of forest fires as well as impact of fires on mountain forest ecosystems is therefore important for the successful management of fires and rehabilitation of burnt areas. In this contribution, the dataset on forest fire occurrence and severity will be analysed for the period 1995-2022. Furthermore, efficiency of fire intervention and the role of public forest service will be assessed analysing selected case studies. In addition, the impact of fire on forest ecosystem and efficiency of post fire regeneration measures will be analysed using restoration plans and dataset on realized regeneration measures. The results shows that most of the forest fires accrued in the period 1995-2022 are small (burned area is smaller than one ha). In this period, nine large fires (burned area > 100 ha) accrued with about fifth of the total burned area of that time spam. Humans cause the vast majority of fires; a natural phenomenon (lightening) is very rarely the cause of a fire. The fires are followed by cascading events, which is mainly manifested in the reduced protective role of forests, greater exposure of forest soils to erosion processes, may affect forest productivity, biodiversity and water retention capacity. Large burned areas also negatively effects social functions such as recreation and tourism. The public forestry service is formally involved in the fire management, cooperates with planning and supervision of fire preventing and protection measures. In the case of intervention places on disposal at the Intervention headquarters' forestry maps with the delineation of all forest roads. It helps individual fire-fighting unit with its spatial orientation, and directs them on the firebreaks and forest roads. In conclusion, the fire resilient forest management will be discussed, as well as improvements of forest fire management and post fire forest restoration actions.

Forest Fuel Load Monitoring in the Himalayan Region Using Earth Observation Satellite Data and Machine Learning Methods

T1.11 Forest Fires in Mountain Regions

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Abstract:
Wildfires in forested areas are vital for ecosystem development and succession, but as cities expand and climate changes, their detrimental impacts have increased. The sensitive Himalayan region is particularly vulnerable to forest fires, posing threats to ecosystems, nearby human settlements, air quality, and climate. Managing these recurring fires requires understanding and managing fuel load, which refers to the amount of combustible biomass available for burning and plays a crucial role in mitigating wildfire risks.

This study emphasizes the importance of quantifying fuel load for effective fire management. Accurate fuel load information enables fire managers to assess fire risk levels and prioritize fuel reduction treatments. Proactive strategies, such as prescribed burns, fuel breaks, and fuel management programs, can be developed based on timely and precise fuel load data to minimize the likelihood and severity of wildfires.

Traditional fuel load estimation methods, such as destructive sampling, provide accurate ground-level information but are impractical for global-scale applications. Satellite-based spatial earth observation data offer a promising solution, providing comprehensive coverage of forest fuel load at a global scale. Optical, synthetic aperture radar (SAR), and light detection and ranging (LiDAR) datasets, with their distinct imaging mechanisms, can be leveraged to map fuel load accurately. Optical data captures leaf and canopy characteristics, while SAR and LiDAR data enable the determination of forest vertical structure.

In this study, an integrated approach for forest fuel load estimation is presented, establishing a relationship between in-situ measurements and earth observation satellite data. Correlations between different fuel load types and optical and SAR data are analysed. Machine learning techniques, including Random Forest and Support Vector Machines (SVM), are employed to develop fuel load estimation models using data from the study area and variables derived from optical and SAR datasets. The focus of the study is on the unique terrain challenges and opportunities in the Himalayan region. Accurate fuel load estimation based on multi-sensor remote sensing data can facilitate proactive fire management strategies, thereby minimizing the impacts of wildfires on ecosystems, human settlements, and the environment.

Fueled by Data – impacts of data type on wildfire modeling outputs

T1.11 Forest Fires in Mountain Regions

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Abstract: Wildfire prediction models require the same base data to function: climate, fuel, topography, and in some cases population. Historically, data has been taken from the ground, but technological advancements in the field of remote sensing have led to more models being fueled purely by satellite-derived data. As the trend to use only satellite data grows, it is essential to understand how and if data source and type affect model outcomes. In this comparative study, we analyze and explore how two different data sources and types impact the modeling of wildfire probability and spread in Sardinia, Italy at a scale of $1km^2$. The wildFire cLimate impacts and Adaptation Model (FLAM), developed at the International Institute for Applied Systems Analysis (IIASA) for modeling wildfire dynamics, incorporates climate, population and biomass data, and human activities to model historic wildfires as well as predict future fire probability and spread under different climate and forest management scenarios. Using different data sources for the input components, we calibrate and validate FLAM to assess how and if model outputs of wildfire probability, frequencies, and burned area are significantly altered based on the input source. The impact of monthly vs yearly calibration is shown, alongside final model results from both datasets. Further, the influence of different population density scales is explored and discussed, especially in the context of mountainous and coastal regions, where high-density cities may be located next to vast low-to-no-population areas – emphasizing the necessity to consider how density variables are expressed and used in models. Our results will provide insight into how and if ground-based data is still necessary for wildfire models and in what contexts, which is essential to ensure reliable modeling and for accurate future projections under climate warming scenarios.

HOT SPOTS MONITORING OF PROTECTED AREAS IN PARAGUAY

T1.11 Forest Fires in Mountain Regions

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Abstract: The monitoring of active hot spots can become essential in the day to day because the biggest problems are found in the fires produced by third parties in protected areas, the objective of this work is to observe and monitor the way in which the active hot spots are presented and generate maps of national interest in the months of May and June with respect to them, the methodology consists of four steps; The methodology consists of four steps: "location of the study area" focusing on the protected areas which are distributed at the country level in the eastern and western region, which are divided into departments and the points of interest are expanded in each one of them; "pre process" which is performed by vectors that are downloaded from EarthData and then transported to a GIS to perform the corresponding analysis; "process" that goes from a geographic information system where the shapefiles of the border of Paraguay and the polygons of the respective protected areas are located to obtaining the data in a qualitative manner; This post-process helps us to obtain quantitative data through numbers generated within the same GIS where a comparative statistic is produced per day of all the protected areas to later send them to the PySinLlamas platform, As a result, the days with the highest number of fire outbreaks were May 24, 2022 with 24 hot spots and June 15 with 62 hot spots, giving us the tool to know the protected areas with the highest risk of fires, which are the Tinfunque National Park and the Mbaracayu National Forest Reserve. Once the statistics are generated, they are of great importance at a national level and help in decision making, remaining as a database within the aforementioned platform, leaving high level comparisons in risk management and decision making, where its potential use is freely accessible to all persons, entities, companies, etc. that wish to visit the aforementioned platform.

Hybrid Forest Fire Prediction Modelling by Transferring Human Domain Knowledge into Artificial Intelligence

T1.11 Forest Fires in Mountain Regions

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Abstract: Due to the combination of increasing climate change-induced heat waves and densely forested areas adjacent to highly populated urban areas, the dynamics of forest fires in South Korea are influenced by a complex interplay of biophysical and anthropogenic factors, posing a significant challenge to response systems. In response to this challenge, various forest fire models have been developed, each with its own strengths and weaknesses: process-based model has high interpretability relying on human domain knowledge but requires substantial efforts for optimization, whereas the machine learning based model automatically identifies features but has limited interpretability. To exploit the strengths of both models, this study aimed to transfer human domain knowledge for interpreting forest fire dynamics into a machine learning process. The algorithms of IIASA's wildfire cLimate impacts and Adaptation Model (FLAM)—a processed-based model integrating biophysical and human impacts—was developed as a neural network, named FLAM-Net. The development of FLAM-Net included enhancing the backpropagation properties of the transferred algorithm to optimize it for the given environment, as well as introducing new algorithms for interpreting national-specific forest fire patterns of South Kora. The FLAM-Net was applied to multiple scales and were integrated through U-Net-based deep neural networks, named Deep Neural FLAM (DN-FLAM), to produce downscaled prediction. The study successfully optimized FLAM-Net for the forest fire dynamics of South Korea, which exhibited spatial concentration near metropolitan cities and the east coastal area, with temporal concentration in spring. Integration of the multi-scale features through DN-FLAM yielded the most optimal performance with Pearson's r values of 0.943, 0.840, and 0.641 for temporal, spatial, and spatio-temporal dimensions, respectively. Projecting future scenarios based on the Shared Socioeconomic Pathways (SSP) climate change scenarios revealed an increase in forest fires until 2050, with a more pronounced spatio-temporal concentration, followed by a decrease due to increased precipitation. This study highlights the advantages of combining process-based models and artificial intelligence as a hybrid model, such as FLAM-Net and DN-FLAM, in terms of interpretability, accuracy, and efficient optimization. These models provide scientific evidence for local-specific climate resilience strategies that can be expanded globally, thereby enhancing worldwide climate resilience with context-specific approaches.

Insolation drives ecosytem resilience after stand-replacing forest fires on South- and North-exposed slopes in a dry central-Alpine valley

T1.11 Forest Fires in Mountain Regions

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Abstract: With ongoing climate change, the risk for extreme forest fires is projected to considerably increase. Beyond the foreseeable economic consequences of stand replacing fires for forestry, questions on the effects on ecosystem resilience regarding the recolonization of plant and animal species are of utmost interest. In mountain forests in densely populated regions such as the European Alps, post-fire tree regeneration is an important concern, particularly in protection forests. To answer questions of post-fire changes of vascular plant species composition and the speed of tree species regeneration, we monitored the revegetation process on two forest fire patches in the Alps (Valais, Switzerland: Leuk 2003 with 300 ha, from 850 to 2100 m asl; Visp 2011 with 160 ha, from 700 to 1500 m asl) that rank among the largest stand-replacing burns since 1900 in that region. The original forests consisted mainly of conifers, with *Pinus sylvestris* at low elevations and *Picea abies*, *Abies alba* and *Larix decidua* at higher elevations.

As an effect of the highly diverse forest and open land patchwork, plant species richness rapidly increased, with considerable amounts of ruderals, grassland and mountain species. In this early stage of succession that lasted 10 years, the average plot richness exceeded the one of ancestral forest plots by 30%.

Post-fire tree regeneration is dominated by pioneers (*Populus* spp., *Salix* spp., *Betula pendula*) that recolonized the burns rapidly and have since dominated the vegetation. Stem numbers 10 years post-fire strongly differ between south and north exposed slopes, with less than 1000 stems per hectare on the south-exposed site and more than 10’000 stems per hectare on the north-exposed slope. On the south-exposed slope, a trees species switch from *Pinus sylvestris* to *Quercus pubescens* can be observed.

The post-fire dynamics on the monitored burns are discussed in the light of diaspore dynamics and climate change.

Landscape-wide loss of threatened temperate Nothofagus forests in the costal range of central Chile: Synergism among fire, land use and climate change

T1.11 Forest Fires in Mountain Regions

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Abstract: Since 2010, forest fire activity has increased in south-central Chile due to climate change. We assessed the effects of fire severity, invasion by the exotic fire-prone *Pinus radiata*, and land-cover composition and configuration of the landscape on the resilience of fragments of *Nothofagus* forests (*N. glauca* and *N. alessandrii*) after a megafire in 2017. We used remote sensing data to estimate land-use classes and cover, fire severity and invasion cover of *P. radiata*. Following the megafire, over 80% of *Nothofagus* forests were moderately or severely burnt. Extreme wildfires favoured by intense drought, heat waves and widespread exotic pine plantations, increased the ability of fire-adapted invasive species to colonize *Nothofagus* forest remnants. The propagation and severity of fire was amplified by the exotic pines located along the edges of, or inside, the *Nothofagus* remnant forests and the highly flammable pine plantations surrounding these fragments. *Pinus radiata*, a fire-adapted pioneer species, showed strong post-fire recruitment within the *Nothofagus* fragments, especially those severely burnt, which reduce the resilience of these forests to fire. Positive feedback between climate change (i.e. droughts and heat waves), wildfires and pine invasions is driving *Nothofagus glauca* and *N. alessandrii* forests into an undesirable and probably irreversible state (i.e. a landscape trap). A large-scale restoration programme to design a diverse and less flammable landscape is needed to avoid the loss of these highly threatened forest ecosystems.

Modeling risks of climate-driven wildfires in protective forests in mountain areas: the FLAM approach

T1.11 Forest Fires in Mountain Regions

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Abstract: Forest fires pose significant threats in various forests worldwide, with mountain areas becoming increasingly vulnerable. The unique characteristics of mountain regions, such as decreased suppression efficiency mainly due to difficult access and/or steep slopes and specific management requirements of protective forests contribute to their heightened susceptibility. Additionally, human activities in seeking recreation can serve as ignition sources, requiring specific consideration, particularly during periods of drought. This study introduces the wildFire cLimate impacts and Adaptation Model (FLAM) developed at the International Institute for Applied Systems Analysis (IIASA) for modeling wildfire dynamics. FLAM utilizes mechanistic algorithms to evaluate the influences of climate, human activities, and fuel availability on wildfire probabilities, frequencies, and burned areas, operating on a daily time step. The model undergoes validation using GIS and remote sensing data to ensure its accuracy and reliability. Future projections are conducted under different climate change scenarios at various scales and resolutions, focusing on protective forests in mountain areas. The presentation of modeling results encompasses fire-related factors specific to mountain regions, simulation of burned areas, adaptation options, and projections of burned areas until 2100. We identify unique factors that increase ignition probability or decrease suppression efficiency in mountainous regions, such as forest road location and density, fire management stations and supplies, and average response times. Our findings align with international analyses that climate change will likely escalate the frequency, size and impact of wildland fires in the mountains in the forthcoming decades, further highlighting the significance of safeguarding protective forests in mountain areas.

Modeling the interaction between bark beetle outbreaks and wildland fire behavior: new perspective for Italian forests affected by the storm Vaia

T1.11 Forest Fires in Mountain Regions

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Abstract: Among the most common natural disturbances affecting Mediterranean mountain regions, forest fires, windstorms and bark beetle outbreaks jointly represent a relevant issue for European forests in geomorphological, ecological and social terms. In this regard, local stakeholders and authorities are nowadays facing critical circumstances, concerning the identification and implementation of efficient silvicultural management of forest stands affected by such issues. The storm Vaia occurred in 2018 in northeastern Italy, creating an unprecedented scenario for Italian Alps. Following the windthrow produced by the storm, bark beetles proliferated first on the downed logs, and later moved to the neighbour standing forest, modifying the quantity and availability of forest fuel. In this context, the development of remote sensing and photogrammetric techniques such as Light Detection and Ranging (LiDAR) and Unmanned Aerial Vehicle (UAV), as well as fire behaviour models, allow researchers to perform detailed terrain reconstruction and estimation of forest fuel, necessary to simulate fire behaviour over disturbed forested areas. Predicting key factors related to wildfire risk (e.g., fire type, rate of spread, flames length) is useful in estimating fire behaviour in windthrown areas affected by bark beetles outbreaks. At the same time models output reliability is principally limited by input data estimation, specifically concerning troubles in retrieving precise data such as fuel characteristics and fire behaviour fuel models in such disturbed areas. Therefore, new methods able to overcome these limitations in forest fire simulations are nowadays needed. The project RETURN aims to improve the implementation of fire behaviour modeling in forested areas affected by similar natural disturbances, enhancing spatial mapping of input layers for fire simulators in the Alpine region. In this research, the joint interaction between bark beetle outbreaks and wildland fire dynamics is investigated by coupling extensive field data collection and fire behaviour models with high-resolution LiDAR and UAV-based analysis. Results could enrich the information available for the local administration of the Alpine region to find effective interventions and management options for the areas affected by similar natural disturbances over time.

Modelling post-fire regeneration patterns under different restoration scenarios to improve forest recovery in degraded ecosystems

T1.11 Forest Fires in Mountain Regions

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Abstract: Changes in disturbance regimes triggered by land-use and climate change can significantly alter forest ecosystems by modifying the distribution of some species and hindering post-disturbance regeneration dynamics. Applied nucleation (AN) can be a valuable active restoration approach for promoting natural regeneration in forest ecosystems affected by extreme disturbance events since it improves seed availability and microsite conditions. Still, AN has been mostly applied in tropical forests, but it has the potential to be applied in Mediterranean mountain forests given the increase in extreme disturbance events in the area. The research aimed to investigate the potential outcomes of a set of AN scenarios in a mountain forest ecosystem of the Northwestern Italian Alps dominated by Scots pine. The area was affected by a large stand-replacing wildfire in 2005 and post-fire salvage logging operations that increased ecosystem degradation and dampened natural regeneration. We assessed the main drivers affecting post-fire natural recovery and identified suitable sites for regeneration through a machine learning correlative model (Bayesian Additive Regression Tree, BART), using the occurrence of natural regeneration as the response variable and several environmental variables as predictors. We predicted the probability of regeneration presence across the landscape under the current situation and a set of AN scenarios characterized by an increase in *nuclei* density, since distance from seed trees emerged as the most important driver for natural regeneration. These predictions made it possible to assess the most efficient active management scenario in terms of regeneration processes. The simulations showed the positive effects of AN and the importance of site selection for tree planting, proving that AN is a promising post-fire management technique for facilitating natural regeneration while minimizing human interventions and their associated economic and ecological costs. To our knowledge, this work is the first AN simulation in temperate mountain ecosystems. The selection of suitable sites can be further improved by identifying favourable microsites at a fine scale through field experiments and cross-scale integration.

Settlers in the aftermath: early regeneration in burnt artificial Pinus nigra forests through an altitudinal and latitudinal gradient

T1.11 Forest Fires in Mountain Regions

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Abstract: Forest fires appear as a destructive phenomenon, consuming years of vegetation growth in a little timespan. In addition, forest fires change the environmental conditions for years to come, sometimes permanently. On the other hand, fire has been present in some biomes for ages, and it will be surely a natural disturbance of tomorrow forests.
Scientific knowledge has accumulated on forest fires and post-fire forest dynamics, but it is still difficult to predict what will happen to a burnt forest, especially today and in Europe: climate change is shifting the ground regarding forests dynamics, and information on long term post-fire forest dynamics are scant in Europe, due to the strong and long-lasting anthropic footprint. Increasing our understanding of post-fire forest dynamics is a first step to reduce disruptions in the provision of forest ecosystem services.
The simplest way to study post-fire forest dynamics is to sample post-disturbance natural regeneration. Especially where fire burns with high severity (primary succession) species that arrive first will probably impose the forest composition for the next decades. Information on this dynamic is particularly relevant for artificial secondary forests, because little or no record may be available regarding their response to forest fires.
In our study, post-fire natural regeneration was sampled in three artificial *Pinus nigra* J.F.Arnold forests burnt with high severity in 2012, 2017, and 2022, respectively. This species was extensively used for afforestation in Southern Europe, and nowadays black pine forests show similar dynamics and a high proneness to fires across all its areal. The three forests differ in altitude, latitude and climate, but have common traits, such as bedrock type, natural regeneration species and potential natural forest composition (nearby stands).
Results show a clear transition from pine to broadleaves forests after fire, mainly due to resprouting. Black pine regeneration is present, but only where severity is low. Common trends across sites hint that general indications may be drawn, although the main intended contribution of our study is to propose an approach to study post-fire forest dynamics in areas with relatively short records of forest fires, such as artificial conifer forests in European mountains.

THE EXIGENCIES OF FOREST FIRE: EXPLORING THE ECOLOGICAL AND SOCIAL IMPACTS OF FOREST FIRES IN THE MAJESTIC HIMALAYAS

T1.11 Forest Fires in Mountain Regions

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Abstract: The Himalayas harbour a remarkable diversity of vegetation, ranging from tropical dry deciduous forests in the foothills to alpine meadows above the timberline. With their vast natural resources and unique geographic features, Himalayas sustain local communities in numerous ways, ensuring their livelihood, well-being and holistic development. The Himalayas being economically less explored and being the most densely populated mountain ecosystem, are highly vulnerable to environmental changes. Forest fires are a devastating disaster in the Himalayas posing significant challenges to the biodiversity and local communities. Fire is widely recognized as a significant factor contributing to forest degradation in India. As a result of the ongoing global climate crisis, forest fire regimes have been constantly changing in the Himalayas and have become a phenomenon of regular occurrence, posing threats to community's resilience and well-being.

This study is conducted in Almora district of Uttarakhand, a Himalayan state. Overall, 22.27% of the forest cover in India is prone to forest fire while in Uttarakhand. A total of 54801 ha forest area has been burnt between January 2000 and April 2023 due to forest fires as per Forest Survey of India (FSI). In this study, the evaluation of forest fire is carried out by examining factors including Elevation, NDVI using ArcGIS and QGIS software. Further analysis of the potential impacts of forest fire on vegetation and its soil has been carried out using primary data collection through the quadrat method and phytosociological study of the fire-affected forest patch.

Additionally, this study also measured the social impacts on community livelihood and well-being. By combining field observations, data analysis, and community feedback, this research provides valuable insights into the ecological and social implications of forest fires in Uttarakhand. The findings from this study can be useful for decision-making for targeted interventions and developing management strategies to mitigate the detrimental effects of forest fires, preserve biodiversity, and safeguard the well-being of the affected mountain communities. It is expected that insights gained will contribute to a more sustainable and resilient approach to forest fire management in Uttarakhand and at the national level.

Keywords: Forest Fire, Himalayas, Community perception, livelihood.

Unravelling the local dynamics of increasing fires in community forests of mid-hills Nepal

T1.11 Forest Fires in Mountain Regions

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Abstract: Forest fire is a global phenomenon and is having unprecedented impacts across continents. Nepal is not an exception to the increasing impacts, where hundreds of acres of forests is lost, or damaged, to forest fire. The severity of forest fire is on the rise in recent decades, wherein community forests have witnessed effects of the calamity over the recent years. This paper investigates the local factors behind the increasing frequency and severity of forest fires in mid-hills of Nepal. The paper draws on three separate cases from the research sites, involving five years of 'Enhancing Livelihoods from Improved Forest Management in Nepal (EnLiFT2)' project's team observations in Bhumlu rural municipality and Chautara Sangachokgadhi municipality of Kavrepalanchok and Sindhupalchok district respectively. This is complemented by informant interviews taken with 25 individuals. The paper primarily examines forest-people-fire relationship to demonstrate the weakening collective actions among the community forest user groups (CFUGs) as an important factor for increasing forest fires in the mid-hills of Nepal. We found the changing forest-people relationship, weakening CFUG governance, and increasing regulatory impositions as important factors driving the alienation of users from the forest thus, undermining collective action in forest management. We argue that strengthening collective action on better forest management to prevent forest fire is crucial over adopting mitigation techniques. The alienation of forest user groups from their forest in the changing socio-economic and forest management context can be addressed to strengthening the collective action for better forest management and ultimately to forest fire prevention and management.

Keywords: Collective actions, forest fire, forest management, forest-people-fire relationship

Vertical characterization of vegetation stratas in a mountainous region with Atlantic climate for incorporation into a fire-risk decision-making tool.

T1.11 Forest Fires in Mountain Regions

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Abstract: The determination of the vertical structure of the forest is key for various issues such as the maintenance of biodiversity and the determination of fire risk due to vertical fuel continuity. The accurate description of fuel properties is thus critical to improving fire danger assessment and fire behavior modeling. In this sense, the ability of airborne LiDAR (Light Detection And Ranging) sensor to penetrate the tree canopy makes this technology suitable for analyzing this variable.

This study analyzed the capacity of low-resolution LiDAR data in the vertical characterization of the different vegetation strata, selecting the LiDAR metrics, or combination of metrics, that best represent the vegetation stratification for the development of regional mapping. With the aim of mapping the characterization of forest fuel maps at the regional level (pixel size of 25 meters), the metrics selected were included in an algorithm able to automatically generate the number of strata per pixel and the relationship of this with vertical continuity as well as with other variables that describe existing forest fuels, such as height and coverage of tree- and shrub strata, fuel type and topographic variables such as slope.

The results were evaluated under several scenarios according to the type of vegetation involved, with the intention of guiding its application in fire prevention and extinction tasks. Automation, scaling, updating, and dissemination of the results were built in a open source programming language and through the construction of an open data medium that can be consulted and/or exploited through an entity's own Spatial Data Infrastructure (IDE). This provides a channel to facilitate the management of spatial data, metadata and visualization services in accordance with the European INSPIRE Directive and the OGC (Open Geospatial Consortium).

Wildfire Hot Spot Mapping in the Alps - Austria Fire Futures

T1.11 Forest Fires in Mountain Regions

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Abstract: The main objective of the Austria Fire Futures study is to develop a unique and innovative concept containing new sets of fire risk hotspot maps at highest spatial resolution under various climate change scenarios and integrate novel insights on local fuel types into forest and forest fire risk models, including new mountain-specific variables such as morphology and recreational activities. To generate such maps on a local scale, fire hazard modeling is necessary to identify endangered forest types in combination with topographic effects. Furthermore, recent fire events in the Austrian Alps show that social aspects, particularly the hiking tourism, are paid too little attention to.
Based on the above motivation, we believe that an innovative and improved fire risk hotspot mapping is the fundament for all further forest- and wildfire prevention and hence needs to be seen as an indispensable tool for an integrated fire management (prevention, suppression, post fire measures) while substantially contributing to mitigating climate change as well as minimizing damage to ecosystems, their services, and people.
The study will improve our understanding of fire-vulnerable forest areas in the Alpine Space that may shift over time and space given the underlying climate and fuel assumptions. This will allow experts, practitioners, and the interested public to take a look into the future in order to comprehend and derive solid short-/medium-/and long-term recommendations for fire resilient and sustainable forest management and fire emergency planning.

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

A Decade of European Ash Breeding: Advancements in Resistance against Ash Dieback

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: European ash (*Fraxinus excelsior*) populations across Europe are facing a significant threat from the invasive fungal pathogen *Hymenoscyphus fraxineus*, causing ash dieback and resulting in the extensive decline of ash forests. The consequent reduction in the ash population has led to habitat degradation for numerous organisms relying on ash substrates.

Conventional breeding for resistance has been considered as a counter measure to develop a more resistant ash population that will be ready to use in operational forestry and for the restoration of ash habitats. In Sweden, the first attempts to establish a new resistant breeding population was initiated in 2013. The high genotypic variation in resistance was shown in clonal seed orchards that were established before the first report of disease in Sweden selected on the basis of growth and quality traits. The number of clones showing high resistance was around 10 out of 106 tested.

However, this limited number of resistant clones fails to ensure sufficient genetic diversity within the population. Consequently, four new trials were conducted between 2016 and 2022, involving over 200 additional clones. These new clones were derived from trees classified as resistant in the field, sourced from remaining ash stands, ash alleys, and parks. The trials were annually monitored to assess resistance against ash dieback.

Additionally, a parallel approach involved propagating numerous progenies from the most promising female trees identified after six years of seed-orchard monitoring. These progenies were planted in seven trials, implementing a "strong forward selection" strategy. The objective was to leverage the high within-family variation and select resistant genotypes within each tested family.

Here, we present the results of quantitative genetic analysis and provides a descriptive overview of the experiments. The findings demonstrate the feasibility of obtaining resistant ash populations in Sweden, highlighting advancements in breeding for ash dieback resistance.

A Multi-omics Approach to Study Disease Resistance in North American Pines

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: White pine blister rust caused by the fungal pathogen *Cronartium ribicola* is a devastating disease affecting all five-needle (*Strobus*) pines in North America. Warming climates bring significant challenges to the management, breeding, and conservation of these economically and ecologically important pine species. In this study, we use a multi-omics approach that includes genomics (Whole-genome re-sequencing, GWAS), transcriptomics (differential expression at 3 infection times), and epigenomics (differentially methylated sites at 2 infection times) to understand the processes and mechanisms of disease resistance and how to ensure health resilience under climate change. In addition, we have developed several resources for public use such as a *de novo* transcriptome, a high-density linkage map and a new, chromosome-scale 32-Gigabase genome assembly for sugar pine (*Pinus lambertiana*).

Adapting Abies pinsapo to Climate Change: Forest Genomics as a Key to Resilience and Restoration

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Forest ecosystems are vital for carbon fixation, biodiversity preservation, and economic value, making their resilience to climate change crucial. However, the increasing threats from pathogens, pests, and environmental disturbances pose significant challenges to forest health. *Abies pinsapo*, commonly known as Spanish fir, is a relict species with a limited distribution in the southern mountains of the Iberian Peninsula. This species plays a critical ecological role, providing habitat for numerous plant and animal species and contributing to the maintenance of biodiversity. Additionally, *Abies pinsapo* forests are essential for ecosystem services, including soil erosion prevention, water regulation, and carbon sequestration. The conservation and sustainable management of this species are of paramount importance to maintain the ecological balance and functioning of these forest ecosystems. This species is highly susceptible to climate-driven changes, including rising temperatures, droughts, and pathogen attacks. Trying to mitigate these threats and ensure the long-term survival of *Abies pinsapo*, an integrative and interdisciplinary approach is underway including molecular and ecophysiological strategies.

The main objective of our project is to gain a comprehensive understanding of the adaptive capacity of *Abies pinsapo* and develop strategies to enhance its resilience to biotic and abiotic stresses. Through the use of state-of-the-art molecular and genomic techniques, we aim to unravel the molecular basis of key adaptive traits and identify potential targets for genetic engineering and breeding programs. The anticipated outcomes of this research project include the generation of valuable genomic resources, the identification of genetic markers associated with stress tolerance, and the development of molecular tools for selective breeding and assisted migration programs. These advancements will contribute to the conservation and sustainable management of *Abies pinsapo* forests, as well as provide valuable insights into the adaptation mechanisms of other coniferous species facing climate-related challenges. We aim to unlock the adaptive potential of *Abies pinsapo* and pave the way for innovative strategies in forest management and conservation.

Advanced tools for optimizing the selection and deployment of genetically improved loblolly pine resistant to fusiform rust

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Fusiform rust, caused by *Cronartium quercuum* f. sp. *fusiforme*, is one of the most damaging fungal diseases of loblolly pine (*Pinus taeda*) and the leading cause of product loss for timber growers in the southeastern United States. The most effective management strategy against fusiform rust is the use of host genetic resistance, which requires an integrated approach that involves both breeding resistant families of loblolly pine and the identification of high-risk areas where the use of improved families is justified and ultimately convenient. And while this approach has been successfully deployed in the last decades, there is still room for optimization, especially now that new cost-effective technologies and improved computational approaches are available. The classification of phenotypes in resistance breeding programs, for instance, currently relies upon the visual detection of symptoms, which is lengthy, prone to human error, and dependent on local disease pressure, which might vary in different years. To optimize the selection process, we developed an approach that combines near-infrared (NIR) spectroscopy with multivariate statistics to identify chemical patterns associated with resistance phenotypes. Using machine learning, we trained our algorithm on spectra collected from 35 families with a handheld device and achieved predictive models that can correctly classify highly resistant or susceptible trees with up to 78% accuracy. To optimize deployment, we improved the current fusiform rust hazard maps by incorporating the effects of both the host genetics and environmental factors on disease incidence. Using data collected over multiple years and progeny tests across the region, we first used a Least Absolute Shrinkage and Selection Operator (LASSO) regression to identify relevant predictor variables and then modeled them using Generalized Additive Models (GAMs) for a non-improved and an improved genetic line of loblolly pine. Finally, we spatially interpolated the disease risk for both families and were able to explain up to 89.2% and 94.3% of the deviance for the non-improved and improved lines, respectively. In summary, by using innovative technological and computational tools, we optimized both the selection and deployment of genetically improved loblolly pine families and hence provided advanced solutions to the management of fusiform rust.

Ash in Distress: results from a large experimental field trial on ash dieback in Austria

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Common ash (*Fraxinus excelsior*) is a highly valuable broadleaved species, whose survival is threatened by the alien invasive ash dieback pathogen *Hymenoscyphus fraxineus*. Studies have provided evidence that ash dieback tolerance has a polygenic basis and identified tolerance-associated genetic loci (Stocks et al., 2019). Here, we report on one of the largest field trials to date aimed at identifying and characterizing ash dieback tolerant genotypes, while capturing the genetic diversity of common ash in Austria. The overall goal of the project "Ash in Distress" is the selection of highly disease-tolerant clones and in consequence the establishment of seed orchards to provide forest owners with improved reproductive material. In detail, seeds were collected from 715 disease-tolerant female trees in 2015 and 2017, resulting in more than 35,000 progeny raised in a community garden. Disease incidence and severity was assessed on all seedlings for three consecutive years. Eventually, approximately 20% of the offspring evaluated remained disease free, providing a broad base for further selection. We observed that susceptibility in juveniles can strongly increase during the first three years following germination, whereas trees showing no disease symptoms towards the end of the third vegetation period are likely to remain symptomless or become only slightly damaged over the following years. Genotype-tolerance association analyses were carried out on over 1,000 individual trees, including a susceptible and a putative tolerant progeny of tolerant mothers, using the 4TREE array (Guilbaud et al., in prep) targeting 13,407 single nucleotide polymorphisms (SNPs). Overall, our genotype-tolerance association analyses did not reveal any candidate loci that could be used for future genotype-informed breeding. Nevertheless, the array is proving to be a powerful tool for studying genetic structure and detecting introgression from closely related species, as well as exploring associations with environmental variables and other traits of interest.

Aspen mosaic-associated virus populations of Populus tremula in Finland and Sweden

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: A new *Emaravirus*, aspen mosaic-associated virus (AsMaV), was identified as the causal agent of the mosaic disease in *Populus tremula*. The genome of AsMaV consists of five negative-sense single-stranded RNA (-ssRNA) molecules. The RNA1 (7.1 kb) encodes for the viral RNA-dependent RNA polymerase (RdRP, 268.2 kDa), RNA2 (2.3 kb), RNA3 (1.6 kb), RNA4 (1.6kb) and RNA5 (1.3kb) encode for the glycoprotein precursor (GPP, 73.5 kDa), viral nucleocapsid protein (N, 35.6 kDa), a putative movement protein (MP, 41.0 kDa) and a protein of unknown function (P28, 28.1 kDa), respectively. Different regions of the virus genome were used to investigate genetic diversity and population genetic parameters. To do this, full-length AsMaV-RNA3, -RNA4, and partial -RNA1 were amplified via RT-PCR with specific primer pairs. Subsequently, the amplicons were investigated by RT-PCR-RFLP and selected variants were subjected to sequencing. The results showed that AsMaV has a conserved genome, however, Finland isolates and Sweden isolates are belonging to different phylogenic groups and probably belong to different populations. RT-PCR-RFLP developed in this study, could detect the locations with the highest number of haplotypes.

Association Mapping in Forestry Tree Crops: Scope, Feasibility Test & Conditions and Models

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: The productivity of Indian forest is 1 cu m/ha/year as compared to global average of 3 cu m/ha/year. It supports different industries like handicraft, pulp, paper, plywood, veneer, etc. There is a large gap in demand and supply. Scientific intervention is required to improve their economic traits like growth rate, stem form, wood quality, etc. Use of genetic markers like SNPs and analysis tools like Association mapping can help in dissecting complex traits and identifying the responsible individual genes and alleles. Association mapping in plants was pioneered by Bartlen *et al.* AM is a method used to determine the relationship between phenotypic variation and genetic polymorphism based on Linkage Disequilibrium. The concept was described by Jennings in 1917. Its quantification was given by Lewtonin in 1964. Candidate gene association mapping and genomewide association mapping are two different approaches of association mapping. Various models from fixed model to mixed model are used in association mapping. A recently developed unified mixed model can even analyze multiple levels of relatedness. In general, feasibility of AM is appropriately measured by Fisher`s exact test. Candidate gene mapping is more feasible technically and financially in case of tree species having large genome size like conifers. GWAS mapping is more useful in dissecting the complex quantitative traits but it is not feasible everywhere. However, compared to linkage mapping, it is a better alternative even in tree species having large genome size as it has the ability to identify individual genes and alleles. The significant QTL associated with tree height, diameter at breast height and stem volume have been successfully mapped in *Populus* sp, etc. With the advancement in high throughput sequencing methods and development of integrated mapping approach, mapping can be done effectively even in non-model perennial tree species. Development of proper statistical tools, design of experiment and interpretation methods may even help in identifying all individual genes responsible for quantitative traits also. AM appears to be a promising tool to accelerate the advancement in the field of tree genomics, breeding, tree improvement, understanding the evolutionary process and exploiting the economic value of forest trees sustainably.

Breeding for Boundaries: genomic variants controlling the formation of defensive barriers against necrotrophic stem decay pathogens in Norway spruce

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Trees must cope with the attack of multiple pathogens, often simultaneously during their long lifespan. In Northern Europe. *Heterobasidion* root- and stem-rot is a major disease of Norway spruce (*Picea abies*) causing vast economic losses. The disease is caused by *Heterobasidion parviporum* and its sympatric congener *Heterobasidion annosum s.s*. While a lot of wok has been done to understand and identify resistance to *H. parviporum* in Norway spruce it is unclear to what extent these resistances are effective also against *H. annosum s.s*. The objective of this work is to compare the genetic component of resistance in Norway spruce to *H. annosum s.s*. with the resitance to *H. parviporum.* To achieve this resistance to either or both pathogens relative resistance was measured using artificial inoculations in half-sib families obtained from the Swedish breeding program. The genetic component of resistance was analysed using genome-wide exome-capture sequenced SNPs and multitrait genome-wide associations. No correlation was found for resistance to the two pathogens in this particular breeding population; however, various associations were found between genomic variants and resistance traits with synergic or antagonist pleiotropic effects to both pathogens. Several of the pleiotropic genomic variants appear to be connected to processes leading to compartmentalization of the pathogen including variants in the Norway spruce *laccase PaLAC5*. Expression analyses showed that *PaLAC5* responds specifically and strongly in close proximity to the *H. parviporum* inoculation. Thus, we hypothesize that *Pa*LAC5 and pleiotropic genome variants with similar expression patterns may be associated with the lignosuberized boundary zone formation in bark adjacent to the inoculation site. We will present further analyzes of allelic variants at the pleiotropic loci and their connection to the formation of defensive barriers using inoculation experiment with *H. annosum s.s*. and *H. parviporum*.

Broad genomics applications in host-pest/pathogen interactions: from tree breeding targets, biosurveillance tools to biopesticide development

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Healthy trees can act as a local climate buffer, reducing energy costs. Physiologically stressed trees, however, have a reduced carbon storage capacity or even become net carbon emitters due to biochemical limitations on carbon uptake. Therefore, it is critical to address *at multiple levels* the current threats to planted and natural forests caused by biotic agents. Different actions need to be taken depending on the type of biotic threat (local, expanding, invasive) and the goal of its management. Assisted gene flow and targeted breeding of host trees for resistance alleles are feasible if the breeding target is already known (e.g., increasing the production of certain chemical resistance compounds). Yet, knowledge of the biology of the pest/pathogen itself can be translated into its successful containment by developing a biopesticide or a tool that allows for biological monitoring. For native species, the preliminary work is certainly easier, since in many cases prior knowledge is already available. However, for alien invasive species, especially those of highest priority due to their aggressiveness, task forces are firstly needed to conduct rapid and in-depth surveys of the species throughout their geographic range within an applied empirical framework (collaborative science).

In my talk I will present three examples of my latest research that all use the power of genomics and molecular biology to: (a) identify top susceptible hosts among the 10 commercially most valuable Canadian conifer species against an invasive polyphagous herbivore (*Lymantria dispar* spp.), unravel the transcriptomics foundation of the high detoxification potential of the pest, and deduce the most promising chemical defense compounds (among foliar terpenoids, phenolics) from extensive host utilisation experiments. Findings are supplemented by genetic parameter estimations for host defense compounds that we found to be improvable through phenotypic or genomic selection; (b) address species identification (taxon), source, route of invasion, invasion history, and traits of invasiveness (cold adaptation, host shift) for the Asian longhorned beetle under a biosurveillance framework; (c) develop a phytoprotective agent against the native spruce budworm based on large-scale production of recombinant budworm DNA and the development of a methodology for encapsulating these DNA fragments.

Can pathogen 'omics' and model plant hosts help improve forest tree resilience to Phytophthora pathogens?

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Pathogens in the genus *Phytophthora* are notorious killers of forest trees, causing diseases such as sudden oak death, jarrah dieback and kauri dieback. In efforts to understand these pathogens and to ultimately determine the molecular basis of how they cause disease, genome, transcriptome and proteome datasets have been generated for many *Phytophthora* species. These datasets have enabled the identification of proteins that are produced and secreted *in planta*. Many of these proteins, termed effectors, are of potential importance in interactions with the plant host. Analysis of effector function is required to determine what those interactions are, but that can be problematic when dealing with a slow-growing and complex gymnosperm host. Thus, in some cases, the use of a model angiosperm plant host is a useful tool for functional analysis of plant-pathogen interactions. The highly destructive pathogen *P. agathidicida* causes kauri dieback, killing *Agathis australis* trees that are of immense cultural and ecological significance in New Zealand. We assembled the genome of *P. agathidicida* to chromosome-level and identified effector candidates. Due to limitations in working with kauri trees, we used *Nicotiana benthamiana* as a model plant host to help analyse the roles of effectors *in planta*. Expression of *P. agathidicida* genes was compared on the two hosts and effector functions determined by infiltration into leaves. Comparison of the *P. agathidicida* gene expression patterns in kauri and *N. benthamiana* highlighted similarities as well as host-specific differences. Functional studies in *N. benthamiana* identified a *P. agathidicida* effector that suppresses defence responses elicited by a wide range of pathogen molecules and thus might be an important virulence factor. Other effectors were identified that appear to be recognised by *N. benthamiana* immune receptors that trigger defence responses. The importance of immune receptors was highlighted by greatly increased growth of *P. agathidicida* on *N. benthamiana* lacking SOBIR1, an immunity co-receptor for extracellular effectors. Identification of effectors with important roles in disease could ultimately lead to management solutions for gymnosperm diseases, for example by identification of pathogen targets for RNA silencing or by identification of host immune receptors for use in breeding for improved disease resistance.

Comparison of defensive lncRNA expression profiles of Pinus spp. with different susceptibility to Fusarium circinatum using a dual RNA-seq approach

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Understanding the complexity of the plant transcriptome that underlies pathogen defence would greatly facilitate the development of an accurate breeding programme for resistance. This is essential in the case of forest diseases for which there are no viable eradication measures, and the use of genetically resistant material seems to be one of the most promising strategies. Pine pitch canker (PPC), a pine disease caused by the invasive pathogen *Fusarium circinatum*, is one such example where, once established, no control methods are available. Although a number of genes associated with resistance to *F. circinatum* have been identified in pine species, the non-coding part of the host transcriptome is still poorly understood. Long non-coding RNAs (lncRNAs) are emerging as important transcriptional regulators under biotic stress in plants, *cis*-regulating the transcription of genes around their transcription site or leaving their sites to exert their function elsewhere as *trans*-acting transcripts. In this study, lncRNAs from the highly susceptible *Pinus radiata* and the resistant *Pinus pinea* inoculated with *F. circinatum* were identified and characterised at an early stage of infection. Overall, 8,783 and 5,255 lncRNAs were predicted in *P. radiata* and *P. pinea*, respectively, using a comprehensive bioinformatics approach. Among them, 37 and 34 lncRNAs were differentially expressed (DE) in *P. radiata* and *P. pinea*, respectively, in response to *F. circinatum* infection. The predicted *cis*-regulated target genes of these pathogen-responsive lncRNAs were related to defence mechanisms, which was consistent with the results of the co-expression network analysis. The dual approach allowed the identification and characterisation of lncRNAs in *F. circinatum* for the first time. Our findings reveal the expression of pathogen-responsive lncRNAs in both pine species and provide new insights into the connection between lncRNAs and key pathways in the regulation of plant disease resistance. In addition, the different lncRNAs used by *F. circinatum* infecting each pine species were identified and will help us to better understand the strategies of this serious pathogen.

Disentangling the origin of an emerging Araucaria araucana pathogen in the Chilean Andes

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: *Araucaria araucana*, commonly known as the monkey puzzle tree or pewén, is an ancient conifer species occurring in the mountain ranges of Chile and Argentina. These trees grow naturally in high altitude environments where they are exposed to extremely cold winter conditions, including long periods of snow cover and dry hot summers. During 2015-2016, *A. araucana* trees were observed displaying severe die-back symptoms in several locations within their natural distribution. Field surveys and monitoring of symptomatic trees revealed a serious canker disease associated with the death of branches. The lesions girdled the branches and, in some cases infected young stems resulting in copious amounts of resin being exuded and ultimately leading to the death of the affected organs. Four fungal species belonging in a novel genus described as *Pewenomyces* (*Coryneliaceae*) were discovered in association with these cankers. Long-term pathogenicity tests under field conditions showed that one of these species, described as *P. kutranfy*, was capable of reproducing these lesions, thus leading to the conclusion that this is the causal agent of the disease. Based on current knowledge, it is suspected that *P. kutranfy* is a native pathogen and the associated disease has arisen due to changes in climatic conditions. An alternative hypothesis that the pathogen has been introduced remains a possibility. To address this knowledge gap, the genome of *P. kutranfy* was sequenced with the objective of developing molecular markers to study the genetic diversity of the pathogen. Illumina sequencing of the ex-type culture of *P. kutranfy* resulted in the assembly of a 29,59 Mb genome and ten microsatellite (SSR) markers were developed using these sequences. The markers were tested on a small subset of isolates, and studies with isolates from two *A. araucana* populations are underway. Results of these studies will provide genetic insights as to whether the pathogens might be native to the area or introduced, its mechanisms of reproduction and its patterns of spread. This study will also aid in determining key areas of research needed to develop disease management strategies.

Dual RNA-seq and host whole genome sequencing provide genetic insights into the sudden oak death host-pathogen interaction

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: The sudden oak death epidemic in the coastal forests of Oregon and California has been characterized by multiple outbreaks over the last three decades, the establishment of 638 square miles of quarantine and generally infested areas in Oregon, and more than US$34 million allocated to control programs in Oregon between 2001 and 2021. In addition, habitat loss and forecasted local extinctions are predicted to have long-term consequences for the ecology of the mixed conifer forests of the region. To date, management efforts have focused on preventing epidemic spread through host removal and sanitation measures, but gaps in our understanding of the host-pathogen interaction during infection and disease prevent the development of new management strategies, such as host resistance. The causal pathogen, *Phytophthora ramorum*, is a generalist oomycete with a hemibiotrophic habit. This trophic strategy results in a dynamic disease cycle, with each phase characterized by unique patterns of gene expression. In pursuit of understanding this host-pathogen interaction, tanoak (*Notholithocarpus densiflorus*) leaves were inoculated with *P. ramorum* and mRNA was extracted from leaf lesions at 2, 7, and 14 days post inoculation (dpi) (n = 12 x 3) and then sequenced. Mock inoculations (n = 3) and pure *P ramorum* cultures (n = 14) were used as controls. 13,821 unique NA1 transcripts and 13,182 unique EU1 transcripts were detected in vivo following sequencing and mapping. Differential gene expression analysis was conducted with the overall goal of identifying genes upregulated during disease development, with specific interest in RXLR and CRN effector proteins, necrosis inducing proteins, and proteins implicated in infection and biotrophy. Analysis was structured to compare: 1) the transcriptomes of NA1 and EU1; and 2) the transcriptomes of each respective lineage among the three dpi time points. In addition, a haplotype-phased reference genome was constructed for tanoak, which is the primary driver of the epidemic in Oregon forests. The genome was constructed using a combination of short and long-read sequencing technologies. The combined genome size of both haplotypes was 1,506.1 Mb with main genome scaffold N50 lengths of 30.1 and 25.4 Mb.

Enhancing Tree Resilience to Climate Change: Biotechnological Strategies and Genome Editing

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Various breeding and silvicultural strategies are being pursued to adapt forest tree species and even entire forests to climate change. In particular, traits such as drought stress tolerance and resistance to already existing but also novel pathogens are two major tree breeding objectives. However, the velocity of climate change is a major problem that is difficult to reconcile with the long generation cycles of forest trees. Here, the implementation of biotechnology provides promising approaches. Plant biotechnological tools, such as tissue culture, genetic engineering and genome editing, as part of plant breeding, can contribute to a rapid climate change adaptation of forest trees. Advantageously, biotechnological treatments are not dependent on flowering and fruiting.

New possibilities and great potential are offered by genome editing techniques such as CRISPR/Cas, which are already being used intensively in crop research and for an increasing number of tree species. Some methods already developed for crop species have yet to be transferred to forest tree species. Even though the basic CRISPR/Cas mechanism seems to be rather universal, the insertion of the Cas nucleases needs to be further addressed when working with different tree species. In addition to classical, gene technology-based approaches to research, DNA-free approaches are also being pursued to generate nature-identical genetic modifications.

Genome editing is being used to characterize the function of genes and to unravel biochemical pathways. A better understanding of the genetic basis of morphological and physiological traits can support genotype-based breeding. Although most of the abiotic and biotic traits are encoded by numerous genes, modifying a few genes can quantitatively increase the resilience against the effects of climate change. However, at least in Europe, regulatory aspects have to be considered when dealing with genome editing.

Evaluating the Effects of Gibberellic Acid Treatment on Cone-Setting Frequency in Picea abies Genotypes: Insights from the Nässja Mini-Seed Orchard

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: The Nässja mini-seed orchard, established in 2008, serves as a research facility encompassing seed orchard management and field trials. Comprising 18 distinct clones, the orchard originated from the late 1980s to early 1990s as part of an indoor seed orchard in 100 L pots before being transplanted to the Nässja site. The primary focus of our field trial is investigating the impact of gibberellic acid (GA) injections into tree trunks. The injections are timed using a formula incorporating temperature sums, with June 22nd as the reference date. Three treatment conditions are examined: control, annual GA injections, and biennial GA injections. The trial consists of 14 rows, with 40 trees per row. The outermost rows act as windbreaks and are not included in the analysis, leaving 12 rows for investigation. Each row uniformly receives a specific treatment regimen. Since 2009, meticulous recording of female and male cone data has been conducted. Female cones are quantified through direct counting, while male cones are classified as present or absent within the designated observation period.

Our research aims to assess the impact of GA treatment on cone-setting frequency in different genotypes of Picea abies. To achieve this, mRNA was extracted from buds growing in expected female cone positions on the Norway Spruce trees in the Nässja field trial, both before and after GA treatment. Subsequently, RNA sequencing was performed at National Genomics Infrastructure, part of the Genomics Platform at SciLifeLab in Sweden to identify and analyze differentially expressed genes between the two treatment conditions. Additionally, in collaboration with the Swedish Metabolomic Centre in Umeå, we are assessing the presence and abundance of gibberellic acids (GAs) in trees before and after GA treatment, to establish a correlation between differentially expressed genes (DEGs) and GA levels. Furthermore, we are exploring potential associations between variations in the member of the SQUAMOSA BINDING PROTEIN-LIKE (SPL) gene family, PaSPL1 locus, expression of different miR156 variants, and observed differences in cone-setting frequency among *P. abies* genotypes. This multi-faceted approach aims to enhance our understanding of the intricate relationship between gene expression, GA presence, and cone-setting frequency in our study system.

Evolutionary consequences of ash dieback in natural populations of Fraxinus excelsior

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Common ash (*Fraxinus excelsior* L.) is a tree species with ecological, economic and cultural importance, which is considered a species with high adaptive potential to climate change, as it can tolerate a wide range of environmental conditions. However, ash dieback, a fungal disease caused by an invasive ascomycete, *Hymenoscyphus fraxineus*, is provoking a sharp decline in common ash populations throughout Europe. Common garden experiments have shown that susceptibility to ash dieback is a heritable trait but only a low proportion of ash trees show low susceptibility to the disease. Taking advantage of trees growing in clonal plantations of common ash (in Denmark, Sweden, Germany, Austria, Ireland and Lithuania) affected by the pathogen, a previous genome wide association study revealed many associated loci with rather small effects. Using 25k loci we could predict up to 63% of variation in disease susceptibility.

Here we collected a total of 246 leaf samples from 19 natural common ash populations from Spain, France, Switzerland, Germany, Poland, Scotland, Denmark and Lithuania. We randomly sampled leaves from young trees, over 2.5 m height that had already survived several years under disease pressure. The health status of young trees was worst in recently affected regions and better in regions with longer pathogen presence. From five locations, we had additional samples from adult trees collected in 2001 before any severe ash dieback damage was visible. Using whole genome sequencing and based on the loci identified in the genome wide association study, we will generate polygenic risk scores to assess pathogen susceptibility in the young and old tree cohorts in order to test if selection in response to ash dieback can already be detected. Furthermore, our approach will allow predictions of susceptibility to ash dieback also in natural populations not yet affected by ash dieback, e.g. in northern Spain.

Experiences from 15 years of genetic research on European common ash (Fraxinus excelsior L.)

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Common ash is an ecologically valuable tree species found both on soils of floodplain forests and on moderately dry lime-weathered calcareous soil. For this reason, it has long been considered an important tree species for climate smart forestry on base-saturated sites. However, ash dieback largely limits their use, especially in moist locations. Since 2009, the Bavarian Office for Forest Genetics (AWG) has been involved in various projects to detect the disease, monitored its effects and progress, and investigated its genetic aspects and conservation measures thereof.

Soon after the first detection of the disease we observed loss of genetic diversity along with the decline of vitality in natural stands as well as in a provenance trial. Driven by field observations of individual differences in susceptibility, a common garden experiment with the clones and progenies of vital and susceptible mother trees was established and regularly monitored in terms of disease symptoms. After eight years of assessment, few clones still showed significantly higher vitality. In all progenies, healthy individuals were present. Paternity analyses in a natural stand and a seed orchard suggest that high vitality has a positive effect on reproductive success and effective pollen transport can occur over long distances. Therefore, for in-situ conservation of ash, less susceptible trees should not be cut in order to maintain the connectivity among ash individuals. Forest management activities in ash stands should promote natural regeneration of healthier adults to potentially favour healthier progeny. Genetic diversity in stands should be kept as high as possible by means of healthy adult trees as well as by high numbers of offspring in the first years to provide a basis for evolutionary forces to act on. For ex-situ conservation and resistance breeding, healthy ash trees were selected throughout Bavaria and propagated. The results of population genetic analyses and a genomic selection method for less susceptible individuals, which will be used to assist final tree selection for seed orchard establishment, will be shown.

Fast identification and selection of Scots pine trees with greater resistance to multiple pathogens using infrared spectroscopy

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Scots pine (*Pinus sylvestris*) is one of the most economically and culturally important trees in Europe. It is the second most abundant tree in Sweden and is a vital component of its plan for sustainable forestry. However, the health of Scots pine is threatened by a number of current and on-the-horizon diseases that can significantly reduce productivity and outright threaten tree survival. Many of these pathogens are already established, and future management options must find ways to mitigate losses. Exploiting natural host resistance in tree breeding programs is the best method for future-proofing our forests, but phenotyping for resistance is a slow and expensive process. Sustainable quantitative resistance to pests in trees typically involves and array of defensive chemicals and anatomical structures. Recent advances in infrared spectroscopy have made it possible to get a “chemical fingerprint” of whole living tissues that can be used in chemometric analyses to identify plants with desirable properties like resistance.

The objective of this study is to use a handheld Fourier transform infrared (FTIR) spectrometer as a rapid phenotyping tool to massively accelerate the selection process of resistant Scots pine genotypes. To achieve this objective, young saplings from several families of Swedish Scots pine trees will be analyzed with the FTIR scanner and then artificially infected with *Diplodia sapinea* or *Gremmeniella abietina*. Trees will then be classified as either relatively resistant or susceptible based on resulting lesion lengths. Using the FTIR data, training and testing chemometric models for predicting tree resistance will be built that can then be applied to naïve trees to facilitate selection efforts of breeding programs.

First application of Near-infrared spectroscopy as a field predictive phenotyping tool for susceptibility of Fraxinus excelsior to ash dieback

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Ash dieback caused by the invasive fungus *Hymenoscyphus fraxineus*, threatens common ash trees (*Fraxinus excelsior*) in Europe. Identifying ash trees with tolerance to ash dieback is one of the key priorities to set-up breeding programs. So far, this is hindered by the very low proportion of tolerant trees, which make it necessary to develop efficient tools for high throughput disease phenotyping. In this study we aimed at implementing NIR spectrometry to predict ash dieback susceptibility in naïve ash trees.

We used a miniaturized handheld near-infrared (NIR) spectrometer to fingerprint leaves and bark to classify 103 grafted ash trees that were subsequently inoculated with *Hymenoscyphus fraxineus*. Based on sig. differences in downwards lesion length and dieback of leader shoots, genotypes were assigned to three phenotype classes. We compared partial least squares-discriminant analysis (PLS-DA) models with the machine learning algorithms, Support Vector Machine (SVM) and Random Forest (RF), and were able to identify tolerance to ash dieback in naïve trees with an accuracy ranging from 0.75 to 0.90.

Our study shows that NIR spectroscopy is a promising tool to identify in situ tolerant ash trees at an early stage before they become infected, making it possible to study thousands of trees at a reasonable cost.

First insights into genetic structure and diversity of Corylus colurna L.

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Genetic diversity is the basis for adaptation and survival of tree species under changing environmental conditions representing the key issue of stability and productivity of forest ecosystems. The first step was the selection of appropriate populations of Turkish hazel for genetic characterization in the countries of origin or within its natural distribution range. Turkish hazel is naturally distributed on the Balkan Peninsula (Bulgaria, Bosnia and Herzegovina, Romania, Serbia, FYR Macedonia, Kosovo, Montenegro, Albania and Greece), Asia Minor, Caucasus and Afghani-stan. Because of its valuable wood, this tree species was overused in all countries. Now Turkish hazel is present only in small isolated populations and is protected under IUCN. For the genetic characterization we collected samples from 25 populations within the distribution range from Bosnia and Herzegovina (west border) to Georgia (east border).

The poster introduces the project “Suitability for cultivating Turkish hazel (*Corylus colurna* L.) under climate change” and its first results of genetic characterization of sampled populations. A clear separation of populations of *C. colurna* from Balkan, Turkey and Georgia were found and confirms the differentiation of gene pools within the natural distribution range of Turkish hazel. Based on our findings, the Bavarian Office for Forest Genetics (AWG) has established a provenance trial in Bavaria and Baden-Württemberg. Therefore, valuable information on trees adaptation and growth from differ-ent provenances will be obtained in the future from such experimental plots. Overall, our results highlight needs to delineate provenance regions, identify conservation units and seed stands for Turkish hazel which are essential for species conservation, provenances research and possible assisted migration attempts.

Genetic and morphological diversity in populations of Annona senegalensis Pers. occurring in Western (Benin) and Southern (Mozambique) Africa

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Understanding morpho-genetic diversity and differentiation of species with relatively large distribution is crucial for the conservation and sustainable management of their genetic resources. The present study focused on *Annona senegalensis* Pers., an important multipurpose wild plant, distributed exclusively in natural ecosystems but facing several threats. The study assessed the genetic and morphological diversity, structure, and differentiation of the species among populations from Western (Benin) and Southern (Mozambique) Africa. The material was evaluated to ascertain the environmental (climatic) determinants of the variation within this species. Four sub-populations comprised of 154 individuals were phenotyped based on nineteen plant, fruit, and leaf morphological traits and further genotyped using ten polymorphic nuclear microsatellite (nSSR) markers. The results indicated strong differences in plant, fruit, and leaf morphological traits between Western and Southern populations. Furthermore, the studied populations were characterized by high genetic diversity, with an average genetic diversity index of 1.02. The Western population showed higher heterozygosity values (0.61-0.71) than the Southern population (0.41-0.49). These two regions were clearly differentiated into two different genetic groups, with further genetic subdivisions reflecting the four sub-populations. Genetic variation between regions (populations) was higher (69.1%) than among (21.3%) and within (9.6%) sub-populations. Four distinct morphological clusters were obtained, which were strongly associated with the four genetic groups representing each sub-population. Climate, mainly precipitation and temperature indexes, explained the relatively higher variation in morphological traits in Western (40.47%) than in Southern (27.98%) populations. Our study provides crucial information for the sustainable management of this species.

Keywords. *Annona senegalensis*; bioclimatic variables; genetic diversity; morphological diversity; tropical plants

Genetic basis of resistance to ash dieback in narrow-leaved ash in floodplain forests of Europe

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Narrow-leaved ash (*Fraxinus angustifolia* Vahl.), one of the keystone tree species of floodplain forests in Europe, is rapidly declining due to highly pathogenic ash dieback caused by the fungus *Hymenoscyphus fraxineus* (formerly *Chalara fraxinea*). We examined the molecular basis of disease resistance at nearly 10,000 genome-wide SNPs (selected in genes showing disease resistance in previous common ash studies, after filtering for minimum allele frequency and linkage disequilibrium) in five narrow-leaved ash populations in the wider area of the Mura-Drava-Danube Transnational Biosphere Reserve. Thirty to 40 adult trees and 30 saplings up to 2 m tall were sampled per population. For each adult tree, health status was assessed on a scale from 1 (healthy) to 5 (only a small part of the crown remaining, 81-99% defoliation). There was no evidence that genetic diversity estimated as heterozygosity decreased in regeneration despite ash dieback. Trees with higher DBH tended to be healthier. Disease resistance had high heritability in field conditions (0.84, CI 0.22-0.93), although it did not appear to be a polygenic trait. Rather, lasso regression using binomial and Poisson models explained approximately 45% of the variance and identified 15 SNPs (common in both models) associated with resistance to ash dieback. Analysis of the transmission of SNPs showing putative resistance to ash dieback from adults to progeny is ongoing.

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Genomic signals of adaption among fungi causing Annosum root rot

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Annosum root rot disease causes severe losses to northern hemisphere forestry due to loss of timber, tree mortality and decreased carbon sequestration. The disease is caused by species from the *Heterobasidon annosum s.l.* species complex consisting of five species with different but overlapping conifer hosts. Two species, *H. anosum* and *H. irregulare*, prefer pine hosts, whereas *H. occidentale*, *H. parviporum* and *H. abietinum* prefer non-pine hosts (e.g. spruce and fir). In this study, we contrast the genomes of the pine type species to the genomes of the non-pine type species in a phylogenetic context with *Stereum hirsutum* as outgroup in order to infer evolutionary differences associated with host adaption. We sequenced and assembled the genomes of the *Heterobasdion* species. Gene predictions with MAKER2, functional annotations with InterProScan, carbohydrate active enzymes (dbCAN), transporters (TCDB) and peptidases (MEROPS), were carried out. We used OrthoFinder to infer gene families and single copy orthologous genes across the study species. Modelling of gene family copy number evolution with CAFE 5 revealed that the spruce and pine type genomes are highly similar with only 20 gene families showing significant, but small changes in gene family size. A majority of the gene families with significant changes in size appears to be involved in secondary metabolism and/or cyclic compound metabolism. No significant changes in gene family sizes between pine and non-pine species were found among neither carbohydrate active enzymes, transporters nor petidases. Single copy orthologous were highly conserved with a median non-synonymous to synonymous (dN/dS) ratio of 0.05 as estimated with the PAML package. However, 146 out of 1304 single copy orthologs show a significantly better fit for PAML model allowing sites with positive selection rather than only negative selection or neutral. Among genes where we observe possible positive selection, GeneOntology terms related to cyclic and aromatic compounds are overrepresented. Our results indicate that adaption to different host types among *Heterobasidion* species appears to be a matter of adaption through changes related to secondary metabolism. This would enable the fungus to cope with the biochemical environments and/or produce defence substances, rather than adapt to actual substrate differences.

Identification and characterization of PaSPL1 gene targets and promoter regulatory elements in the Nässja seed orchard

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: One of the most significant foundational industries in Sweden is the forestry sector. In 2008, the Nässja mini-seed orchard was established as a field trial and seed orchard. The field trails, consist of 18 different genotypes and a total of 500 *Picea abies* trees, where flowering data has been recorded since 2009. In this trial, we have found clear differences in cone-setting frequency between the different genotypes. Due to Norway srpuce's infrequent and hard to predict flowering, it is critical to understand the pathways that lead to cone production. We have previously shown that cone-setting in Norway spruce is regulated by a SQUAMOSA BINDING PROTEIN-LIKE (SPL) transcription factor, *PaSPL1*.

As an initial step to identify natural sequence variations that could explain genotype dependent difference in cone-setting frequency, we sequenced the putative promoter, *i.e.* 3000 base pairs upstream of the translational start codon in the 18 genotypes. Further, we compared the sequences to identify short nucleotide polymorphism (SNPs), indels, and regulatory elements that could be correlated with cone-setting frequency. We will evaluate the functional significance of the identified regulatory elements and binding sites in order to understand the potential function of the components in gene regulation. Additionally, predicted regulatory elements in the promoter of *PaSPL1*, genes that target *PaSPL1,* and genes targeted by *PaSPL1* will be validated experimentally using techniques such as Y1H, reporter gene assays, promoter deletion, and site-directed mutagenesis. The findings of this work will contribute to our knowledge of gene regulation and reproductive shift in plants as well as offer potential applications in the manipulation of plant development and flowering pathways. Utilizing the most advanced molecular and genomic technologies, we will work together to create a model for future forest breeding that will ensure productivity, biodiversity, and climate stability for Swedish forest owners.

Identification of genes and pathways involved in the defence response of Pinus nigra to Diplodia sapinea by combining transcriptomics and metabolomics

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: The European black pine (*Pinus nigra* J.F. Arnold) is a conifer of great economic and ecological importance and is widely used for afforestation and reforestation in Central Europe as a potential substitute for native species threatened by global warming. Unfortunately, the fungus *Diplodia sapinea* (Fr.) Fuckel is causing severe damage and worldwide economic losses to this and other *Pinus* host tree species. The lack of genomic resources and the scarce knowledge of the induced molecular defence responses limit breeding perspectives. In the present study, we investigate for the first time the molecular responses of two *P. nigra* provenances (representing two subspecies) to *D. sapinea* infection using a combined transcriptomic (RT-qPCR, RNA-Seq) and metabolomic (terpenoids, phenolics, hormones) approach in a greenhouse controlled infection experiment over a period of 21 days with the aim to identify genes and pathways involved in the induced defence response. In the absence of a complete *P. nigra* reference genome, we used two strategies to establish an appropriate standard RNA-Seq protocol, firstly by using the only publicly available *P. nigra* reference transcriptome and secondly by using the most complete available reference transcriptome of the closely related pine species *P. sylvestris*. The combined transcriptomic and metabolomic approach suggests that the response of *P. nigra* to *D. sapinea* infection becomes systemically activated 21 days post infection. This activation is characterised by a significant increase in key signalling hormones associated with plant defence, including jasmonic acid, abscisic acid, and salicylic acid. This coincides with the most notable differential gene expression, primarily involving the major pathways associated with plant defence mechanisms. As a result, the induction and release of several phytoalexins and defence-related proteins were observed. Furthermore, we show that some of these systemically induced responses are provenance specific. Finally, this study identifies the key genes and pathways involved in the defence response of *P. nigra* to *D. sapinea*, providing a solid basis for further characterisation of its variation in natural populations with different susceptibilities, as a prerequisite for any association studies to better elucidate the resistance mechanism and to select improved reproductive material.

Interaction between Scots pine, Melampsora pinitorqua, and Diplodia sapinea; does M. pinitorqua leave trees more vulnerable to Diplodia tip blight?

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Recent reports have highlighted the occurrence of young Scots pine stands infected by both *Melampsora pinitorqua* (pine twisting rust) and *Diplodia sapinea (*Diplodia tip blight*)* in various locations in Sweden. *M. pinitorqua* is a rust pathogen that alternates between Scots pine (*Pinus sylvestris* L.) and European aspen (*Populus tremula)*, causing bending or breaking of the pine's annual shoots. The pathogen *D. sapinea* causes economically significant infections on conifers across the globe. The dominating pine species in the Nordic countries, Scots pine, is among the species susceptible to *D. sapinea*. The pathogen can persist in a susceptible host without causing apparent disease, with an onset of disease symptoms when the host is subjected to abiotic stress. In this project, we study the ecological, physiological, and genetic aspects of the interactions between Scots pine and these fungi. We hypothesise that trees severely affected by *M. pinitorqua* will exhibit a higher frequency of *D. sapinea* infections and that the abundance of *D. sapinea* will increase in *M. pinitorqua*-infected tissue. We also hypothesise that the allele frequencies and expression of cellular and metabolic defence responses will correlate with differences in the expression of disease upon infection with *M. pinitorqua* or *M. pinitorqua* and *D. sapinea*.

Phenotyping was conducted on 567 trees to assess symptoms caused by *M. pinitorqua* and *D. sapinea*. Tissue samples from healthy trees, *M. pinitorqua*-infected trees, and trees showing symptoms of both pathogens were collected for metabolite profiling, gene expression analysis, and quantification of the pathogens. Genotyping was performed on the studied trees and their parents to investigate the genetic architecture of disease resistance.

This study contributes to a better understanding of the complex interactions between tree hosts and pathogens, aiding in disease management and tree breeding programs. The results have implications for enhancing resistance to multiple pathogens and improving strategies for sustainable forest management.

Interaction of Douglas fir provenances with environmental conditions in two IUFRO provenance tests in Bosnia and Herzegovina

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: This study aimed to examine the interaction between the effects of the genetic structure of provenances and two localities of provenance tests in Bosnia and Herzegovina. The results will be used for the selection of best provenances for further use in wood production.

Two IUFRO provenance tests of Douglas fir (Goleš Radalje – Travnik, and Zavidovići Gostović), with different environmental conditions, were established in 1972. Seedlings 2+2 years old were planted in three blocks, total 192 plants per provenance. Six provenances were represented in both tests (1029 - Thasis, Canada, 1036 – Alberni, Canada, 1060 – Sequim, Washington, 1090 – Cougar, Washington, 1099 – Pine Grove, Washington, 1100 – Grand Ronde, Oregon). Diameters at breast height and heights of all survived trees were measured in 2022 (56 year-old trees). The variances of traits caused by provenance tests, provenances, and interaction of provenance tests and provenances were examined using multivariate analysis.

Test of Between-Subjects Effests showed statistically significant differences in diameters at breast height caused by provenance tests but not caused by provenances or interaction between provenance tests and provenances. Test of Between-Subjects Effests showed statistically significant differences in heights caused by provenance tests, provenances, and by interaction of provenance tests x provenances. Provenance 1029 had the best growth in height in provenance test Goleš Radalje but the worst in Zavidovići Gostović. All provenances showed better growth in height in Goleš Radalje provenance test, and better growth in breast height diameter in Zavidovići Gostović provenance test.

The obtained results can be used for the selection of the best provenances for afforestation at predefined habitats that correspond to the conditions of the experimental plots, as well as for raising clone plantations or seed plantations of the species.

Lessons learned from successful conifer resistance breeding program in the United States

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Forests deliver a wide array of essential ecosystem services. However, throughout the world, pathogens and pests, many of them non-native and invasive, continue to cause high mortality to forest tree species. Breeding to develop populations of trees genetically resistant to these deadly pathogens or pests can be a powerful tool to help retain the utility of affected species. The USDA Forest Service has been active in resistance breeding for more than 60 years, with several notable successes that make it a world leader in this area. Programs to develop resistance to white pine blister rust (caused by *Cronartium ribicola*) and to Port-Orford-cedar (POC) root rot (caused by *Phytophthora lateralis*) are the two most successful examples. Dorena Genetic Resource Center (DGRC) has evaluated resistance to white pine blister rust in all nine 5-needle pine species native to the U.S. as well as *P. lateralis* resistance in POC. DGRC uses traditional selective breeding methods in all its programs, incorporating the naturally occurring resistance present within those species. The resistance programs also emphasize incorporating wide genetic diversity and associated field trials serve as sentinels to durability and stability of resistance as well as to monitor species adaptability under climate change. Resistant seed is now available for three of the pine species as well as POC and are being used for restoration and reforestation by multiple organizations. Continuity, staffing, facilities, and partnerships have all been essential components of these operational programs. A sustained focus on the applied output (resistant seedings for planting) rather than basic research has also been key. With examples of successes in tree resistance breeding now available, there is renewed interest world-wide in undertaking similar work. Studying what has worked in these programs should help increase the efficiency and likelihood of success in other resistance programs. As a complement to the applied resistance programs, a look at information from sentinel plantings is underway to help identify potential future threats to U.S. forests.

Looking for resilience? Who you gonna call? Abies pinsapo Boiss!

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health
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Abstract: Currently, little is known about the molecular response to climate change-related stresses in the Spanish fir (*Abies pinsapo* Boiss), a conifer species of great ecological relevance, which is in danger of extinction. Furthermore, the lack of available complete genomes as well as standardised protocols for handling biological samples makes the study of molecular responses in conifers a difficult task. In this context, our group recently achieved the complete transcriptome assembly of *A. pinsapo* (Ortigosa et al. 2022), enabling functional genomic studies in this species.

Our study aims to shed light on molecular mechanisms governing the response to abiotic stress in *A. pinsapo* within its natural ecosystem by identifying gene families associated with the response to increased temperature and water stress. Our investigations have already identified candidates' genes and revealed their differential seasonal expression patterns across various tissues in *A. pinsapo* from distinct geographical areas and with diverse weather conditions. These findings hold the potential to significantly enhance our understanding of how *A. pinsapo* adapts to environmental stressors. Moreover, the acquired knowledge will provide important information for the development of sustainable forest management strategies in the vulnerable forest of the southern Iberian Peninsula, combating the adverse impact of climate change.

Master regulator of alkene biosynthesis pathway mediates disease resistance in Populus trichocarpa to Sphaerulina populicola

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: A genome-wide association study was conducted on a population of 917 unrelated *P. trichocarpa* individuals and phenotyped for *Sphaerulina populicola* leaf spot. Using high-coverage whole-genome sequences the analysis revealed a single locus on chromosome 10 that exhibited associations with *S. populicola* leaf spot (P<0.001). This association revealed PotriKCS1, an alkene biosynthesis gene, was significantly associated with leaf spot. PotriKCS1 elongates monounsaturated fatty-acids and is responsible for the recruitment of unsaturated substrates during cuticle development. Trees with a functional copy of PotriKCS1 have been shown to accumulate a variety of alkenes in their cuticular wax; whereas trees lacking PotriKCS1 do not accumulate these alkenes in their cuticular waxes. The presence of the alkenes in the epicuticular wax of *P. trichocarpa* leaves is correlated with increased susceptibility to the co-evolved leaf-spot pathogen *S. populicola*. Gas chromatography–mass spectrometry (GC-MS) was conducted on three biological replicates of 24 genotypes of *P. trichocarpa* to determine the composition of leaf cuticular waxes. Pentacosene was among the top alkenes detected with a strong correlation (r=0.66533) to susceptibility. Chemical complementation of the trees lacking pentacosene in their cuticular waxes increased susceptibility in two greenhouse experiments. These results support our hypothesis that the presence of specific cuticular wax components promotes susceptibility to leaf spot disease in some genotypes of *P. trichocarpa.*

Multitrait GWAS and supervised machine learning reveal the genetic architecture of Fraxinus excelsior tolerance to ash dieback in Europe

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: European ash (*Fraxinus excelsior*) is under intensive attack from the invasive pathogenic fungus *Hymenoscyphus fraxineus*, causing ash dieback at epidemic levels throughout Europe. Previous studies have found that host phenology, such as autumn yellowing, are correlated with susceptibility of ash trees to *H. fraxineus*; however, the genomic basis of ash dieback tolerance in *F. excelsior* remains poorly understood. Here, we integrate GWAS (genome-wide association study) with machine learning to reveal the genetic architecture of ash dieback tolerance and its relationship to phenological traits. We confirm genetic correlation between ash dieback crown damage and intensity of autumn leaf yellowing, within multiple sampling sites in six European countries (Austria, Denmark, Germany, Ireland, Lithuania, Sweden). A relatively small number of single nucleotide polymorphisms (SNPs) explained a large proportion of the variation in both disease tolerance and autumn leaf yellowing with 25k SNPs explaining 63% of variation in ash dieback

crown damage and 10k SNPs explaining 63% of variation in leaf yellowing. We identified 8 SNPs encoding non-synonymous substitutions within genes related to plant defence (6 SNPs) and phenology (2 SNPs). These 8 SNP variants have relatively high explanatory power of the observed traits and are functional homologs of pathogen defence genes (pathogen triggered immunity, pathogen detection), and phenological variation (regulation of flowering and seed maturation, auxin transport). Overall, our results suggest a multifactor defence response, according to which a combination of direct defence mechanisms and phenological avoidance of severe disease constitutes tolerance to ash dieback.

Negative effects of warm winters on dormancy release and apical dominance of seedlings from continental and maritime populations of Scots pine

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Negative effects of warm winters on dormancy release and apical dominance of seedlings from continental and maritime populations of Scots pine

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Our aim was to study the differential effects of variable chilling on dormancy release and apical dominance of Scots pine seedings from northern Finland, continental Russia, Lithuania, Czech Republic, and Spain. We applied 10 chilling treatments from 0 to 12 weeks of chilling on one year old seedlings starting from 1st of September 2015 in a climatic chamber. A single treatment simulated weekly temperature fluctuations from +5C to +15C during a 12-week period from the 1st of September. After the chilling treatments the seedlings were moved to forcing conditions at +15C. We used 20 seedlings per population and treatment. He results showed that increased chilling markedly decreased the heat requirement for budbust for all populations. The continental populations required markedly less amount of chilling and were more sensitive to the temperature fluctuations during the chilling period than the maritime populations. Most defects related to apical dominance loss were observed in continental populations. We also found that the warm spells during chilling period may partially cancel the effects of chilling. Warm spells may disturb apical dominance of Scots pine seedlings by causing latent/ abnormal budburst of top bud on the leader.

New and Emerging Insect Pest Tragocephala nobilis Fabricius threats domestication of multipurpose tree Tetrapleura tetraptera a (Schum and Thonn.)

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Tragocephala nobilis an insect pest was recently found on a multipurpose tree species, Tetrapleura tetraptera in Ghana. Although the pest has been previously reported on other tree crops such as cocoa and Coffea arabica, this is the first report on *T. tetraptera. T. tetraptera* is a deciduous tree crop with numerous nutritional and medicinal benefits. The pest is found to attack *T. tetraptera* tree and damage is first observed as die-back of twigs and branches leading to the formation of a witches broom in the crown. This is followed by a series of tunnels created by the larvae on the main stem resulting in branch death and tree mortality. Given the threat posed by the pest to *T. tetraptera*, a broader study has been commissioned looking at genetics selection and other management tools that could contribute to developing an integrated pest management strategy for this pest in *T. tetraptera* plantations.

New genomic resources to assist breeding for Dutch elm disease resistance

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Elms were once common trees in Europe and North America. They were key members of riverine and montane habitats and commonly used in urban landscaping. They had substantial ecological, cultural and ornamental value. Unfortunately, a series of pandemic waves of the so-called Dutch elm disease, caused by fungi from the genus *Ophiostoma*, wiped them out from most of these areas.

Ulmus minor, a species found all over Europe except further North, was specially affected. Several entities initiated conservation actions along breeding programs, although, in the latter, success has been limited to the date. The main reason was the low natural resistance of most European elm populations, mustering a poor pool of founding individuals to kick off breeding programs. Nevertheless, in Spain, an appreciable number of trees with high and moderate resistance was found, leading to the establishment of a low-input breeding program (also known as Spanish elm breeding program). However, the program is facing the limitations inherent to breeding undomesticated, not economical organisms: lack of investment from industrial sector and reduced scientific information to guide it. That knowledge scarcity is even more pronounced in the genetics of the resistance.

Obtaining more insights into the genomics of the genus and the disease would surely speed up breeding. On that ground, several research initiatives, brood from the collaboration of several public institutions, have emerged: (1) a draft reference genome for *U. minor* using Illumina and PacBio sequencing platforms and state-of-the-art assembly software, attaining an acceptable genome quality (N50 > 1 Mbp); (2) combining it with whole-genome sequencing of 12 other genotypes to create several lists of SNPs amenable for target genotyping; (3) also, by means of restriction enzyme Genotyping-by-Sequencing, studying the population genetics of the species in Spain and evaluating interspecific introgression; (4) through genotyping and phenotyping crosses, analysing Quantitative Trait Loci (QTL) associated with resistance; (5) and finally, applying that information to the genomic prediction of the Mendelian sampling of the resistance in the crosses, to effectively accelerate breeding and reduce costs.

New pathogen, Diplodia sapinea, in Finland: genetic tools aiming to determine the factors leading to increased virulence of the pathogen in Scots pine

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: *Diplodia sapinea* is a new pathogen of Scots pine (*Pinus sylvestris* L.) and juniper (*Juniperus communis* subsp. *communis*) in Finland. It has a harmless endophytic lifestyle in its cycle, but various environmental factors (drought, elevated temperature, radiation) are assumed to launch its pathogenic mode, causing disease called "Diplodia tip blight". Based on our findings, *Diplodia sapinea* is currently distributed on the south-west coastal area of Finland. Citizen science was successfully utilized in the definition of the *D. sapinea* distribution: up to 30% of the received samples were found positive for the fungal pathogen. The genetic structure of Finnish *D. sapinea* subpopulations was examined using novel *D. sapinea* culture collection, complemented with isolates extracted from specimens originating from citizen observations. Preliminary results generated with ten newly developed nuclear microsatellite markers show that Finland harbour unique genotypes but also share same genotypes with other European countries. The impact of abiotic factors to *D. sapinea* virulence was studied experimentally using three-year-old half-siblings of Scots pine originating from four geographical location. The host-pathogen interaction (necrosis) will be phenotyped in order to uncover possible variation in the *D. sapinea* tolerance of different Scots pine provenances. Furthermore, fungal differential gene expression will be examined to define the effects of abiotic disturbances to the virulence of *D. sapinea*. Diplodia tip blight is a challenging disease to manage, and early detection and prevention are essential to limit its spread. The goal of this work is to increase awareness of *D. sapinea* impact on pine trees in Finland and promote further research into sustainable management strategies to combat this fungal pathogen.

Nuclear technologies to improve the resilience of forest species in the face of climate change

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Nuclear technologies have multiple applications in the area of medicine, industry, agriculture and energy. In the forestry field, its application is unknown, although ionizing radiation is a tool widely used in agricultural genetic improvement, generating genetic diversity and improving variety productivity throughout the world with 3,275 mutant cultivars registered in 224 species. Nuclear technologies could be of great importance in the new scenario of climate change that is affecting native forest ecosystems and the significant reduction in production of plantations. The application of low doses of sublethal gamma radiation known as "hormesis" have short-term metabolic and physiological effects, increasing seed germination and initial plant growth, and there is a relationship with epigenetic effects that manifest as adaptive responses in the irradiated species. The higher doses of gamma radiation, known as mutagenesis, generate heritable mutations on DNA, and allow them to be included in conservation and genetic improvement programs in fast-growing native or exotic species that require adding an adaptive and/or commercial characteristic of interest that cannot be be achieved by conventional systems. Since 2020, INFOR and CCHEN have been developing the CHI5052 project for mutagenesis of forest species affected by climate change with funding from the International Atomic Energy Agency (IAEA), which includes in a first stage the determination of LD30 and LD50 doses in Eucalyptus globulus. and Quillaja saponaria for the generation of M1 populations. and the phenotyping and genotyping of M1 plants. This paper provides the strategy of the program and the preliminary results of the effect of 0, 10, 20, 30 Gy gamma doses on the germination and initial growth of Eucalyptus nitens.

Pan-genomes for exploring genetic variation beyond SNPs - examining the role of structural variants in resistance to ash dieback disease

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Characterizing the full spectrum of genetic variants across individuals is crucial for genome-assisted breeding and understanding forest genetics more broadly. Substantial progress has been made using reference genomes from a single individual and short-read population resequencing data, which allows the identification of thousands of single nucleotide polymorphisms (SNPs). However, this approach often fails to capture another important class of genetic variants commonly associated with pathogen resistance - structural variants (SVs). These include inversions, deletions, insertions and rearrangements of large regions of DNA sequence between individuals. Pan-genomes, which integrate genome assemblies from multiple individuals, provide an improved approach for genotyping SVs from short read data at a population scale. In this study, we constructed a pan-genome for *Fraxinus excelsior* (European ash) - a keystone European tree species currently under severe threat from ash dieback disease (ADB), caused by an invasive fungal pathogen. Whilst SNPs associated with ADB resistance have been identified, preliminary evidence from short reads mapped to a single reference genome suggested SVs associated with resistance may also exist in *F. excelsior* populations. Using Oxford Nanopore Technologies long-read sequencing, we constructed *de novo* genome assemblies from 50 *F. excelsior* individuals of geographically diverse origins, used these to construct a pan-genome for the species, and characterized the landscape of SV variation. We are using this pan-genome to genotype short-read sequence data from large-scale field trials of *F. excelsior* phenotyped for ADB damage, to identify SNPs and SVs associated with resistance. This will allow us to explore the potential impact of pan-genomes on tree breeding and understanding forest genetics more broadly, as well as the genetic basis of resistance and potential for rapid adaptation in *F. excelsior* in response to an acute pathogen threat.

Pathophysiology and transcriptomic analysis of Pinus armandii inoculated by ophiostomatoid fungi associated with Dendroctonus armandi

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: *Pinus armandii* is extensively abundant in western China and, as a pioneer tree, prominently influences local ecology. However, pine forests in this region have been significantly damaged by *Dendroctonus armandi* infestations closely associated with ophiostomatoid fungi. Herein, the aims of this study were to identify the diversity of ophiostomatoid fungi associated of *D. armandi* infesting *P. armandii* in western China. Subsequently, a subset of those strains was inoculated to determine the pathological physiology and molecular changes of *P. armandii*. A total of 695 ophiostomatoid fungi strains were isolated from 1,040 galleries and 89 adult beetles, at four sites. Seven species belonging to five genera were identified: two novel taxa, *Graphilbum parakesiyea* and *Ophiostoma shennongense*, a reassigned neotype, *Leptographium qinlingense*, three known species, and an unidentified *Ophiostoma* sp. 1. *Ophiostoma shennongense* was the dominant taxon in the ophiostomatoid community, with an abundance of 78.99%. Four representative ophiostomatoid species (*L. qinlingense*, *O. shennongense*, two dominant and widespread species, as well as *Gra. parakesiyea*, *Ophiostoma* sp. 1, two less frequently obtained but widely distributed across the sampling area) were selected for artificial inoculation to verify their virulent. The results of this research showed that *L. qinlingense* produced the longest lesions while *Gra*. *parakesiyea* produced the shortest. All strains could induce monoterpenoid release and the monoterpene contents in *P. armandii* were positively correlated with fungal virulence. Co-inoculation of two dominant highly and weakly virulent pathogen reduced the pathogenicity of highly pathogenic fungi. Transcriptomic analysis of *P. armandii* (CK, LQ, QS and OS) showed that many important chemical defenses in conifer such as terpenoid biosynthesis, flavonoid biosynthesis, MAPK signaling pathway and plant-pathogen interaction were activated. Compared with the control, the number of differentially expressed genes (DEGs) of co-inoculation (QS) was less than that of highly virulent pathogen (LQ) and more than that of weakly virulent pathogen (OS). The expression (LQ vs. QS) of flavonoid biosynthesis genes, phenylpropanoid biosynthesis genes and plant-pathogen interaction genes were downregulated. Co-inoculation decreased the expression of host-related defense genes. This study provides a valuable scientific theoretical basis for the management of ophiostomatoid fungi associated with *D. armandi*.

Phyllosphere microbiome assembly of susceptible and resistant Norway spruce genotypes against Heterobasidion

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Microbiome ubiquitously inhabits the plant endophytically or epiphytically. They play significant roles in plant growth and health, and have been considered as the extension of the host genome. Plant microbiome assembly could be a reflection of the plant's genetic background, plant behaviors, and environmental changes. Phyllosphere microbiome has been shown to have a close link with the plant immune system as well as the host's genetic background, and in turn, correlates with the host's health. Phyllosphere has also proved to have potential in plant adaptation to drought through microbial engineering. However, Norway spruce, as one of the most important tree species in the timber industry, its phyllosphere microbiome and the correlation with host genetic background have been very little studied. Our objectives are to identify and characterize the phyllosphere microbiome assembly of Norway spruce resistant and susceptible to *Heterobasidion* infection. Secondly to identify if there is vertical transmission of microbiome from seeds to seedlings. Thirdly to evaluate the impact of seasonal variations on the microbiota. In this study, the five most resistant and susceptible two-year-old seedlings were selected out of 402 Norway spruce genotypes. Four replicates of each genotype were planted in southern Finland. Needles from each biological replicate were collected in May, July, and September. Seeds of each genotype were also collected. DNA of needles and seeds were extracted. The Fungal ITS region as well as the bacterial 16S region were amplified. The results provided insights into the phyllosphere microbiome structure, interaction pattern, and functional composition. The results also highlighted the differences in core microbiota between the two resistant groups as well as the seeds.

Population genetic structure of the rare pine wood-living longhorn beetle in Sweden: effects of forest composition and management history

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Forestry is a source of renewable raw materials and bioenergy but also has a key role in the conservation of insects and other organisms attached to dead wood. However, the Swedish Forestry Agency's forecasts showed that many biologically valuable forest types, including older pine forests, risk being displaced by more homogeneous forest landscapes dominated by younger, dense stands of spruce. Wood-living insects represent excellent indicators of biodiversity in forestry and nature conservation. In pine forests, the rare pine wood-living longhorn beetle *Tragosoma depsarium* has great potential as a signal species for valuable habitats. It has specific habitat requirements, especially in sunlit older pine forests, developing on coarse, dead pine logs and has an important role in the ecosystem by breaking deadwood. However, little information is known on the distribution and the genetic diversity of this rare species in Sweden. Genetic markers are useful tools to study species evolution and demographic events that have happened over time, shaping species distribution. Thus, we aim to describe the genetic diversity and population structure of *T. depsarium* in Sweden, and determine if populations have suffered loss of genetic diversity due to forest management and isolation. For this purpose, the geographic distribution of the beetle in Sweden was assessed at a large scale through extensive pheromone trapping, and several populations were sampled along its distribution range. to be sequenced by RADseq. DNA was extracted for each individual and sent for RAD sequencing. The sequencing results will be analysed using a population genomics approach.

Progress in Breeding Pinus radiata for Resistance against Invasive Dothistroma Needle Blight Fungal Pathogens in Kenya

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: *Pinus radiata* (D. Don) is a fast growing high altitude commercial plantation tree species native to California-USA but successfully introduced and widely planted in many parts of the world. In Kenya it was introduced in 1930s as an industrial species for timber, plywood, pulp and paper markets. However, the species' susceptibility to *Dothistroma* blight disease led to a restriction in its planting on large scale. Dothstroma blight control measures initially tried in Kenya involved the use of copper based fungicides which were later abandoned due to environmental concerns. Control of the blight by breeding the trees for disease resistant was initiated as a viable long-term way of managing the disease. Research to develop *P. radiata* resistant to *dothistroma* blight has been undertaken by selecting among local populations *P. radiata* genotypes which show blight-resistant and higher growth. This initiative was supplemented by infusing new *P. radiata* germplasm from New Zealand. Both sets of material were planted in progeny trials to test their growth within *dothistroma* blight infested environments. The performance of the trials was evaluated by assessing growth parameters of tree height, diameter at breast height-DBH, and *Dothistroma* disease severity on all the material tested. Results show significance variation in growth performance among the different selected and introduced progenies. The best performing among the infused progenies attained a mean height, DBH and tree volume of 34m, 43cm, 2.2m^3/tree respectively after growing at the test site for 30 years. Among the local selections, the best progenies attained a mean height, DBH, and tree volume of 30m, 35cm and 1.3m^3/tree respectively after 24 years. Assessment of disease severity levels among the progenies was in the range of 0-50% infection. The growth and productivity of the trees in these trials compares to the commonly grown *Pinus patula* species which at 30 years in Kenya grows to means of 35m and 45cm height and DBH respectively. These results shows that the breeding programme for *P. radiata* resistance to Dothistroma disease in Kenya is achieving progressive results that will enable the species to be successfully grown in Kenya for commercial purpose.

Recurrent events of hybridization helped range expansion and climate change resilience in two conifers

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: The current global climate change is expected to affect biodiversity negatively at all scales leading to mass biodiversity loss. Population-level changes in allele frequencies provide species to innovate adaptation to changing climates and prevent extinction. However, populations' responses to changing environmental conditions are heterogeneous across different ecosystems. This is often exhibited through adaptations of species to their local environment and reflects their potential for future climate change resilience. Detecting such environment-associated alleles requires whole genome sequencing of many populations and/or long-running common garden experiments. However, this is far from being practical for species with long generations. Here, in the present study, using exome capture genomic sequences, we tested multiple methods to assess local adaptation and climate change resilience in two widely distributed conifers, Norway spruce (*Picea abies*) and Siberian spruce (*Picea obovata*). We show that local adaptation in conifers can be better detected through a combination of allele frequency variation, population-level ecological preferences, and historical niche movement. Moreover, we integrated both genetic and ecological information into genetic-offset predictive models to show that hybridization plays a central role in expanding the niche breadth of the two conifer species and may allow both species to cope better with changing future climates. Further, the recurrent gene flow between the two species during many cycles of glaciation allowed the hybrid populations in the contact zone of the two species to acquire intermediate allele frequencies; this intern provided them with enough standing genetic variations to quickly adapt to changing climate. Therefore, hybrid populations are more likely to persist through future climatic changes. Integrative analysis of genomics and ecology, also allowed us to identify genetically isolated populations that are at risk under current climate change.

Resistance breeding programme of black alder (Alnus glutinosa) to Phytophthora ×alni in the Czech Republic

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: One of the most important species of riparian stands and carr habitats is *Alnus glutinosa* (AG). This autochthonous tree growing all over Europe is strongly threatened by *Phytophthora ×alni* (PA), an oomycete pathogen that cause rapid destruction of the riparian and alder carr ecosystems. In 2009, research of AG susceptibility against the pathogen has started. 90 healthy AG genotypes originated from different regions of the Czech Republic were used for in vitro susceptibility tests (branch inoculation). Best of them were vegetatively propagated and preserved in our stoolbed.

From their maturity, for the last 5 years, the trees have been used in controlled crossings to obtain progenies (open pollination of respective mothers have been used as a control). All obtained seedlings are artificially inoculated several times per year with several highly aggressive PA isolates. More than 40 different combinations have been tested up to now. The differences in susceptibility among tested progeny were found. Progeny of genotypes with higher resistance to PA have a higher proportion of surviving plants compared to progeny of susceptible genotypes. After the first artificial inoculation three quarters of seedling from susceptible trees died while the mortality in progeny of more resistant trees was around 30-40%. After two vegetation periods most of the descendants of susceptible trees died. Survival rates of progeny from more resistant trees were around 15 %.

Nowadays, there are some highly resistant AG seedlings that could be used in further resistance breeding or as a source for vegetative or generative propagation. Selected trees could be planted in riparian stands and could increase the stability of the carr and riparian ecosystems.

Secondary metabolites for decay resistance in Finnish forests: disclosing the stilbene biosynthesis pathway in Scots pine and Norway spruce

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Scots pine and Norway spruce are the two most economically important tree species in Finland. This study investigates the stilbene biosynthesis pathway in these tree species as a source of secondary metabolites against decay and diseases. Scots pine accumulates stilbenes in the heartwood in the form of pinosylvin and its monomethyl ether, which are derivates from cinnamic acid. However, the enzyme that catalyses the reaction from cinnamic acid into the intermediate cinnamoyl-CoA, possibly an acyltransferase related to 4-coumarate:CoA ligase (4CL), remains unknown. Using transcriptome data from Scots pine under pinosylvin forming conditions, we identified four candidate 4CLs, of which one (Ps4CL2) showed strong cinnamic acid activation. We propose that Ps4CL2 is involved in pinosylvin biosynthesis in Scots pine. Contrary to Scots pine, Norway spruce accumulates stilbenes in the bark and in the form of resveratrol and its derivatives (e.g. the hydroxylated piceatannol and the methylated isorhapontigenin). Current observations from our transcriptome data of Norway spruce bark reveals several candidates responsible for hydroxylation and methylation of resveratrol.

The gene flow between Araucaria angustifolia populations through coalescent theory

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: *Araucaria angustifolia* (Brazilian-pine, araucaria) is a conifer tree of high ecological and social value in Brazilian subtropical region due to its high-quality wood and pine nuts production used for feeding. However, the species have been heavily exploited. The remaining populations are isolated and may encounter difficulties adapting to climate change. So, this study examined the gene flow between populations of araucaria across its geographical natural range through a coalescent approach. Genomic DNA samples were collected from 185 trees in a provenance and progeny test sampled from 15 natural populations. The genotyping was performed using a 3K Axiom SNP array (2022 SNPs) and 28 microsatellites. Gene flow demographic models among the populations were tested to verify the direction (North or South) of the migratory flow between neighboring populations. All models were run at MIGRATE-N software. The migration rate, the effective number of migrants per generation (xNimij), and the effective population size (Ne) were estimated. The mean Ne observed using the SNPs markers for populations further north (959.02) is slightly higher than that southern (893.61). We identified neighboring populations with more intense migratory flows than the others and the general tendency of migratory flow between these populations. Thus, we identified populations that stand out as the main sources of migrant individuals showing a negative migration balance; and the ones that receive a high migration flow. We also noticed populations that stand out for their weak connection with others. By correlating the migration parameters with climatic variables, we observed that the minimum average temperature in the coldest month, and the amount of rain in the driest month present a high and significant correlation with xNimij. A negative correlation was observed between the rainfall regime and xNimij. So, the greater the amount of rain in drought period smaller the number of migrant individuals. About temperature, we observe a positive correlation between migration and average minimum temperature up to a specific temperature, after which the regression curve inflects. In general, the observed gene flow suggests a connection between the remained populations, being the greatest sources of genetic diversity of the species found in southern Brazil.

Towards the integration of disease resistance in tree breeding, can genomic selection support early selection of Heterobasidion-resistance?

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: *Heterobasidion* root- and stem-rot is a major disease of Norway spruce (*Picea abies*) in Europe causing significant economic losses as well as reduced carbon sequestration by infected trees. The disease is caused by *Heterobasidion parviporum* and its congeners in the *Heterobasidion annosum s.l.* species complex. The potential to improve Norway spruce for resistance to *H. parviporum* through breeding has been well established in several previous studies for backward selection of the best parental trees or the forward selection of the best progeny. However, the bottleneck in applying such resistance selection in the breeding operations is the requirement of disease exposure either through natural infection or artificial inoculation. Such processes require long-term testing or come with high costs. To develop reliable methods for early selection of resistant trees without inoculation based testing, we explore the possibility to use genomic selection (GS) to identify resistant trees in the Swedish breeding program. To achieve this, resistance was measured using artificial inoculations in progenies from 50 full-sib families in each of two Norway spruce breeding populations with 10 connecting families in the Swedish breeding program. In total 1920 plants were both phenotyped and genotyped on the 50 K Norway spruce SNP chip. GS models are built for each population and the models and phenotypic data will be used to test if the prediction accuracy based on genomic information can match the prediction accuracies in phenotypic selection, within and across populations. The results from the phenotyping work, GS model building and testing will be discussed as well as the potential applications of this work in the Nordic breeding and deployment chains.

Unlocking the genetic diversity of timber species in Terengganu Forest Reserves, Malaysia

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Terengganu, a state in eastern Peninsular Malaysia harbors numerous valuable and highly endangered timber species. Approximately 544,000 hectares have been designated as Permanent Reserved Forests. To date, Terengganu has 45 forest reserves, predominantly made up of dipterocarp woods. However, there is very little information on the genetic variation of timber species occupying these Permanent Reserved Forests. Genetic diversity is vital to ensure the success of the rehabilitation in the forest areas. It reflects the reservoir of a species for short-term ecological adaptation and long-term evolutionary change. Low genetic diversity can threaten the long-term viability of the restored forests. Balancing sustainable logging with biodiversity protection is crucial, considering the state's reliance on forestry revenue and the inherent dangers of illegal logging and processing activities to endangered species and environmental health. This study aimed to assess the genetic diversity within 12 timber species in Terengganu Forest Reserves, Malaysia using inter-simple sequence repeat (ISSR). This study improves our understanding and provides new insight into the genetic diversity of timber species inhabiting Terengganu Forest Reserves of Malaysia. The data from this study is essential in designing effective conservation strategies for Terengganu timber species. The results will be presented and discussed during the congress.

Keyword: Timber species; genetic diversity; ISSR; Terengganu Forest Reserves

Using a common garden experimental trial to reveal tree disease dynamics

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Predicting how trees will respond to disease is vital for the management of both natural and planted forests. However, understanding tree disease dynamics is often limited by the lack of robust estimates of variation in host susceptibility and tradeoffs with other traits. Scots pine (*Pinus sylvestris*) is the most widely distributed pine species and is economically and ecologically valuable. It is impacted by the foliar pathogen *Dothistroma septosporum,* the causal agent of Dothistroma needle blight (DNB).This causes distinctive lesions on needles often resulting in needle loss and growth retardation. We evaluated genetic variation in DNB susceptibility in a multisite progeny-provenance trial of Scots pine planted in Scotland and genotyped using a 50k SNP array. The trial was surveyed regularly over eight years for DNB symptoms and duration of needle retention. DNB susceptibility over multiple years was associated with the climate at the site of provenance origin. Trees originating from hyper-oceanic sites in the west of Scotland, where conditions were warmer and wetter (i.e. environments expected to favour pathogen growth and dispersal), showed evidence for local adaptation to the pathogen, with lower levels of susceptibility compared to populations from the cooler, drier east of the country. Trees with higher levels of susceptibility showed lower growth than those that were more resistant, although the growth differential was apparent many years prior to exposure to DNB, indicating that it was not entirely a consequence of infection. Association analyses identified a set of SNPs which show promise in their ability to predict susceptibility to DNB in Scots pine. Our findings will help in early identification of Scots pines that are vulnerable to DNB, guide conservation of the ecologically important Caledonian pinewoods, and improve the economic viability and resilience of breeding programmes.

Variability of morphological traits of pedunculate oak in changed environmental conditions (in situ and ex situ)

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Pedunculate oak is an economically and ecologically very valuable species at the European level as well as specifically for Bosnia and Hercegovina, and research into variation of this species is very important.

In 2007, pedunculate oak leaf material was collected in 27 populations in Bosnia and Herzegovina along with seeds, which were used to establish a provenance trial. In the trial, leaves were collected in 2021, and 14 morphological traits were measured in both types of material. Descriptive statistics by populations and provenances were calculated, and correlation coefficients between leaf traits for populations and provenances.

Analysis of variance showed generally non-significant differences between generations, but significant variation among populations and population-by-generation interactions. However, the correlations between generations were non-significant for most traits, and neither were the correlations with climatic parameters. The results indicate both genetic and environmental effects on leaf morphology. The utility of leaf morphology for gene conservation is shortly discussed.

Variation in phenology traits and growth in a multi-site provenance trial of wild cherry (Prunus avium L.) in the Netherlands, Belgium and Germany

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: There is a need for forest managers to diversify forest stands in order to increase resilience to climate change and upcoming pests and diseases. Wild cherry (*Prunus avium*) is seen as one of the candidate species, due to its superior wood quality, relatively fast growth, silvicultural value, and high litter quality. The objective of the study is to investigate provenance performance under different environmental conditions with the ultimate aim to identify seed sources that are well-adapted to the present climate but can also deal with the predicted climate change. The results from these provenance trials may guide forest managers in their decision whether to use local or more southern seed sources from warmer or drier areas. For this, we established a wild cherry provenance trial network in the Netherlands, Belgium, and Germany with two trials per country. Seventeen provenances from five Western European countries were planted. All provenances were from approved seed sources either seed orchards (Qualified) or seed stands (Selected). We did repeated assessments of budburst, leaf fall, survival, and height growth. We analyzed differences between provenances by modeling spatial trends using the 'SpATS' R-package and using a multi-site approach. In general, we observed consistent differences in adaptive traits like budburst and leaf fall. Based on the results, recommendations for seed transfer will be discussed.

Yellowhorn Xso-miR5149 targeting XsGTL1 enhances water-use efficiency and drought tolerance by regulating leaf morphology and stomatal density

T1.12 Forest genetics tools to improve forest resilience to climate change and forest health

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Abstract: Yellowhorn (*Xanthoceras sorbifolium*) is a unique edible woody oil tree species in China. Drought stress is the

major yield-limiting factor of yellowhorn. MicroRNAs play an important role in regulating the response of woody

plants to drought stress. However, the regulatory function of miRNAs in yellowhorn remains unclear. Here, we

first constructed coregulatory networks integrated with miRNAs and their target genes. According to GO function

and expression pattern analysis, we selected the Xso-miR5149-*XsGTL1* module for further study. Xso-miR5149 is

a key regulator of leaf morphology and stomatal density by directly mediating the expression of the transcription

factor *XsGTL1*. Downregulation of *XsGTL1* in yellowhorn led to increased leaf area and reduced stomatal density.

RNA-seq analysis indicated that downregulation of *XsGTL1* increased the expression of genes involved in the

negative control of stomatal density, leaf morphology, and drought tolerance. After drought stress treatments,

the *XsGTL1*-RNAi yellowhorn plants were less damaged and had higher water-use efficiency than the WT plants,

while destruction of Xso-miR5149 or overexpression of *XsGTL1* had the opposite effect. Our findings indicated

that the Xso-miR5149-*XsGTL1* regulatory module plays a critical role in controlling leaf morphology and sto

matal density; hence, it’s a potential candidate module for engineering enhanced drought tolerance in

yellowhorn.

T1.13 Forest management for climate change mitigation

Analysis of Forest Sector Management Strategy Using Korean Dynamic Stand Growth Model to Achieve Carbon Neutrality in South Korea

T1.13 Forest management for climate change mitigation

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Abstract: Since the Paris Agreement, the role of forests as a source of greenhouse gas sink has been emphasized, and each country has decided to submit an NDC to respond to the new climate regime. South Korea also plans to achieve NDC (Nationally Determined Contributions) in 2030 (25.5 million tons in the forest sector) and carbon neutral policy in 2050 in line with the international situation, and is making efforts to find management plans for forest sinks. Using the Korean dynamic stand growth model, this study sought strategic measures to solve problems like age class imbalance and expand sinks through forest biomass. As a result, the climate scenario is SSP1, the forest management scenario is when clear-cut harvest according to the legal final cutting age and thinning is implemented about 200,000 ha, reforestation of appropriate species to respond to climate change, and access to the forest road is within 1km, it was found that the overall sequestration of the forest increased. The current sequestration of 40.52 million tCO_2 yr^{-1} will decrease to 23.03 million tCO_2 yr^{-1} in 2050 but is predicted to increase to 35.24 million tCO_2 yr^{-1} in 2100 through growth of climate-appropriate species and age-class balance. Furthermore, it was analyzed that HWP (Harvested Wood Products) also contributes to its role as a carbon substitute with 7.73 million m^3 per year. In conclusion, this study is meaningful in that it presents a future strategy for responding to the new climate regime by reflecting the environmental and ecological characteristics of South Korea. Furthermore, these results can contribute to the forest sector's plans and policies for sustainable development.

Ash fertilization as a tool to achieve carbon neutrality: Long-term effects on tree growth and carbon balance of peatland forests

T1.13 Forest management for climate change mitigation

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Abstract: For Finland to achieve carbon neutrality by 2035, the land use sector is expected to achieve an annual impact of 3 Mt CO2 eq. Ash fertilization of drained peatland forests, which has been practiced in Finland for decades, is considered one of the most cost-effective ways to increase carbon sequestration through its profound and durable effect on tree growth. The effect on growth is stronger in sites with high soil nitrogen availability, but which lack potassium and phosphorus. However, estimations of the climate effect of ash fertilization are based solely on the stand growth. The critical question is whether ash fertilization enhances soil processes in a way that results in increased soil emissions, undermining the positive climate impact of increased tree stand carbon sink. Fertilization could decrease methane (CH_4) emissions because increased tree growth may lead to decrease in water table level (WT). We studied the long-term effect of ash fertilization of forestry-drained peatlands on the ecosystem carbon exchange, including soil, tree and ground vegetation components, and accounting for CO_2 and CH_4. Research questions were: 1) Does fertilization cause a long-term increase in heterotrophic soil respiration (R_h) in drained peatland forests and is this increase associated with an increase in litter production? 2) What is the ecosystem carbon balance and how is it affected by ash fertilization? 3) Do responses to ash fertilization vary between nutrient rich and nutrient poor sites? The experimental setup included 8 sites that were selected from the population of ash fertilization experiments established between 1937-2014, and fertilized with doses currently applied in practical forestry. R_h and CH_4 fluxes were measured with closed chamber method biweekly throughout two growing seasons, and WT and soil temperature throughout the study period. Tree biomass production, and above- and belowground litter production was determined. Based on these field measurements, annual fluxes were calculated, soil carbon balance, CO_2 sink due to tree growth and ecosystem carbon balance were determined. We will represent results of the long-term effects of ash fertilization on nutrient availability, tree growth, heterotrophic respiration, and carbon exchange of drained peatland forests with varying fertility.

Assessment of biomass flow in agroforest parklands in south-central Sahelian part of Niger.

T1.13 Forest management for climate change mitigation

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Abstract: Agroforest parklands in the Sahel offer many goods and services, knowledge of which in terms of flow, in particular productivity, removal and the input of organic matter, remains limited. This study, carried out in central southern Niger following north-south agroecological gradient, aims at providing knowledge on biomass flows for better formulation of management policies for its forest ecosystems. The methodology was based on socio-ecological surveys of 184 households and the ground inventory of vegetation through 240 plots for trees and 80 plots for herbaceous plants. The indirect method was used to assess tree biomass and integral harvest for herbaceous plants.The surveys focused on the amount of biomass taken for the different needs coupled with the measurements of wood per household. Productivity was estimated at 11.411±8.377 t/ha (north) and 16.44±8.544 t/ha (south) (P = 0.000). The total biomass harvested was estimated at 2.11 ± 0.83 t/ha (north) and 3.01 ± 0.98 t/ha (south) (P=0.000). The annual input was estimated at 1.424 ± 0.15 t/ha (north) against 1.714 ± 0.311 t/ha (south) (P = 0.08). The flow was equal to -0.692±0.681 t/ha (north) and -1.292±0.67 t/ha (south). The results of this study could be a database for future formulations of policies for the management of agroforestry parklands in central southern Niger.

Assessment of masting behavior in a tropical wet forest in Puerto Rico.

T1.13 Forest management for climate change mitigation

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Abstract: Large pulses of seed production occur in many tree species every few years in many forest types. This study examines the interannual patterns of reproduction in the Luquillo Experimental Forest in Puerto Rico focusing on evidence of masting behavior. We analyzed 30+ years (1992-2022) of fruit and seed production records in the 16 ha Luquillo Forest Dynamics Plot using 120 0.5 m^2 traps visited biweekly. The community was composed of 70 species of shrubs, trees, and climbers of various types. We used the coefficient of variation (CV > 1) to identify potential masting species in the community. Our findings indicate that more than 50 percent of the community exhibit masting behavior by this standard. No species, however, exhibited negative autocorrelation of seed production, indicative of synchronized endogenous (e.g., resource-based) reproductive cycles. This suggests the importance of disturbance events or other environmental triggers of masting behavior. We then identified years of high seed production in individual species using the deviation from long-term mean method. All species exhibited masting by this standard, even those with a CV < 1. However, only a handful of peaks among species fell within four years of major disturbance events (two hurricanes [1998, 2017] and one major drought [2015]). Overall, pairwise synchronicity among all species was skewed positive. However, this appeared to be a result of a general negative trend in reproduction in many species rather than synchronized masting behavior. This may be due to the effects of Hurricane Hugo (1989) before the start of the time series. This was the first major hurricane to strike the region in 57 years, before the more recent ones, thus having lag effects on the entire community. Beyond this, we suggest that other unidentified environmental conditions may be critical to triggering peaks of seed production in this tropical forest.

Can woodlands and shrublands contribute to Kenya's national carbon accounting?

T1.13 Forest management for climate change mitigation

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Abstract: Woodlands and shrub lands, which occupies about half of Kenya's forested area plays a critical role in climate change mitigation and adaptation. Due to increasing levels of degradation attributed to anthropogenic activities and climate change, there is a need to assess and monitor dynamics of biomass for sustainable management. Furthermore, the carbon offset projects and calibration of remote sensing models require local ground data. Previous carbon accounting studies have mainly concentrated on closed canopy forests with the exclusion of woodlands. Studies were carried out in Tiva research station and Kibwezi woodlands under the Socio-Ecological Observatory for Studying African Woodlands (SEOSAW) network to estimate above ground biomass (AGB), which is the most affected carbon pool. The study also determined the contribution of tree species and size to the AGB. The sites were stratified into dense, moderate and open vegetation. Within each stratum Permanent Sample Plots (PSPs) of 0.5 ha and 1.0 ha were established in Tiva and Kibwezi, respectively. Sub-plots of 0.02 ha were laid for trees species identification and measurement of Diameter at Breast Height (DBH) and total height (H). Our findings identified 30 and 26 tree species in Tiva and Kibwezi, respectively. The tree density ranged from 58 to 682 stems ha^{-1} in Tiva and 60 to 658 stems ha^{-1} in Kibwezi. The mean AGB within Tiva was 9.3 ± 5.46 ton ha^{-1} while in Kibwezi; it was 52.0 ± 7.43 ton ha^{-1}. The species contribution to AGB was dominated by *Adansonia digitata* (42%) *Commiphora africana* (30%) and *Sterculia stenorcapa* (11%) in Kibwezi while in Tiva, *C. Africana* (46*%), Acacia mellifera* (13%) and *Commiphora eminii* (9%) had the highest proportion of AGB. The tree species and its size had significant contribution on the AGB as attested by the dominant tree species recorded. Woodlands have a potential in contributing to national carbon accounting if more effort can be directed towards sustainably managing them. Periodical studies are recommended to determine carbon storage potential and changes over time due to changing dynamics in land use practices within the drylands of Kenya.

Keywords: Above Ground Biomass (AGB), Carbon stock, Drylands, Savannah, Woodlands

Carbon Stock of Calophyllum inophyllum Provenances from Eight Islands, Indonesia: Associated Soil Physicochemical Properties and Litter Fiber Content

T1.13 Forest management for climate change mitigation

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Abstract: *Calophyllum inophyllum* is a multipurpose tree species that has recently been proven to be effective source of biodiesel, with reported huge CO2 sequestration potential. Besides that, the species has a wide natural distribution; it bears fruit throughout the year, with high productivity, and the seeds can be harvested non-destructively. *C. inophyllum* is able to grow in a variety of sites, including degraded lands, thus avoiding competition with food production on arable land. In this study, we quantified carbon sequestration and storage in plant biomass and soil organic carbon of *C,inophyllum* provenances from eight islands in Indonesia, conducted in a Calophyllum Provenance trial plots in Gunungkidul, Java Island, Indonesia. Tree component and soil samples were collected from 32 sample plots on a provenance trial area covering 3 hectares. Analysis of variance was used to determine variations in carbon stock between different provenances. Allometric equations were modelled to estimate total biomass carbon (tBC), and redundancy analyses (RDA) were used to determine the effects of soil physicochemical properties and litter fiber on carbon stock. These were followed by a variation partitioning analysis (VPA). The results showed that the average of tBC was 18.21ton ha^{-1} ranging from 13.66 ton ha^{-1} (Selayar) to 27.50 ton ha^{-1} (Bali Timur) and tSOC was 75.91 ton ha^{-1} ranging from 32.84 ton ha^{-1} (Ketapang) to 120.27 ton ha^{-1} Yapen). No significant variations found in tBC, carbon content by component, or total soil organic carbon (tSOC) between provenances. A polynomial regression equation based on coefficient of determination (R2) and root mean square error (RMSE) was used to estimate tBC. Most variations (76%) were affected by soil chemical properties. tSOC was strongly affected by soil thickness, C:N ratio, and total P rather than other soil physicochemical properties. Sand content, hemicellulose and base saturation all had inverse correlations with tSOC. tBC had a strong positive correlation with exchangeable P, total K, NH4 and DOC and negative correlations with aggregate stability index. This study is useful for evaluating and improving forest soil management, monitoring ecological and environmental conditions, and formulating climate policy.

Carbon stocks of homestead forests have a mitigation potential to climate change: A case from Chittagong Hill Tracts, Bangladesh

T1.13 Forest management for climate change mitigation

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Abstract: Homestead forests of Bangladesh (0.27 million ha land) have potential of providing co-benefits of conserving biodiversity and storing carbon (C). The study aimed to estimate C stocks and how stand structure affects the tree biomass C in homestead forests of the Chittagong Hill Tracts (CHT), Bangladesh. A total of 176 homestead forests at three altitudes in the CHT were randomly surveyed. All woody vegetation were measured, and litter and soil (0–30 cm depth) were sampled. The results show that the above- and below-ground tree biomass C stock in the top two altitude forests was up to 37–48% higher than in low altitude, due to significantly higher tree density and species diversity. An increase in species diversity index by one unit increased the biomass stock by 23 Mg C ha^{-1}. The C stock of litterfall in low altitude forests was 22–28% higher than in the top two altitudes owing to the deposition of litters downslope by gravity and deliberate use of pruned materials as mulch for soil improvement and conservation, resulting in up to 5% higher total soil C. The topsoil C was 10–25% higher than the deeper soil, depending on the altitude. The forest stored a total of 71 tree species and 89 Mg C ha^{-1}, which can contribute to climate change mitigation while conserving biodiversity, moisture, and hill soil in small-scale forests. This study would help policymakers to strengthen the recognition of small-scale forests for mitigation in REDD+ (reducing emissions from deforestation and forest degradation, the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks) by generating C credits for owners from sustainably managed forests.

Climate change and local adaptation in forest trees - can maladaptation to future climates influence carbon sequestration belowground?

T1.13 Forest management for climate change mitigation

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Abstract: The urgent need to sequester atmospheric carbon dioxide (CO_2) in forests to mitigate climate change and support sustainability goals is widely recognized. While the potential of fast-growing tree populations for aboveground carbon (C) sequestration has been extensively studied, less attention has been given to understanding how these locally adapted tree populations influence plant-soil interactions and subsequently impact belowground C sequestration. Such knowledge gaps are crucial to effectively address the complexities of carbon dynamics in forest ecosystems.

In our project, we are quantifying the belowground C sequestration in relation to the aboveground tree biomass increment, in a 70-year-old *Pinus sylvestris* provenance trial in the boreal forests of Sweden. To simulate the impact of climate change, we are examining the effects of a southern transfer distance variation of up to 5 latitudinal degrees. We have estimated soil respiration, soil C and nutrients content, tree mortality, litter input, vegetation and microbial biomass and analyzed the soil microbial communities. By integrating and analyzing these variables, we aim to gain novel insights into the mechanisms underlying belowground C sequestration in areas where *P. sylvestris* trees of varying provenances have been planted. This knowledge is valuable when making decisions about forest management practices that could increase forest resilience to climate change. For instance, an increase in tree growth enhances the uptake of atmospheric CO_2 but may also simultaneously accelerate root respiration, leading to a net release of C from the system. Further, there is a risk of negative feedback loops that could impair forest capacity for C sequestration, because as the climate changes, it may make locally adapted tree populations maladapted to future climates. The outcomes of our research hold significant potential to inform the development of sustainable forest management practices in the face of a changing climate.

Combing multiple feature selection methods and structural equation modelling for exploring factors affecting stand biomass

T1.13 Forest management for climate change mitigation

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Abstract: Recognition of biotic and abiotic factors affecting biomass in natural mixed forests is of great importance for forest biomass estimation and management. However, the results obtained from different variable selection methods are often inconsistent and there is lack of the systematic analysis. The objective of this study was to combine multiple feature selection methods with structural equation modelling to identify more representative variables for better stand biomass estimation. Seven methods were applied to test the differences for variables affecting stand biomass based on data from 286 permanent sample plots in natural coniferous-broad leaved mixed forests in northeast China. They included Pearson correlation analysis, principal component analysis (PCA), stepwise regression, redundancy analysis (RDA), generalized additive model (GAM), random forests (RF), and boosted regression tree (BRT). Totally there were 64 candidate variables covering stand, biodiversity, climate and soil features. We found that there were significant differences in variables selected among feature selection methods. Variables common to all methods were the species diversity (*N_Sp_Div*), stand structural diversity (*N_ Size_ Div*), nearest taxon index (*NRI*), community weighted mean based on dry matter mass of leaves (*CWM.LDMC*), soil pH, degree-days above 18°C (*DD18*). These variables were included into the structural equation model (SEM) to further explore the direction and magnitude of the impact on stand biomass. The SEM results showed that stand average age and stand density had the greatest positive influence and that structural diversity had a significant positive effect on stand biomass. *DD*18 affected stand biomass directly and indirectly, but the total effects were negative. Soil pH affected stand biomass indirectly via additive stand density index (*aSDI*). The combination of multiple feature selection methods and structural equation modelling was an effective for understanding factors affecting stand biomass. The study provides a generic method framework for exploring the influencing factors of biomass at large scale.

Comparative Assessment of Jurisdiction-based REDD+ Benefit Sharing Policy Options in Indonesia

T1.13 Forest management for climate change mitigation

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Abstract: Mechanisms to share sharable benefits of jurisdictional-based REDD+ in incentivizing beneficiaries, particularly at site level, have become an essential and simultaneously one of the most challenging parts of REDD+. Public finance approaches through the intergovernmental fiscal transfer (IFT) system have been proposed to channel the REDD+ shareable benefits. However, the public finance approach has also its challenges such as a long-process of bureaucracy, needed interventions in the aspects of collection, allocation and distribution, and inflexibility of fund utilization. In the context of Ministry of Finance (MoF) and Ministry of Environment and Forestry (MoEF) have established a public service agency for environmental fund management (BPDLH) as a non-structural institution to manage funds for the environment, including REDD+. As a nascent institution, BPDLH is constantly looking for the best mechanism for distributing REDD+ benefits to beneficiaries in subnational jurisdiction i.e.: through provincial budget (APBD); using intermediary agency; and direct to beneficiaries. This paper will be looking into the three currently available options for benefit sharing by the BPDLH and evaluate the effectiveness, efficiency, equity, and feasibility of these options. Analyses will be made in regard to the advantages and disadvantages of each option in achieving the intended targets, thus determining the best policy approach that can be implemented sub-nationally. The paper also delivers a set of recommendations of what is the best approach is for policy makers, in this case is BPDLH, in sharing the benefit of jurisdiction-based REDD+ to achieve its overarching goals.

Development of soil greenhouse gas fluxes in former croplands: the role of tree species, the environment and the soil microbiome.

T1.13 Forest management for climate change mitigation

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Abstract: Greenhouse gas (GHG) emissions, in the form of CO_2, CH_4 and N_2O, from land use change and agriculture are responsible for up to 20% of anthropogenic emissions, mainly due to deforestation, livestock production and crop fertilization. Afforestation is proposed as an effective means to sequester atmospheric carbon in biomass and soils. However, there is a lack of knowledge about the resultant soil GHG fluxes from temperate afforested ecosystems and how it develops with time. Furthermore, tree species choice (deciduous/conifers) may impact the soil biogeochemistry differently through the soil physicochemical properties and the soil microbiome with a currently uncertain outcome in relation to GHG fluxes and the climate mitigation potential.

In this study, we are investigating the development of soil GHG fluxes, soil physicochemistry, and the soil microbiome on arable land using a well-established forest chronosequence (Vestskoven, Denmark), which is a former cropland area afforested over the last 50 years with Norway spruce (*Picea abies*), oak (*Quercus robur*) and beech (*Fagus sylvatica*). The total of 14 selected sites in Vestskoven includes 4 stand ages per tree species. We measured GHG fluxes (N_2O, CH_4 and CO_2) *in situ* once a month for a period of 13 months, and sampled soil for physicochemical and molecular analyses.

Preliminary results show that net soil CO_2 fluxes increase with stand age due to higher soil C content and heterotrophic respiration and net CH_4 uptake increases due to more porous soil. We compared our chronosequence data with similar data from old growth forest soils with the same tree species. In addition to tree species and age, soil water content and temperature content are the key drivers of change in GHG fluxes 50 years after afforestation. Finally, soil fungal and bacterial community composition is changing over time, especially ectomycorrhizae, which could explain some of the variation in GHG emissions from the different tree species over the chronosequence.

Development stage mediates the effects of diversity on aboveground biomass in Northeastern China's temperate forests

T1.13 Forest management for climate change mitigation

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Abstract: Biodiversity and ecosystem functioning relationships (BEFs) has been extensively studied in various ecosystems. However, these relationships can change as forest matures (i.e., forest development stage), and the underlying mechanisms remain underexplored. Using a large temperate forest dataset with 2,392 permanent plots in northeastern China, we examined the relationships between multidimensional diversity (i.e., tree species richness, functional diversity, and functional composition) and aboveground biomass (AGB) across the five development stages (< 30, 30-50, 51-70, 71-100, and > 100 years). We found the positive BEFs using both species richness and functional diversity, but these positive effects decreased with increasing forest development stage. However, the relationships between community-weighted mean (CWM) and AGB showed two peaks in young (< 30 years) and mature (71-100 years) stands. Interestingly, the stronger effects of CWM on AGB compared to functional diversity in mature stands revealed that BEFs are driven by mass-ratio effects (i.e., dominant species) rather than niche complementarity, the average effects of CWM on AGB were significantly greater than the average effects of functional diversity. Our findings how the stand developmental stage influences the effects of biodiversity on ecosystem functioning in natural forests which could help identify effective strategies for maintaining or enhancing ecosystem services in forests at different stages of succession.

Does CDM Regenerated Forest Accumulate more Carbon Stocks in the Soil than the Biomass? The case of Humbo in Ethiopia

T1.13 Forest management for climate change mitigation

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Abstract: Investigating the amount of carbon pools in forest ecosystems makes it possible to understand different carbon stocks in the forest ecosystem. Humbo CDM naturally regenerated forest is managed through direct involvement of the local community and funded by World Vision Ethiopia and the Canadian government through a global carbon credit framework. Therefore, the aim of this study was to quantify the amount of biomass and soil carbon stocks along altitudinal gradients in the Humbo CDM forest in southern Ethiopia. A total of 54 nested sample plots of 20 m by 20 m were established on transects of elevation gradients with a spacing of 100 m between plots. Inventories of woody species and soil samples (010 and 1020 cm depth) were collected within each nested sample plot. Soil organic carbon was analyzed using the Walkely-Blacks method, while above-ground biomass was estimated using the Chave method. To analyze equality of means, ANOVA was used for multiple comparisons between height classes at =0.05. Total carbon stocks decreased significantly ($p<0.05$) between the three elevation gradients. The total carbon stocks significantly ($p < 0.05$) differed among the three altitudinal gradients. The biomass carbon stocks are not significantly different between middle (1610–1750 m.a.s.l.) and lower (1470–1610 m.a.s.l.) elevations but both of them significantly ($p < 0.05$) differed from higher (1750–1890 m.a.s.l.) elevation. The results show an increasing total carbon stock, particularly soil organic carbon, from lower to higher elevations. It was concluded that CDM-regenerated forest ecosystems have the potential to accumulate higher soil carbon stocks than biomass, which varies significantly along elevation. The highest ecosystem carbon stock was contributed by SOC. We recommend that carbon-related awareness raising for local people and promotion of local knowledge can be considered as a possible option for sustainable forest management and climate change mitigation.

Does the mechanical site preparation used in Fennoscandia today really increase soil carbon losses?

T1.13 Forest management for climate change mitigation

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Abstract: The carbon content in the soil of northern forests exceeds twice the amount stored in tree biomass. Concerns have arisen that soil disturbance, such as mechanical site preparation, could lead to a depletion of the soil carbon stock, thereby impeding climate change mitigation. However, these concerns were based on a few studies conducted in different forest ecosystems worldwide and encompass a wide range of site preparation practices.

Later research from about 15 forests on mineral soil on the two most commonly used mechanical site preparation practices in Fennoscandia, patch scarification and disc trenching, has shown that these practices do not significantly affect soil respiration during the first two years. A temporary increase in soil respiration immediately after site preparation was observed, but this disappeared after two weeks. While soil respiration from mounds and tilts were generally higher than from undisturbed soil during the first year, the respiration from pits and furrows were significantly lower, resulting in a lower overall average compared to undisturbed soil. These findings suggest minimal impact on soil carbon stock in the initial years.

Long-term studies assessing the effects of site preparation on soil carbon stock after decades are scarce. Existing studies on site preparation methods used in Fennoscandia on mineral soils do not indicate significant loss of soil carbon; instead, they suggest no substantial change after 10 and 25 years. Studies on stump harvest, which involve extensive soil disturbance, have shown similar results after 20-30 years, despite expectations of more severe soil disturbance and increased biomass harvest.

When considering climate change mitigation, both soil and biomass carbon stocks must be considered. Mechanical site preparation promotes tree growth. Thus, if the effects on soil C stock are minor, site preparation on mineral soils may contribute to climate change mitigation rather than causing adverse effects. Ongoing analyses and soil carbon inventories from additional site-preparation experiments on mineral soils aim to provide further insights into the long-term effects on soil and biomass carbon stocks approximately ten and seventeen years after treatment.

Estimated biomass carbon in thinned Cunninghamia lanceolate plantations at different stand-ages

T1.13 Forest management for climate change mitigation

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Abstract: Chinese fir (*Cunninghamia lanceolate* [Lamb.] Hook.) is a fast-growing species which is not only important as a timber-supplier, but also as an available sink for carbon (C) storage in biomass. Stand age and density are two critical factors that can determine tree C sequestration as interrelated drivers through natural self-thinning. *C. lanceolate* were planted using 1-year-old bare-root seedlings at the initial density of 1800 stems ha^{-1} in a 15-ha montane area of Hunan Province, China in 1987. The plantation was thinned twice 10 and 20 years after planting to leave trees of 437.5 ± 26.6, 675.0 ± 155.2 and 895.8 ± 60.1 stems ha−1 as low, medium, and high densities, respectively. Tree height and diameter at breast height (DBH) were measured every 2 years beginning from 23 years (2009) to 31 years (2018) after establishment, timber volume (TV) and biomass C were estimated accordingly. We did not find any interactive effect of age and density on any variables except for height. Both TV and biomass C increased with stand age or decreased in higher densities. The allometric height- DBH relationship can be fitted by an exponential rising- to-maximum model with higher maximum value over time. The decline of biomass C along density fit with the inverse first-order polynomial model which indicated that at least 1300–1500 stems ha−1 may be needed to maximize TV and biomass C for a longer term over 20 years. Therefore, to control the density to a reasonable level, over 1300 stems ha−1 in a rotation over 20 years old will be practical for tree biomass C in Chinese fir plantations.

Estimates of forest biomass carbon using region-specific biomass equations and volume-derived biomass relationships

T1.13 Forest management for climate change mitigation

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Abstract: Forest biomass and carbon content factor (*CCF*) are essential parameters in carbon accounting, thus, accurate estimates of forest biomass are of great importance for the assessment of carbon storage and carbon budget at large scales. In this study, tree sample data and national forest inventory (NFI) data were used to estimate forest biomass carbon in the Three Gorges Reservoir Region (TGRR), China. In order to estimate the biomass of each tree, above- and below-ground biomass equations were explored for six dominant tree species in TGRR based on 892 harvested sample trees. The aboveground biomass equations were both compatible with tree volume equations and additive system of biomass equations (including stem wood, bark, branches and foliage). Biomass and volume at stand-level were calculated by summing the biomass and volume of all single trees within each plot. Using the continuous biomass expansion factor (*BEF*) method and 2178 sampling forest plots of TGRR, the relationships between biomass and volume were developed for nine forest types. The *CCF*s of different components were measured for six dominant tree species in TGRR by using the dry combustion method, and a weighted CCF of whole tree was obtained. By applying the volume-derived biomass relationships and *CCF*s for different forest types, total forest biomass carbon and its dynamics were assessed in TGRR from 1999 to 2013. The results showed that, 1) The *CCF*s were 0.5490, 0.5223, 0.5142, 0.4914, 0.4779 and 0.4471 respecticely for *Pinus massoniana*, *Cunninghamia lanceolata*, *Cupressus funebris*, *Quercus*, *Betula* and *populus*; 2) The aboveground biomass equations obtained good model fitting and prediction, of which the coefficient of determination ranged from 0.912 to 0.980 (except *Betula* 0.801–0.812), and the total relative error and the mean prediction error were less than 3.0% and 10.0%, respectively; and 3) The estimate values of total forest biomass carbon were 39.328, 52.781 and 68.066 Tg for different periods, with an annual increase of 5.64%. The average total forest biomass carbon density were 27.262 Mg/ha in 1999–2003, 32.665 Mg/ha in 2004–2008, and 36.991 Mg/ha in 2009–2013. Our results can contribute to more accurate estimates of forest biomass and carbon stocks at local level.

Explicit Modelling of Uneven-Aged Stand Dynamics to Improve GHG Emissions Estimates in Eastern Canada

T1.13 Forest management for climate change mitigation

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Abstract: Canada developed the Carbon Budget Model of the Canadian Forest Sector (CBM-CFS3) for national-scale accounting and reporting of GHG emissions and removals in managed forest, which meets Tier-3 standards for international reporting. CBM-CFS3 adopts an age-based yield curve approach that represents well the even-aged stand development typical of a vast portion of the Canadian boreal forest. Significant portions of the Canadian managed forest, however, are characterized by uneven-aged stand dynamics, which may not be adequately represented by current monitoring tools and carbon budgeting framework.

Here we investigate the potential of landscape model LANDIS-II combined with the Forest Carbon Succession (ForCS) module, which allows for an explicit representation of uneven-aged stands and associated silvicultural practices. 1- We assess the mitigation potential of forest management scenarios typical of deciduous, mixedwood and boreal forests of eastern Canada, 2- we present a calibration and validation exercise conducted in Montmorency teaching and research forest of Laval University, and 3- we compare CBM-CFS3 outputs with those obtained from LANDIS-II/ForCS.

Our results suggest that temperate and boreal forests of eastern Canada react differently to a forest management intensity gradient with regard to their respective capacity to act as carbon sinks. Net GHG capture is increased by an intensification of forest management in temperate hardwood forests, while less productive boreal forests, on the contrary, improved their net balance under longer harvesting rotations and conservation scenarios.

Using modelling tools that explicitly represent uneven-aged stand dynamics allows for improved assessments of the impacts of partial harvesting on net carbon balance, and those of climate change, which alters interspecific interactions and successional patterns. A considerable amount of uncertainty remains, however, and additional work is required before such an approach can become operational for accounting and reporting of GHG emissions and removals at national scale.

Facilitating forest carbon sequestration through increasing forest biomass and forest soil protection

T1.13 Forest management for climate change mitigation

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Abstract: Diversity of objectives for sustainable forest management covering climate change mitigation, biodiversity, and bioeconomy may lead the operational forestry into diverging directions. The key question appears to be whether forests should be managed to increase the yield of forest biomass or limit the release of carbon from forest ecosystems aiming to improve the balance of greenhouse gases. The presentation aims to introduce key findings of a study conducted in Lithuania, with the primary objective to identify potential solutions to increase carbon sequestration potential of national forests. There were two parts of the study. Firstly, we conducted a qualitative analysis of the situation, by: (1) using in-depth interviews to disclose the positions of key forestry stakeholders regarding the role of forestry in carbon management and the instruments to improve it; (2) analysing relevant provisions in existing and proposed EU legal basis; (3) making an overview of the initiatives to accumulate carbon through forest management in other countries; (4) and making a meta-analysis of other studies relevant to the subject, conducted in the past in Lithuania and some in the EU. More than fifty potential forest management methods to facilitate carbon sequestration in Lithuanian forests were identified. Secondly, all the proposals were assessed for their performance using available forest decision support tools, SWOT, in-depth economic analyses for their robustness against the main principles of the proposed carbon sequestration certification schemes. The potential of each solution was compared with the expectations of forestry stakeholders, identifying and explaining the gaps between expectations and feasibility.

Facilitating wildfire mitigation strategies on Wildfire Crisis Strategy landscapes

T1.13 Forest management for climate change mitigation

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Abstract: Understanding when, where, and how to intervene in forests to reduce overall economic costs and losses from wildfires is a crucial question with significant implications for forests managed by the U.S. federal government. The effective management of wildfires, including the removal of hazardous fuels that contain potentially marketable biomass products, is a high priority, as is demonstrated by new efforts on a subset of western U.S. federal land parcels defined by the 2022 Wildfire Crisis Strategy (WCS).

This study aims to address this challenge by quantifying and characterizing the biomass available within these landscapes and assessing the market impact of predicted biomass outputs using updated spatial equilibrium models and tools used for socio-ecological analysis of wildfire management.

The research project has several objectives. Firstly, an existing model will be modified to accurately quantify biomass for potential removal and explore innovative uses that are currently not considered in the selected forest. Secondly, the capacities of forest products facilities, such as mills, will be mapped and assessed to determine their capacity to process the identified biomass removals. Additionally, the project will quantify expected volumes and values of the removals, taking into account factors such as budget, treatment objectives, employment, market supply and demand dynamics, and local mill capacity.

Furthermore, the study will evaluate the potential for new uses of treatment products derived from biomass while considering the associated costs, revenue generation, job opportunities, and the impact of wildfires under different conditions and assumptions related to the demand for treatment products. By exploring alternative assumptions and scenarios, the research aims to provide a comprehensive analysis of the economic and environmental aspects of fire mitigation strategies specifically in the WCS landscapes.

Overall, this study aims to enhance our understanding of how economic variables intersect with fire resilience and management, bringing novel insight into the socio-ecological impacts of wildfire management.

From source to sink – recovery of the forest carbon balance after harvest

T1.13 Forest management for climate change mitigation

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Abstract: In Sweden, >80% of the productive forest is managed by clear-cutting, plantation of coniferous monocultures and rotation periods of 60 – 120 years, usually with some thinnings. The carbon losses after clear-cutting are intensively debated and it has been suggested to take a long time before the re-growing forest becomes a net carbon sink again. We analyzed ecosystem carbon fluxes from eddy-covariance measurements in five young forests in southern Sweden where the previous stand had been harvested by clear-cutting or wind-felled: three stands with Norway spruce (*Picea abies* (L.) Karst.), one with Scots pine (*Pinus sylvestris*) and one with Larch (*Larix x eurolepis* A. Henry). Among the spruce stands, one had the stumps harvested, one was fertilized and one received no special treatments. The observed stands transitioned from annual carbon loss to annual carbon gain 8–13 years after disturbance, depending on site productivity and management. This duration corresponds to approximately 15% of the rotation periods at these sites. The lowest carbon emissions and shortest recovery time was observed in the stand where the stumps of the trees, in addition to the stems and logging residues, were removed after harvest. This stand not only returned to a carbon sink within this time period but the total carbon gains since disturbance also equalled the total losses after only 11 years. Among the other stands, the highest carbon uptake was observed in the fertilized spruce stand. On a seasonal basis, the onset of net carbon uptake in spring was usually 1 month later in the larch stand than in the other stands because of phenological differences.
Extrapolation in combination with chronosequence data suggests that conventionally regenerated stands reach a neutral carbon balance after approximately 30% of the rotation period, i.e., when the carbon losses after clear-cutting are balanced by subsequent uptake. These findings highlight that production stands in southern Sweden act as carbon sources during a relatively small part of the rotation period, and that this period can be significantly reduced by implementing measures that enhance productivity or minimize the amount of woody debris remaining after disturbances.

Futures scenarios for sustainable forest management on forest potential: Balancing Carbon Sequestration and Sustainable Resource Utilization

T1.13 Forest management for climate change mitigation

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Abstract: Recent climate policy advancements at the European Union level have led to more focused and definitive strategies for addressing climate change, with specific reduction targets assigned to countries, particularly in the forestry sector. On the way to 2050 EU climate neutrality, the focus is increasing on Land Use, Land Use Change, and Forestry (LULUCF), particularly within the forestry sector, which highlights the importance of forest management practices (FMPs) as effective tools for balancing carbon sequestration and the provision of forest services.

The study examines FMPs applied to over 3.5 million hectares of public forests in Romania, encompassing a wide range of forest types. By analyzing the impact of these practices on forest structure over a 35-year period, this research models the potential for carbon removal by 2050 based on different mitigation strategies. Forest management plans in Romania, revised every decade, adhere to silvicultural principles that promote a balanced distribution on age classes of forest and a controlled harvesting of wood resources. Sustainability indicators, including natural regeneration promotion and extended rotation ages of up to 140 years, ensure a balance between wood resource harvested and carbon removal from the atmosphere.

To facilitate emissions modeling, a comprehensive database of forest management practices implemented in Romania since 1984 has been compiled, incorporating stand and tree species data. Evaluating carbon balance in different types of forest management practices over time, the research modeled future carbon reduction strategies using the EFISCEN and CBM carbon budget and generate scenarios for forest dynamic characterized by varying harvest intensities trough FMPs approaches.

The study provides a deeper understanding of the often-overlooked impact of these practices on carbon sequestration and greenhouse gas emissions. It highlights that long-term conservation or non-intervention may not necessarily lead to higher annual carbon stocks removal potential due to factors like increased mortality and decreased yield, underscores the role of strategic forest management in reducing greenhouse gas emissions and combating climate change. Example of FMPs close to nature approach on a temperate forest type offers comprehensive and valuable insights into the consistent and sustainable forest management measures that can be adopted to meet climate neutrality.

HOW DO DIFFERENT SOURCES OF UNCERTAINTIES AFFECT VOLUME AND BIOMASS ESTIMATES?

T1.13 Forest management for climate change mitigation

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Abstract: Estimates of population parameters in forestry are fraught with uncertainties that should always
be assessed and reported so that the accuracy of the results is known and understood. The aims of this study were (i) to quantify the total uncertainty on volume and biomass estimates and the share of this total due to different sources of uncertainty, such as design-related uncertainty, modelling-related uncertainty – including that emerging from an embedded height-diameter model– and that due to measurement errors, and to (ii) explore the economic implications of ignoring uncertainty in volume and biomass estimates. For these purposes, we used the case study of Acacia mearnsii stands in the South of Brazil. To evaluate how the above uncertainty propagates, we defined five scenarios where the different sources of uncertainty are progressively and incrementally added. Scenarios 1, 2, and 3 focus on the impact of height models on the uncertainties of volume and biomass estimates. We assume that in these scenarios the explanatory variables dbh and h were measured error free. In scenarios 4 and 5, in addition to continuing with the effect of the height equation, we added systematic and random errors on dbh in plots. We fitted Spurr model in linear fashion with mixed-effects to predict individual tree volume and biomass. The greatest uncertainty occurred when we used all predicted heights, both to fit the model and to
estimate the volume and biomass in the plots. The systematic error in the inventory plots led to the second largest uncertainty. In the third place is the uncertainty due to random errors in the explanatory variables used in volume and biomass models. One of the main conclusions of this study is that uncertainty sources interact in different ways and are propagated in the final uncertainty calculations in terms of volume and biomass. These sources of uncertainty may be more significant in the model or inventory, but they directly influence the total uncertainty. Understanding the effect of multiple sources of uncertainty in any estimate helps identify the most effective way to direct monitoring efforts to improve confidence in those estimates.

Impact on soil functions and soil greenhouse gas emissions by harvesting technologies on compaction-prone forest soils

T1.13 Forest management for climate change mitigation

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Abstract: Temperate forests are a significant sink for the greenhouse gases (GHG) methane (CH_4), carbon dioxide (CO_2) and soil emissions of nitrous oxide (N_2O) are low. However, forest management can have a significant long-term impact, and soil compaction caused by heavy forest machine operation, in particular, can be a driving force. Especially silty and clayey soils are compaction-prone and have a low recovery capacity. These changes may affect the soil microbial community and influence soil respiration, methane uptake, and nitrogen turnover.

Results of a one-year measurement campaign in an Austrian beech forest catchment on Stagnic cambisol over Flysch sediments (N 48°07'16", E 16°02'52'', 510 m MASL) revealed a significant reduction in the CH_4 uptake rates and increased soil CO_2 and N_2O emissions at skid tails, six years after harvesting. Compared to the forest stand annual global warming potential (GWP_{100}) was 58% higher at skid tails.

The objective of the current project HoBo (Securing the Sustainability of Forest Soil Functions via Optimized Harvesting Technologies, https://dafne.at/projekte/hobo) is to determine the effects of harvester-forwarder use with/without tracks (HF/HFt) and cable-yarding with motor-manual-felling (CMM), on several soil functions to provide further recommendations for a site-adapted technology use for heavy soils.

We will present results from currently performed measurements at three forest stands on heavy soils, at the Flysch zone and the Molasse basin (North Alpine foreland basin), recently thinned by HF, HFt and CMM techniques. To gain insights into the effects on soil chemistry and microbiology, and changes in microbial community, we conduct soil analysis at 6-week intervals for nitrogen

availability, microbial carbon and nitrogen biomass, and phospholipid fatty acid (PLFA) analysis. Impacts on soil GHG flux rates of CO_2, CH_4, and N_2O are measured with trace gas analyzers (Li-Cor 7810 and 7820), either manually (Li-Cor Smart Chamber 8200-01S) in a 3-weeks interval at the recently thinned stands, or continuously (5-minute interval) with automatic chambers at the plots that were harvested seven years ago, at the LTER-CWN research site Klausen-Leopoldsdorf (https://deims.org/bb472a51-f85f-4de0-8358-f21ecbe2a102).

Intensive forest harvest increases N2O emission from soil: A meta-analysis

T1.13 Forest management for climate change mitigation

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Abstract: A comprehensive evaluation of the impact of forest harvest on soil N_2O flux at the global scale is currently
unavailable. In this study, by using a global meta-analysis of 64 observations from 29 peer-reviewed publications
over the last 30 years, we elucidated how forest harvest impacted soil N_2O flux and related soil properties.
Intensive forest harvest significantly increased soil N_2O flux with a mean effect size of 0.85 and the increase was
associated with elevated soil temperature, increased concentration of NO_3^--N and decreased soil pH. The effect on
soil N_2O flux lasted for around six years, and soil N_2O emission depended on existing forest types in the late stage
(the recovery period >6 years) after harvest. Forest harvest clearly increased soil N_2O flux, with effect size
ranging 0.73–2.12, in broadleaf forests but did not significantly affect it in coniferous and mixed broadleaf-
conifer forests. In addition, the time required for the complete recovery from harvest in terms of N_2O flux
was difficult to define because of the scarcity of long-term experiments. Overall, this study provides the first
formal global-scale assessment on how forest harvest intensity, forest types and the time since harvest affect soil
N_2O flux. The findings of this study help to narrow the knowledge gap regarding the effect of forest harvest on
soil N_2O flux, and to facilitate decision making to decrease soil N_2O emission post forest harvest.

Is the tree health visible in the satellite signal? Relating tree growth, environmental data, and satellite imagery

T1.13 Forest management for climate change mitigation

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Abstract: Rapid global warming due to climate change and associated extreme weather events, such as storms, heavy rainfall, and prolonged dry periods, is the biggest threat of this century, causing pre-mature forest decline. The long drought of recent years has led to massive forest damage. According to the Forest Condition Report 2020, only "21% of the examined trees in our forests are still without crown damage", which is a clear sign of the catastrophic condition of the forests. In this condition, forests must be adapted to the new climate change conditions, and long-term climate-adapted forest conversion is required. In this study, we want to develop a decision support system to foster climate-adapted forest conversion. This would be based on tree species composition and vitality data, soil conditions, and climate data, which are harmonized and analyzed using Artificial intelligence (AI) methods. Two main objectives are: 1) monitoring near real-time forest decline, 2) building a link among environmental variables, tree health indicators (through tree growth), and remote sensing data. AI methodologies will be used for pattern recognition in satellite imagery to generate a high-resolution tree species map using a combination of Sentinel-2 time-series data and high-resolution orthophotos. Based on satellite imagery, a forest condition monitoring system will be developed to detect deviations from the current vegetation state as observed by satellite systems from expected vegetation conditions. The monitoring will be supported by semi-automated data collection of local conditions with a sensor network in the field. A mixed forest stand in Landshut, Germany, has been selected for conceptualizing, installing, and measuring LoRaWAN-based sensor network. LoRa-based sensors, including dendrometers, soil sensors, air temperature, and humidity condition sensors, are installed locally at the trees to provide additional parameters besides the available extraterrestrial data. Moreover, canopy cameras have been installed in the trees to understand the eco-physiological behaviors of the trees as a proxy of health parameters. Results will show how tree species combinations determine ecological indicators (tree growth) of the temperate trees under the climate change condition following the recommendation of suitable tree species combinations at the right place.

Methane oxidation in forest soils under different thinning intensity

T1.13 Forest management for climate change mitigation

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Abstract: Forest thinning is a widely employed management practice aimed at increasing tree biomass. However, its potential impact on methane oxidation, a valuable aspect of forests in terms of climate change mitigation, has yet to be assessed. In this study, we conducted a comparative analysis of methane oxidation rates, the abundance of methanotrophs, microbial enzyme activities, and soil chemical properties in temperate forests subjected to varying degrees of thinning over 2 years. In contrast to previous findings, we observed that soils exhibited the highest methane oxidation rates under moderate thinning intensities. Our analysis suggests that the active development of understory vegetation resulting from moderate thinning provides a substantial supply of organic matter to the soils, thereby facilitating methane oxidation. This study unveils a previously unrecognized influential factor, organic matter availability, in methane oxidation, offering new insights into forest management strategies for effective climate change mitigation.

Modeling vertical distribution of soil organic carbon in Zhejiang Province of China

T1.13 Forest management for climate change mitigation

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Abstract: Exploring the distribution characteristics and influencing factors of soil organic carbon in the mesoscale range are of important theoretical and practical significance for the measurement of soil organic carbon content and agricultural production management. This study selects 838 distributed soil samples with different depths from Zhejiang Province in China. In the vertical direction, a vertical model of soil organic carbon density (SOCD) is established from five typical forest types. The relationship between SOCD and soil depth follows an exponential regression model. With the increase of soil depth, the unit SOCD continues to decrease, and the decline rate gradually slows down. The proposed vertical model combines MGWR model and exponential model, and it can well predict SOCD in soil layers with different depths.

Native, drought tolerant tree species as valuable option to enhance resilience of Central European forests to climate change

T1.13 Forest management for climate change mitigation

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Abstract: Recent climate models predict an increase in hot, extremely dry summers in Central Europe. Currently predominant species differ in their capability to cope with those conditions. Especially on marginal sites, coniferous species showed a severe decrease in vitality during the last years. Therefore, the composition of Central European forests is expected to change drastically in the next decades. Under these circumstances, the introduction and promotion of alternative admixed species is a viable option to increase forest stability. Particularly, native and drought resilient species may be a reasonable option to complement present prevailing species and to maintain a close to nature composition. In our study we assessed the growth and drought reaction of five rare native tree species, i. e. European hornbeam (*Carpinus betulus* L.), European white elm (*Ulmus leavis* Pall.), field maple (*Acer campestre* L.), true service tree (*Sorbus domestica* L.) and wild service tree (*Sorbus torminalis* (L.) Crantz). Based on tree-ring data we I) evaluated their species-specific dendrometric growth characteristics and variability and examined the influencing site and tree variables on annual growth. II) We quantified their reaction to single drought events, also depending on site and tree variables. III) We compared the species-specific reaction of the focus species to oak (*Quercus robur* L., *Quercus petraea* (Matt.) Liebl.) and European beech (*Fagus sylvatica* L.). They are abundant species in Central Europe, and their growth dynamics under drought stress are well-known by forest managers. Our results show, that besides European white elm, the rare species have on average a lower annual growth, but a higher growth variability than European beech and oak. However, especially field maple and wild service tree appeared to be better adapted to drought than European beech and partially even recovered better than oak. Combining the aspects of growth stability and drought tolerance, we conclude that rare native tree species are well suited to drought conditions. Admixtures of those species may play an important role in forest stand transformation towards more climate resilient forests. However, this also requires adjusted silvicultural concepts that consider the species-specific allometric characteristics and allow the promotion of the rare species.

Pilot construction of national forest management aimed at improving forest quality and carbon sink capacity

T1.13 Forest management for climate change mitigation

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Abstract: As the largest terrestrial ecosystem, forests play a variety of service functions in carbon sequestration and sink enhancement to cope with climate change, wood products supply, health and entertainment improvement, as well as ecological protection. The Plantation area of China is 1.314 billion mu, which ranks first in the world. In the past 10 years, China has replanted 960 million mu, contributing about a quarter of the new green area of the world, and becoming the country with the fastest growth in forest resources. However, the forest quality of China, especially the quality of plantation forest is not high, which influence the full play of a variety of functions, China is shifting the direction of forest development from increasing green space to improving quality and efficiency. This paper reviews the relevant work in forest management in China in the past 20 years, and emphasizes on the policies, funds, technology and other aspects of the pilot work of sustainable forest management launched in 2023. Through the multi-level and continuous promotion of forest management work by the state, province, city and forest farm, the researchers attempt to realize the conviction that Lucid Waters and Lush Mountains are Invaluable Assets, and ensure that the forest can play the role of "four reservoirs".

Pinus pinea circadian cycle monitored through high-resolution dendrometers across seasons

T1.13 Forest management for climate change mitigation

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Abstract: Stone pine has relevant socio economic impacts, with increasing interest by establishing productive plantations in several countries. Stem diameter variations (SDVs) result in reversible depletion and replenishment led by the tree water status, and in irreversible diameter growth. The intra-daily temporal monitoring of hourly SDVs contribute in understanding the tree's response to changes in environmental conditions. The goals of the study were to describe the stem circadian cycles monitored with high-resolution band dendrometers during one year in adult stone pine trees growing in a semi-arid coastal environment, and to describe the category of stem cycles and their seasonal frequency. To study stem circadian cycles, the hourly SDVs were accumulated and splitted into three phases covering approximately 24 hours: contraction (P1), expansion or swelling (P2), and stem diameter increment (P3). In all seasons, the time of onset and duration were calculated for each phase. Results revealed that short cycles (<21 h) and long cycles (>28 h) were few; most of the circadian cycles were regular (24±3 h). P1, the daily shrinkage, occurred in the afternoon, when transpiration is higher than the root water uptake; P1 also included the night during winter. The maximum P1 was observed in summer. P2, the daily water uptake that follows P1, occurred in nights and mornings in winter and autumn, and mostly in nights of spring and summer. P3, the irreversible growth, in summer and autumn occurred mostly during mornings, and in spring, the fastest growth period, during nights and mornings. Time series of mean circadian cycle SDVs during one month of spring, summer, autumn and winter are presented. The highest stem diameter accumulation occurred in spring, and the lowest in autumn. Growth-temperature relationships, interesting to understand growth processes and environmental drivers, were studied. The temporal variability pattern showed lower growth under higher daily temperature across seasons. A Spearman correlation was found among SDVs and air temperature throughout the year (ρ ρ=-0.43, $p<0.0001$), and in every season. Our results add new insights into daily growth-climate relationships, especially important to face climate change challenges in semi-arid environments.

Potential reductions in carbon emissions from Indonesian forest concessions through use of reduced-impact logging practices

T1.13 Forest management for climate change mitigation

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Abstract: To estimate how implementation of reduced-impact logging (RIL) practices could reduce carbon emissions from selective logging in Indonesia, we compiled data from 15 concessions in Kalimantan and 10 in the Papuan provinces, including data from 2010-2012 and new data from 2020. Data were collected harvested timber as well as on collateral damage caused by felling, skidding, and clearing for haul roads and log yards. Emissions data, expressed per cubic meter of wood harvested, per area harvested, or per Mg of timber harvested (i.e., the Carbon Impact Factor) were 1.30 ± 0.30 Mg C m^{-3}, 27.52 ± 8.70 Mg C ha^{-1}, and 6.88 ± 1.65 Mg Mg^{-1}, respectively. Felling, hauling, and skidding caused 43-59%, 24-36%, and 17-21% of these emissions, respectively. Potential emissions reductions calculated as the difference between observed emissions and those of the five best-performing concessions are 0.66 ± 0.30 Mg C m^{-3}, 20.85 ± 8.70 Mg C ha^{-1}, and 4.14 ± 1.65 Mg Mg^{-1}, which represent overall reductions of 51%, 76%, and 60%, respectively. Extrapolating these estimates to all forest concessions in Indonesia using average log production data from 2018-2021 results in an estimated annual emissions reduction of 14.47 Tg CO_2 from adoption of RIL, which is 2.9% of Indonesia's nationally determined contribution (NDC) from the forestry sector.

Prolonged rotation in combination of forest drainage – a solution to increased carbon storage in hemiboreal coniferous forests on organic soils?

T1.13 Forest management for climate change mitigation

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Abstract: Forests are expected to play an important role to achieve global climate change mitigation goals by increasing carbon removal from the atmosphere and reducing greenhouse gas emissions. Forests contain several carbon pools (i.e. tree biomass, soil, deadwood, etc.). Old-growth (prolonged rotation) forests are recognized as significant long-term carbon storages, however carbon stocks in such forests vary significantly due to site type, tree species, species structure, and natural disturbances. Even though tree biomass is a significant and dynamic carbon pool that can be managed, natural disturbances can notably deplete the carbon stock. An important management practice in hemiboreal region is forest drainage to enhance tree growth. Therefore, the aim of this study is to compare the carbon stocks in drained and undrained Scots pine forests on organic soils.

The study object is Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) forests on organic soils (71 to 188 years old), where tree biomass and deadwood carbon stock was evaluated. The selection criteria for the old-growth forests (representing prolonged rotation) included the actual presence of the chosen forest type, an age group of over 130 years, a dominant target species representing over 60% of the basal area, and no evidence of prior logging activities.

Coniferous forests on drained organic soils have significantly higher carbon stock compared to undrained stands. This indicates that stand drainage enhances tree growth and carbon storage, and highlights the potential of forest management to improve carbon stock of periodically wet forest stands on organic soils. The deadwood carbon stock in coniferous stands was small, yet significantly higher for drained sites, and did not differ between tree species of the same forest type. The annual carbon stock difference in drained forest stands is significantly greater than in sites without drainage systems; however the carbon stock difference decreases with age. The decreasing trend of carbon storage efficiency (annual carbon stock difference) with age suggests the potential for forest management with shorter rotation cycles to mitigate climate change, while increasing the carbon removal from atmosphere and storing it in the wood products (boost land use efficiency).

Risk Assessment of the Forest Sector as a Carbon Sink According to Climate and Land Use Changes

T1.13 Forest management for climate change mitigation

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Abstract: South Korea is facing problems due to climate change, leading to significant changes in land use. Meanwhile, two-thirds of the national territory is covered with forests, and they play a major role in carbon sequestration. This emphasizes the need to evaluate the risks in forest areas as a carbon sink. Moreover, there have been limited studies conducted in Korea on the changes in land use under climate change. This study aims to assess the effects of forest management and land use changes on the carbon sequestration of the forests under extreme climates. Land use simulations, the extreme climate scenario, and the forest management options were used in this study. Land use simulations included the following types: a condition where forest area decreases, a condition with maintaining the current status, and a condition with increased forest area. The climate scenario used in this study was the Shared Socioeconomic Pathways (SSP) 5-8.5, which assumes high greenhouse gas (GHG) emissions. The overall scenario with each of simulations integrated were as follows: 1) no human intervention in forest management with the land use scenario of decreased forest areas, 2) maintaining the current status both on forest management and land use, and 3) implementing optimum forest management with the land use scenario of increased forest areas. The scenario involving larger forest areas and optimal management (scenario no.3) exhibited the lowest risks, demonstrating significant differences from the first and second scenarios. Also, areas with high age-class came out to have higher risks when evaluated at the region level, including areas such as Gangwon-do, a typical region experiencing a reduction in northern temperate forests, and Gyeongsangnam-do, a distinctive region transitioning to warm-temperate forests. Therefore, forests should be managed not only according to policies but also considering changes in land use. This study contributed to understand and evaluate the capacity of forests sequestrating carbon in the future. Furthermore, this study may contribute to the development of the next National and Regional Forest Plans.

Seasonality of albedo and FAPAR in the temperate secondary forest ecosystem: A comprehensive observation using Qingyuan Ker towers

T1.13 Forest management for climate change mitigation

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Abstract: Reforestation have been highlighted as a significant intervention for climate change by altering the land surface albedo and vegetation productivity. Previous studies have reported the effect of land-use/cover change on the land surface albedo, yet few studies have examined how changed understory and canopy structures derived from reforestation contribute to forest albedos and further influence fraction of absorbed photosynthetically active radiation (FAPAR, a proxy of gross primary productivity). Using the Qingyuan Ker Towers (three towers in a watershed; natural mixed broadleaved forest, T1-MBF; natural Mongolian oak forest, T2-MOF; larch plantation forest, T3-LPF), albedos for three spectral regions (global solar radiation, SR; photosynthetically active radiation, PAR; near-infrared radiation, NIR) and FAPAR were monitored. We continuously measured canopy effective leaf area index (LAI_e) and understory greenness, and examine their relationships to albedos in a temperate secondary forest ecosystem. The result showed that SR and NIR albedos of MBF and MOF were greater than those of LPF, and their PAR albedos were comparable. SR and NIR albedos were comparably and positively correlated with canopy LAI_e and understory greenness, while PAR albedo was negatively correlated with canopy LAI_e and understory greenness. Understory greenness explained 75.6% of changes in NIR albedo of LPF in the peak growing season, indicating a strong control of understory vegetation on the albedos. In addition, SR albedos were significantly correlated with FAPAR, with stronger correlations in MBF (r = 0.69) and MOF (r = 0.93) than that in LPF (r = 0.3), showing a co-benefit of carbon uptake and albedo in broadleaved stands, but the co-benefit was weakened in coniferous plantation stand. These findings suggested that increasing vegetation green biomass and introduction of broadleaved trees into monocultural coniferous plantation may increase forest albedo and co-benefit of albedo and FAPAR to combat climate warming.

Site index estimation for China fir plantations in china based on spatial clustering of environmental variables

T1.13 Forest management for climate change mitigation

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Abstract: Site index estimation for China fir plantations in china based on spatial clustering of environmental variables

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Absract:The environmental uncertainty derived from climate change suggests that some commonly used empirical indicators of forest productivity, such as site index, may not be suitable for future growth prediction in the following decades. As a consequence, the development of statistical models that relate these indicators with environmental variables may be a crucial support resource for practical forest management.In this research, we tested three different statistical learning techniques for estimating site index of Chinese fir(Cunninghamia lanceolata) stands in fifteen province in the south of china.The predictors used for this task were a set of 43 physiographic, soil, and climatic variables obtained from available raster maps for this region, whereas the site index data came from the sixth and seventh national forest resources continuous inventory data, with a total sample size of 23 239.The proposed learning techniques produced models of easy interpretation in comparison to other "machine learning" approaches, and accounted for up to 45% of the response's variability. The random forest,GAM,GLM provided models with high performance but at the expense of including a large number of predictors. Using the group analysis in ArcGIS, the plots in the study area was gruoped according to the environmental similaruty and spatial proximity. The GAM with spatial clustering seemed to be the most suitable technique, as it explained above 40% of the site index variability with a reduced amount of predictors, and did not show undesirable patterns in the residuals and predicted values. Besides, the growth-environment relationships represented by this model seemed to be ecologically coherent.

Keyword: China fir, Site index estimation,environmental variables,spatial clustering

Small oases below the canopy: the effects of water-filled tree holes on local microclimate and biodiversity

T1.13 Forest management for climate change mitigation

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Abstract: Forests and their special microclimates are key elements in the mitigation of climate change and biodiversity loss worldwide. The relevance of forests in biodiversity and biogeochemical processes is shaped by microclimates, which can be described as stable, buffered, cooler and more humid than those of the adjoining open habitat. Tree-related microhabitats are especially important substrates and structures for biodiversity in forests but their effects on local microclimates in temperate regions are largely unknown. Water-filled tree holes (WHs) are special microhabitats, "aquatic islands on trees", that are important for insect larvae and mesofauna colonizing these waterbodies and feeding on the detritus. These temporary microhabitats can sustain water throughout dry periods for many vertebrate species as well.

In an abandoned Turkey oak-dominated coppice stand, in Northern Hungary, the microclimatic conditions of 80 WHs and adjacent forest plots were measured at the peak of the growing season of 2021. While closed forests could cool down air temperatures up to 5°C, WHs had an additional negative offset of 2.5°C and could increase air humidity by extra 15 percentage points (5 vs. 20%). The local microclimate of WHs and the adjacent closed forest differed significantly for means and extremes of all tested variables (air temperature and humidity, vapour pressure deficit), which was mainly driven by WH entry area, WH volume, and water amount.

Besides their substantial effects on the local microclimate, WHs are the only known habitat of European red-listed bryophyte species *Codonoblepharon forsteri* (Dicks.) Goffinet). Systematic mapping of the species showed that Turkey oak is an important host tree species (87 records). The main drivers – bare surface on the WH periphery, distance from the closest occurrence, and diffuse light – of the colonization of the species were also unfolded.

Moreover, by camera trapping, we could gain the first insights into the WH-use of vertebrate species – such as *Felis silvestris, Vulpes vulpes* or *Coccothraustes coccothraustes* – in oak-dominated forests.

We can conclude that the importance of microhabitats and habitat trees as climatic refugia increases, and the need for active protection is essential facing global climate change to mitigate its negative effects on forest biodiversity.

Soil CO2 fluxes and stocks in two typical Mediterranean oak-dominated ecosystems

T1.13 Forest management for climate change mitigation

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Abstract: The concentration of CO_2 in the soil is approximately four times larger than in the atmosphere, and minor changes in soil respiration may significantly impact the balance of atmospheric CO_2 and its effect on climate change. This work studies the mechanisms of soil respiration and C cycling in oak-dominated deciduous and evergreen Mediterranean forests and aims to: i) assess the difference in soil CO_2 emissions among the two types of ecosystems, ii) investigate the seasonal variance of carbon fluxes in those ecosystems, and iii) determine the effect of soil temperature and humidity, as well as of inputs from litterfall, forest floor and roots on soil respiration. The methodological approach of this work quantifies the contribution of the two independent processes that cause soil CO_2 efflux: i) root-derived C breakdown (autotrophic respiration of roots) and ii) soil-derived C decomposition (heterotrophic respiration of litter and SOM). Thus, the following treatments were applied: control [C] (undisturbed), no-litterfall [NL] (aboveground litterfall excluded) and no-litterfall -no-roots [NLNR] (both litterfall and roots excluded). In the NLNR treatment, roots were excluded by putting 20–25 cm deep trenches (20 cm wide) and placing fiberglass sheets to prevent root access. Three monitoring plots were established in each of the two ecosystem types. Every plot included three replicate measuring points for each of the three treatments. In total 54 polyvinyl chloride (PVC) collars were established for the performance of soil respiration measurements once every three months for one year, using a Li-8100 automated soil CO_2 efflux system. At the same time, soil temperature (°C) and volumetric soil moisture content (%) were determined. Here we present the preliminary results of soil respiration differences among two representative oak-dominated Mediterranean ecosystems and we attempt to identify the effects of climatic drivers and of litter inputs on the seasonal fluctuation of soil CO_2 fluxes, in order to enhance our understanding of C cycling in these forest types.

Stand biomass and productivity under future climate change varied among larch plantations in north and northeast China

T1.13 Forest management for climate change mitigation

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Abstract: Understanding the effects of climate change on forest biomass and productivity is vital to adaptive forest management. In the present study, the 3-PG$_{mix}$ model was parameterized to simulate the effects of climate change on stand biomass and productivity of four types of larch plantations (*Larix olgensis, Larix gmelinii, Larix principis-rupprechtii* and *Larix kaempferi*) using 552 sample plots collected from the 6th, 7th and 8th National Forest Inventories north and northeast China. The 3-PGmix model is suitable for simulation of growth and yield of larch plantations, and the simulated and measured values of stand variables were consistent with each other (R^2 was between 0.71 and 0.96). Future climate change (increased temperature, precipitation and CO_2 concentration) could promote the growth of four larch species. Compared with the current climate, the stand variables showed an increasing trend in the 90 year simulation period with the same trend of RCP8.5 > RCP 4.5 > current climate. Furthermore, the response of larch plantations to climate change varied with tree species and site levels. With the exception of *Larix kaempferi*, the increased size of stand growth at low site levels was larger than that of high site level; but the increased mortality at high site level was larger than that of low site level. Implications for adaptive forest management were discussed.

The national voluntary carbon credit registry for the forestry sector in Italy

T1.13 Forest management for climate change mitigation

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Abstract: Contesto

Il crescente interesse della società civile e dei settori produttivi per gli impegni internazionali e dell'Unione Europea (UE) per combattere il cambiamento climatico e ridurne gli impatti sul capitale naturale ha portato a una maggiore attenzione politica e sociale sul ruolo svolto dai settori forestale e agricolo e dal servizi ecosistemici forniti.

Argomento

I crediti volontari di carbonio sono stati venduti nell'ambito dei Mercati Volontari in Italia e un'analisi di mercato del "Centro Monitoraggio Carbone" (NMC), gruppo di lavoro coordinato dal Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA), mostra che raramente i crediti sono accompagnati da certificazione da parte di un organismo di certificazione esterno, nazionale o internazionale; invece, i crediti sono certificati secondo linee guida interne o talvolta venduti senza certificazione.

Grazie all'articolo 45 della legge n. 41 approvata il 21 aprile 2023, sarà istituito in Italia un registro pubblico dei crediti di carbonio generati su base volontaria dal settore agroforestale nazionale.

Metodo

Il Centro Monitoraggio Carbonio del CREA-PB, nell'ultimo anno ha istituito un Comitato Tecnico Scientifico (STC).

The STC drafted the document called Climate Credit Forestry Code (CFC 2.0) from a guideline document called Carbon Forestry Code (CFC) made in 2014 that was updated according to national and international regulations inherent to carbon removals and carbon markets. In particular, the CFC 2.0 was made consistent with the proposed regulation of carbon removals.

Results

The main requirements defined are: additionality, baseline, permanence and impacts on other ecosystem services such as biodiversity, soil and water resource.

I CFC 2.0 requires that net removals that generate carbon credits be calculated through the following general formula: Climate credits= ACt - ACb- GHG

Conclusion

L'introduzione di linee guida istituzionali riconosciute e dell'anagrafe pubblica nazionale per il settore agricolo e forestale consentirà di regolamentare il mercato anche in Italia. Pertanto, consentiranno alle organizzazioni pubbliche e private che vogliono compensare le proprie emissioni di utilizzare crediti di carbonio certificati generati in Italia dal settore forestale.

The Response Relationship between Nitrogen and Phosphorus Contents in Camellia oleifera Leaves based on Ground Hyperspectral and Machine Learning

T1.13 Forest management for climate change mitigation

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Abstract: Abstract: Nitrogen and phosphorus are essential elements for plant growth. They play an important role in representing plant growth, physiological regulation, and fruit harvest. Hyperspectral technology provides a non-destructive, rapid, highly accurate, and cost-effective method for estimating nutrient content in plant leaves. However, there have been few reports on the remote sensing-based nutrient diagnosis of *Camellia oleifera* leaves. In this paper, 160 *Camellia oleifera* samples were used. Spectral data were obtained using a full-band ground object spectrometer. Based on preprocessing, different combinations of spectral indices were compared to reveal the spectral response characteristics of leaf nitrogen content (LNC) and leaf phosphorus content (LPC). Furthermore, spectral variables were screened, and optimal LNC and LPC estimation models based on three machine learning algorithms were constructed. The results showed that the spectral sensitive region for leaf nitrogen and phosphorus content was mainly reflected in green light, followed by red light and the long-wave direction of short-wave infrared. Savitzky-Golay first derivative (SGFD) pretreatment method was generally superior to the multiplicative scatter correction (MSC). At the canopy scale, the maximum of absolute values of correlation coefficient between LNC, LPC, and spectral transformation features were 0.56 and 0.49. The optimal LNC and LPC models were SGFD-NDSI-BPNN, with determination coefficients R^2 of 0.81 and 0.79, and RMSEP of 0.55 g/kg and 0.06 g/kg, respectively. The research results provide a reliable theoretical basis for the optical remote sensing monitoring of nutrient content in *Camellia oleifera* on a large scale.

Towards meeting net-zero emissions: carbon dioxide removal potential from Norwegian forests

T1.13 Forest management for climate change mitigation

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Abstract: There is an increasing interest in using forests as a natural solution for enhancing terrestrial carbon dioxide removal, which is considered to have a significant potential role in climate mitigation efforts. Thus, carbon dioxide removal strategies from the forest sector might be key in achieving net-zero commitments and climate targets. Here, we assessed a range of carbon dioxide removal strategies oriented to increase carbon sequestration from Norwegian forests. These strategies include intensification of forest management (intensification of established practices in the forest sector), change in tree species (conversion from low-productive broadleaf forests to high-productive spruce forests), tree planting (spruce planting in areas currently undergoing the transition to low-productive broadleaf forests but which do not yet meet the FAO forest definition), and use of biochar from forest residues. Intensification of forest management and use of biochar would increase CO_2 removals in the short (2030), medium (2050) and long-term (2100), with very little effect in the short-term and increasing towards the end of the century. While change in tree species would increase CO_2 emissions in the short and mid-term, tree planting would have a negligible effect. Both change in tree species and tree planting (spruce conversion) would lead to an increase in CO_2 removals from the second half of this century. By the end of the century, the largest accumulated CO_2 removal potential was for tree species change and intensification of forest management strategies, following by tree planting and biochar strategies.

What alternative forest management approaches can we do to achieve carbon neutrality: A case study in Northeastern China

T1.13 Forest management for climate change mitigation

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Abstract: Forest ecosystems play a pivotal role in mitigating climate change and providing essential ecosystem services (ES) to the natural biosphere. With China being the world's largest developing nation, its commitment to achieving carbon peak by 2030 and carbon neutrality by 2060 underscores the need to explore sustainable approaches for optimizing the ecological and economic benefits of forests. This study focuses on evaluating the economic value of forest ecosystem services in significant state-owned forest areas of Northeast China. Employing a comprehensive methodology combining geographic information system (GIS) modeling, scenario modeling, and economic estimation techniques, we conduct a 40-year scenario-based prediction of wood supply and carbon sequestration at representative sites to assess the impact of alternative forest management strategies on the studied services. The scenarios considered include: Scenario A, representing the prevailing management approach with logging prohibition; Scenario B, incorporating nature protection-oriented management; and Scenario C, emphasizing wood production-oriented management, both in comparison to Scenario A. Forest management scenarios are simulated over a 20-year timeframe. Our findings not only offer valuable insights for the management of China's natural forests to achieve the “dual carbon” goal, but also contribute to the ongoing discourse surrounding the trade-offs and synergies between carbon sequestration and the socio-ecological benefits associated with wood production.

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

Annual flux of radiocesium from canopy to forest floor more than ten years after the Fukushima accident

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: More than ten years have passed since the Fukushima Daiichi Nuclear Power Plant accident, it has been pointed out that forest radiocesium (^{137}Cs) cycle is probably near the quasi-equilibrium state (^{137}Cs flux from canopy to forest floor is balanced with that of uptake from forest floor to trees). Observation of the ^{137}Cs flux from the canopy to forest floor is one of the essential attempts to improve the accuracy of prediction of ^{137}Cs activity concentration in the stem toward the resumption of forestry. In this study, we investigated the annual flux of ^{137}Cs via litterfall, throughfall, and stemflow in deciduous broad-leaved and Japanese cedar forests in Kawauchi Village, Fukushima Prefecture, from 2021 to 2022. Our observational results showed that annual flux of ^{137}Cs from canopy to forest floor in deciduous broad-leaved and Japanese cedar forests was 2600 and 930 Bq/m^2, respectively. Both of the above annual fluxes were less than 1% of the total ^{137}Cs inventory in the forest system. In addition, it was suggested that litterfall plays the most dominant role in the annual flux of ^{137}Cs from canopy to forest floor in forests more than ten years after the accident.

Availability of logs and litter of Japanese konara oak by estimation of radiocesium concentration from the leaves and the initial deposition

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: The contamination damage caused by cesium-137 (hereafter ^{137}Cs) released and deposited as a result of the Fukushima Daiichi Nuclear Power Plant accident has forced restrictions on the use of deciduous broad-leaved *Quercus serrata* forests in the Satoyama landscapes, which are used to produce logs for mushroom production and leaf litter for compost production for organic farming. To examine relationship between the ^{137}Cs concentrations in different parts of the tree, and the current availability of tree trunks and fallen leaves based on provisional permissible values of ^{137}Cs, we collected overstory branches, leaves, and fallen leaves by litter traps and tree trunks of *Quercus serrata* in several areas of different initial deposition levels neighbor to Fukushima prefecture, And the estimation of ^{137}Cs concentrations was made in tree trunks and fallen leaves from overstory branches and leaves and fallen leaves. The distribution of ^{137}Cs concentration in each individual *Quercus serrata* tree was highest in the overstory leaves. At the highly contaminated area both of the tree trunks and fallen leaves were unusable compared to the provisional permissible values (logs for mushroom production (50Bq/kg), leaf litter compost (400Bq/kg)), on the other hands the intermediate and low contaminated area showed the value of usable for the log and litter based compost production. Linear regression analysis showed that the best fit of the regression equation was obtained between the upper leaves and the trunk (bark) and between the upper leaves and fallen leaves, suggesting that the ^{137}Cs concentrations in the trunk and fallen leaves can be estimated from the concentrations in the upper leaves and branches. For the estimation of tree trunk and litter concentration from initial deposition for each area determined by airborne radar measurements by the Japan Atomic Energy Agency, a significant linear regression equation was obtained between initial deposition and overstory leaves. The relationship suggests that it is possible to estimate the concentration of overstory leaves from the initial deposition and of trunk and fallen leaves from overstory leaves. The results of this study will contribute to the rapid assessment of logs and litter availability under heterogeneous gradient of ^{137}Cs contamination.

Biogeochemical recycling of K and Cs isotopes in deciduous forest stands on the long term after deposition

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: Due to atmospheric releases from the Chernobyl and Fukushima accidents, Cs-137 long half-live (30y) and its incorporation into the biogeochemical cycle of elements lead to its persistence within forest ecosystems, affecting forest ecosystem services even more since their decontamination is hardly possible. Predicting its behavior and transfer dynamics over time is of key importance to help recovering benefit from forest products. Such assessment studies require the transfer processes to be documented with numerous data to encompass the variability of environmental factors (e.g. species, age, climate, deposit). To date, the root-uptake which is known to be the major process of Cs-137 intake in trees after the transition phase (>10y) couldn't be robustly assessed due to the remaining contribution of initial foliar uptake. More, data remain scarce for deciduous trees as most post-Chernobyl and post-Fukushima field studies mainly focused on evergreen species.

Relying on stands monitoring data collected during the post-accident long-term phase (>30y) in 4 various deciduous forest stands (France, Ukraine), we compared their Cs-137 concentrations and inventories distributions in trees as well as those of stable chemical analogues (Cs-133, K). To differentiate annual root-uptake from internal translocations fluxes in trees, we assessed their biogeochemical cycling fluxes (mass balance approach).

On the long-term, the Cs-137 initial foliar uptake contribution was no more visible at our sites due to biomass dilution and Tag (aggregated transfer factor) values were one order of magnitude lower than reference ones (IAEA, 2009) likely indicating a long-term decrease of Cs-137 bioavailability in soil. The concentrations of Cs-133 and Cs-137 normalized by the exchangeable inventories in soil were linearly correlated ($r>0.7$, $p<0.05$) and differences between isotopes were explained by the soil depth root density. The Cs isotopes were more sequestered than K in roots. Compared to evergreen coniferous forests, uptake rates (y^{-1}) were up to twice higher for K but up to 10 times lower for Cs isotopes, consequently exhibiting a stronger Cs/K discrimination. In a Q. serrata stand sampled in 2014-2018 (Japan, early-medium stage) where dynamics were slower than for coniferous, use of Cs-133 and K to assess the magnitude of Cs-137 root uptake rate is underway.

Comparing stable and radioactive caesium in a boreal forest landscape

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: Radiocaesium was a major contaminant from the Chornobyl and Fukushima accidents, and Cs remains one of the most widely investigated elements in radioecology. The knowledge is largely based on studies of the radioactive isotope Cs-137, but Cs also occurs naturally as the stable isotope Cs-133. Because Cs-133 has been present in the environment over longer timescales than Cs-137 and has a different source – weathering rather than atmospheric fallout – it can provide additional insights into what processes govern the long-term fate of Cs in the complex boreal forest landscape.

This presentation will compare measurements on stable Cs-133 and radioactive Cs-137 from one of the most well-investigated catchments in the boreal forest region, the Krycklan catchment in northern Sweden. Measurements of Cs-137 date back to the Chornobyl accident in 1986, and sporadic measurements of soil, peat, stream water and biota have continued since then. The available research infrastructure has also been used to collect extensive data on Cs-133 in mires, soil water, groundwater, precipitation, biota and stream water from several catchments with contrasting characteristics, e.g. different catchment sizes and soil types. This has provided an overview of the natural abundance of Cs in different compartments across the forest landscape and allowed an assessment of the long-term transport and accumulation patterns of Cs. Complementary data on chemical analogues like K and Rb provides additional insights into what biogeochemical processes control the fate of Cs.

Although Cs-133 and Cs-137 chemically are identical, the results display substantial differences between the isotopes. Partly, this can be attributed to the radioactive decay of Cs-137 and its shorter presence in these ecosystems, but partly this also reflects how the two isotopes entered the ecosystems. For example, higher export of Cs-137 has often been observed from mires than from forests, but for Cs-133 the relationship is the opposite. Combined with evidence from other elements this suggests that the higher Cs-137 retention in forest soils is more related to hydrological flow pathways than higher mobility of Cs in peat. Hence, comparing these isotopes can help disentangle what processes are important for the long-term fate of Cs in the landscape.

Forest radioactive contamination: long-term dynamics and impact on ecosystem and society — Session overview

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: This presentation aims to provide an overview of the session and its objectives. The session focuses on sharing knowledge about forest-related radioactivity from around the world, including insights from long-term studies conducted in Chernobyl and Fukushima. Specifically, the session will explore the dynamics of radioactive materials and radiation in forest environments, encompassing all forest components, such as trees, soil, water, mushrooms, wildlife, and more. Additionally, the session will highlight the indirect impacts on forest ecosystems and society. Abandoned forests undergo changes in their biology and landscapes, which affect both society and wildlife. The potential risks of forest fires will also be addressed. Social studies will explore the effects of forest contamination on people's lives and the forest industry, as well as communication and education initiatives aimed at engaging local residents.

Further accumulation of radioactive cesium from 2014 to 2020 in the inner heartwood of trees contaminated by the Fukushima nuclear accident of 2011

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: Understanding the dynamics of radioactive cesium (^{137}Cs) in stem wood containing substantial amounts of heartwood at the time of the Fukushima nuclear accident of 2011 is important for predicting the level of ^{137}Cs contamination of mature wood in Fukushima, Japan. Our previous study revealed that approximately 3 years after the accident (i.e., 2014), the amount of accident-derived ^{137}Cs that had transferred to the innermost heartwood tended to be small compared to the natural distribution pattern of stable cesium (^{133}Cs). Currently, it is unclear whether ^{137}Cs accumulates further in the inner heartwood or whether the distribution pattern of ^{137}Cs approaches that of ^{133}Cs over time. To clarify the ^{137}Cs dynamics after 2014, we conducted a follow-up investigation in 2020 at the same sites as those studied in 2014. Wood disks were collected from four cedar trees (*Cryptomeria japonica*), two trees each of cypress (*Chamaecyparis obtusa*) and larch (*Larix kaempferi*). The trees were approximately 50–70 years old. Wood disks were divided into segments every 2 cm along the radial direction from the cambium to the pith. The ^{137}Cs and ^{133}Cs concentrations were determined using a Ge detector and an inductively coupled plasma mass spectrometer, respectively. In 2014, the ^{137}Cs concentration tended to decrease from the outermost to the innermost heartwood (near the pith), while the ^{133}Cs concentration was distributed almost evenly throughout the heartwood. In 2020, the ^{137}Cs concentration in the inner and outer heartwood of many wood disks were similar, which reflected the distribution pattern of ^{133}Cs. However, in some wood disks with a relatively large heartwood area, the ^{137}Cs concentration tended to decrease slightly toward the innermost heartwood. Overall, the results demonstrate that the distribution patterns of ^{137}Cs and ^{133}Cs in heartwood become similar after several to ten years after the accident, although it may take more than a decade for ^{137}Cs to reach a steady-state distribution in stem wood with a relatively large heartwood area.

Inflow of absorbable radiocesium to forest soil at rhizosphere by stemflow

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: Evaluating the uptake mechanism of radiocesium by trees is necessary for developing the reducing method of the radiocesium concentration of trees in radioactively contaminated forests because the temporal trend of radiocesium concentration in stem wood differs depending on the tree species and standing conditions. Therefore, it is important to elucidate the dynamics of radiocesium that can be absorbed by trees in the rhizosphere where absorbing roots are distributed. This study investigated the relationship between the inflow of radiocesium by stemflow and radiocesium stocks in soils. We measured radiocesium amount by stemflow and dissolved and exchangeable radiocesium in different soil depths (0–5 cm, 5–10 cm, 10–15 cm) at four directions of trees for two Japanese cedar stands and a Konara oak forest in Fukushima prefecture, Japan. In addition, the preferential flowpaths of stemflow were detected by spraying the stems with colored dye under three rainfall conditions. Radiocesium amount by stemflow was higher for the Konara oak forest than the Japanese cedar forests. In the oak forest, dissolved and exchangeable radiocesium stocks in soil were high clearly under preferential flowpath of stemflow. In addition, on the soils of preferential flowpaths of stemflow, whereas vertical distributions of dissolved radiocesium are constant, some exchangeable radiocesium existed at deeper soils (10–15 cm). These results indicated that exchangeable radiocesium existed at the deeper soil layer because dissolved radiocesium was supplied to deeper soils by stemflow at the rhizosphere.

Influence of slope positions on Cs-137 uptake by trees in Japanese steep mountain forests

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: In Japanese steep mountain forests, the degree of organic layer development and soil physico-chemical properties change depending on the slope positions. This may also affect the dynamics of ^{137}Cs originating from the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident in the forest ecosystem. In this study, we investigated the aggregated transfer factors (T_{ag}) of Japanese cedar needles, branches, barks, and stem woods along the slope in a Japanese cedar forest, which is located around 20 km northwest of the FDNPP. Additionally, air dose rates and soil properties (including exchangeable potassium which inhibits the ^{137}Cs absorption by plants) were also measured. Our results indicated that there were no significant differences in the ^{137}Cs inventory in forest soils (organic and mineral soil layers) and air dose rates among slope positions, suggesting that the initial ^{137}Cs deposition was almost equal regardless of the slope positions. However, ^{137}Cs activity concentrations in needles, branches, and stem woods tended to be relatively high at the ridge, and all maximum concentrations were found at the ridge. T_{ag} values in needles, branches, and stem woods also were higher at the ridge than those at the middle and low positions. There were no differences in bark between slope positions. The exchangeable potassium in the surface mineral soil layers (0–5 cm) did not vary depending on the slope positions. At the ridge, large amounts of ^{137}Cs were retained in the organic layers (about 25 times that at the low position), which were thick and the lower part of the organic layers was covered by dense fine roots. Oppositely, at the low position of the slope, the organic layers were thin and the dense fine roots were rarely observed. Therefore, large T_{ag} values at the ridge could be explained by that 137Cs are retained in the thick organic layers and are absorbed by the trees through the dense fine roots. We concluded that great attention should be paid to the slope positions to interpret soil-to-tree transfer of ^{137}Cs in mountainous forested areas in Japan.

Influences of Rooting Activity by Wild Boar on Cesium-137 soil profile after the Fukushima Daiichi Nuclear Power Plant accident

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: Cesium-137 (Cs-137, physical half-life of ca. 30 years) was a main anthropogenic radiological contaminant released from the 2011 Fukushima Daiichi Nuclear Power Plant (FDNPP) accident in Japan. Initially, contaminants from the accident were deposited on the surface soil layers in the terrestrial ecosystem surrounding Fukushima, but over time vertical migration of Cs-137 in the soil has occurred, with most Cs-137 now distributed a few centimeters below the soil surface. Wild boar (*Sus scrofa*) are present in the FDNPP region and impact the landscape and ecosystem, particularly through rooting behavior that can significantly disturb the soil. Soil disturbance caused by wild boar rooting likely alters the distribution of Cs-137-contaminated soil profiles, especially around the FDNPP area given the regional population increase of wild boar following the FDNPP accident. Our objective was to determine whether rooting by wild boar alters the distribution of Cs-137 contamination within soil profiles through collection of soil cores from control sites and two different types of rooting samples, new depressions and old (i.e. several months old) depressions, within the difficult-to-return zone surrounding the FDNPP. The mean soil migration depth of Cs-137 was 7.1 ± SD 2.3 cm across all rooting sites and 4.0 ± SD 1.2 cm across all control sites. The Cs-137 ratio [activity concentration of Cs-137 at each depth / the maximum activity concentration of Cs-137 in each core sample] was highest in the 2-4 cm soil profile and immediately decreased after 4 cm depth at the control sites. However, the ^{137}Cs ratio in soil layers at sites disturbed by wild pig rooting was deeper (i.e., 6-10 cm) than control sites, more dispersed throughout the soil profile, and decreased more slowly than control sites. There was no difference in the soil profiles between new and old rooting sites. These results demonstrate that soil disturbance from wild boar rooting can directly influence the distribution of contaminants within soil profiles. However, the extent to which deeper layers are affected by contamination depends on the unique characteristics (i.e., depth of rooting) of each wild boar rooting disturbance.

Inter-specific characteristics and intra-municipal variation of 137Cs concentrations in wild mushrooms after the Fukushima nuclear accident

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: Due to radioactive contamination following the Fukushima Daiichi Nuclear Power Plant accident in 2011, shipping restrictions have been imposed on wild mushrooms in a wide area of eastern Japan. The shipping restrictions on wild mushrooms in municipalities are made without distinguishing between species, and because of the wide variation in concentrations from sample to sample, lifting is done on a species-by-species basis based on a large number of tests. In order to contribute to more efficient restriction and its lifting, I focused on the variation of radiocesium (^{137}Cs) concentration for each species obtained within the same municipality, and 7,920 sample data collected in prefectures in eastern Japan from 2014 to 2019 were analyzed. The ^{137}Cs concentrations of mushroom species collected in municipalities could be regarded as a lognormal distribution. The geometric standard deviation (GSD) for each species and municipality, which is an indicator of the variability of the lognormal distribution, tended to converge as the number of samples increased, while the values were considered to vary to 2–3 by species. The ratio of the geometric mean (GM) of ^{137}Cs concentrations for each species was constant regardless of the sampling municipality, suggesting that the trend in species concentrations is common regardless of the region. The concentration distribution considering the variation of species showed that there were cases where the concentration distributions overlapped even when the geometric mean concentrations differed by a factor of 10. On the other hand, there were cases in which the concentration distributions were very similar even though the species differed (e.g., *Pholiota microspora* (nameko) and *Panellus edulis* (mukitake), or *Mycoleptodonoides aitchisonii* (bunaharitake) and *Pleurotus ostreatus* (hiratake)). Such information is important when considering shipping restriction or its lifting.

Long term effects of ionising radiation in the Chernobyl Exclusion zone on DNA integrity and chemical defence systems of Scots pine

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: The Chernobyl Nuclear Power Plant (ChNPP) accident in 1986 resulted in extremely high levels of acute ionising radiation, that killed or damaged Scots pine (*Pinus sylvestris*) trees in the surrounding areas. Dead trees were cleared and buried, and new plantations established a few years later. Today, more than three decades later, gamma and beta-radiation near the ChNPP is still elevated compared with ambient levels but have decreased by a factor of 300 and 100, respectively. In the present work Scots pine-trees growing at High (220 μGyh^{-1}), Medium (11 μGyh^{-1}), and Low (0.2 μGyh^{-1}), of chronically elevated ionising radiation in the Chernobyl Exclusion zone were investigated with respect to possible damage to DNA, cells and organelles, as well as potential increased levels of phenolic and terpenoid antioxidants. Scots pine from the High and Medium radiation sites had elevated levels of DNA damage in shoot tips and needles as shown by the COMET assay, as well as increased numbers of resin ducts and subcellular abnormalities in needles. Needles from the High radiation site showed elevated levels of monoterpenes and condensed tannins compared with those from the other sites. In conclusion, substantial DNA damage and (sub)cellular effects, but also mobilisation of stress-protective substances possessing antioxidant activity are observed in Scots pine trees growing at elevated levels of ionising radiation more than three decades after the ChNPP accident. This demonstrates that the radiation levels in the Red Forest still significantly impact the plant community.

Low-dose-rate radiation effects on tree mutations: Insights from mutation surveys in Japanese cedar and flowering cherry

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: Understanding the impact of low-dose-rate radiation on genetics, especially in natural settings, remains a significant scientific challenge. Following the Fukushima Dai-ichi Nuclear Power Plant disaster, naturally occurring lands became contaminated. This study investigates de novo mutations (DNMs) in germ line cells of Japanese cedar and flowering cherry trees exposed to ambient dose rates ranging from 0.08 to 6.86 $\mu Gy\ h^{-1}$ and distributed inside and outside the "Difficult-to-return Zone." Both tree species are extensively cultivated in Japan for forestry and horticultural purposes. In the case of Japanese flowering cherry, artificial crossing was performed to produce 69 seeds/seedlings, and only two potential DNMs were detected in uncontaminated areas. For Japanese cedar, 146 haploid megagametophytes were utilized as samples for the next generation. The use of megagametophytes from open pollination provided several advantages, including reduced radiation exposure in contaminated zones due to the elimination of artificial crossings and simplified data analysis owing to the haploid nature of megagametophytes. By directly comparing nucleotide sequences between parent trees and megagametophytes, an average of 1.4 candidate DNMs per megagametophyte sample (range: 0-40) was identified after optimizing filtering procedures through validation via Sanger sequencing. Interestingly, no correlation was found between observed mutations and ambient dose rates or the concentration of ^{137}Cs in cedar branches of the mother trees within the growth areas. Moreover, our findings suggest that mutation rates vary among genetic lineages and are influenced by the growing environment. Remarkably, the results indicate that the germplasm of Japanese cedar trees growing in contaminated areas did not exhibit a significant increase in mutation frequencies. These findings emphasize the complex nature of genetic responses to low-dose-rate radiation and underscore the importance of considering both species-specific differences and environmental factors.

Phytoremediation of heavy metal polluted gold mining sites

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: Mining is a key economic activity in Kenya, contributing 1% of the country's GDP and 2% of export earnings. Since it is largely artisanal, it is a major source of pollution in which associated heavy metals end up contaminating the top soil and surface water resources. We assessed heavy metal contamination levels in Macalder, a major artisanal gold mining site in western Kenya. The concentration of lead (3,773 ppm), chromium (1,093 ppm), zinc (4,443 ppm) and Arsenic (3,363 ppm) were significantly higher than WHO recommended levels (Pb – 300 ppm), (Cr-1,500 ppm), (Zn-100 ppm) and (As-10 ppm). Following a survey of naturally growing plant species in the area, we tested the phytoremediation potential of six woody species from the area for a period of 60 days. The species were *Albizia coriaria, Senna siamea, Ficus sur, Ficus benjamina, Jatropha curcas* and *Euphorbia tirucalli.* We added two bamboo species to the list, namely: *Bambusa vulgaris* and *Bambusa blumeana*. There were three treatments for this assessment: highly contaminated soils, moderately contaminated soils and pure sand, which served as a control. The results indicated that all the species were able to grow in the pure sand throughout the period of 60 days. *Albizia*, *Senna*, and *Jatropha* could not grow in both highly contaminated and moderately contaminated soils beyond the first 7 days. *Ficus* was able to grow in the moderately contaminated soil for the 60 days, but did not manage more than 7 days in the highly contaminated soil. The two bamboo species managed to grow in all the soils for the 60 day period. This experiment is proceeding to the stage of analyzing the concentration level of heavy metals in the tissues of the woody species that were able to grow in the contaminated soils. The results suggest, however, that not all plant species that grow in heavy metal contaminated soils have the capacity to support phytoremediation of such sites. The expectation of the study is to end up with plants species with the capacity to not only grow in the contaminated soils but also mop up the heavy metals.

Radioactive contamination and radiation protection in Fukushima forests

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: After the Fukushima Daiichi Nuclear Power Plant accident, which resulted in a Level 7 nuclear disaster, the Japanese government promptly established regulatory limits in various fields. It put in place measures to protect people against radiation exposure to radioactive materials released into the environment. Most of the regulatory limits were established within one year of the accident, and restrictions on food distribution and access to forests are still in place. In this study, we estimated the additional exposure dose due to the nuclear accident based on the long-term monitoring data conducted in the forests, and discuss the optimized countermeasures to be taken in the event of a nuclear disaster. Air dose rates related to external exposure in forests sometimes changed significantly depending on the forest type during the first year or two after the accident; however, they continued to decline at a constant rate generally according to the rate of radioactive decay over a long period in most forests. Therefore, external exposure associated with forest activities can be accurately estimated based on the air dose rate and time spent. Internal exposure, on the other hand, was mainly caused by ingesting wild edible forest products with high radiation levels, but the standard limit of 100 Bq/kg of radiocesium applied to general food products keeping those products from the market makes the exposure risk extremely low. It should be noted, however, that eating large quantities of wild animals, wild vegetables, and mushrooms for private consumption in mountain village areas could be a potential internal exposure risk. Most measures taken against radioactive materials after the nuclear power plant accident have focused on specific activities of forestry workers and mountain village inhabitants. As a result, the concept of monitoring and controlling total annual exposure doses, considering both external and internal exposure, has not been widely adopted. Now that the contamination situation has settled down, it would be a lesson to make the most of the severe nuclear accident by reviewing more than ten years of monitoring data and considering preparedness for future accidents from the perspective of optimizing radiation protection of people.

RADIOECOLOGY OF PALM FOREST

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society
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Abstract: Palm forests, also known as palm groves or palm plantations, cover large areas in tropical and sub-tropical regions. There are often other vegetation types present, such as undergrowth plants, shrubs, and vines. These forests provide habitats for a wide array of animals, including birds, insects, reptiles, and mammals. Palm forests are economically significant in many regions. Palm trees produce valuable resources such as coconuts, palm oil, dates, and palm wine, which have various commercial applications. Palm oil, in particular, is extensively used in food products, cosmetics, and biodiesel production. With global warming the role of palm trees as a source of various product could grow.

With the development of nuclear energy in countries with an arid climate, there is a need to analyze possible emergency situations and their consequences, including identifying ways of food contamination with radionuclides and their spread through the food chain. Since palm trees play an important role in the nutrition of the population of countries with an arid climate, experiments were carried out at the Khalifa University of Abu Dhabi to determine the coefficients of transfer of radionuclides from soil to palm fruits, leaves, and bark. These experiments represent the first step in preparing a radioecological base, and the results will be presented.

Redistribution of the soil 137Cs inventory through litter and sediment transport on a hillslope covered by deciduous forest in Fukushima, Japan

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: The long-term behavior of radiocesium (^{137}Cs) activity concentrations in forest ecosystems and their downstream impacts remain important issues in the deciduous broadleaf forests of Fukushima, Japan following the Fukushima Daiichi Nuclear Power Plant accident. To predict ^{137}Cs cycling and discharge in the forest ecosystem, it is important to understand the spatial dynamics of the ^{137}Cs inventory and transport along hillslopes. Therefore, we observed the spatial distribution of the ^{137}Cs inventory and ^{137}Cs transport via sediment and litter of a deciduous forest hillslope in Fukushima, Japan in 2016 and 2017 and examined how the spatial distribution of ^{137}Cs inventory was formed using a mass balance model. In 2017, the ^{137}Cs activity concentration was significantly greater in the downslope riparian area (455 kBq/m^2) than in the upslope ridge area (179 kBq/m^2). Annual ^{137}Cs transport within litter and sediment contributed < 0.5% to the current ^{137}Cs inventory, and cannot explain the current spatial variation of ^{137}Cs inventory on the hillslope. The mass balance model results showed that if the initial ^{137}Cs deposition was distributed uniformly in 2011, the spatial distribution of the hillslope ^{137}Cs inventory was influenced mainly by the movement of leaf litter with a high ^{137}Cs activity concentration.

Releases of 137Cs and 210Po by combustion of boreal peat and forest soil samples contaminated by Chornobyl fallouts

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: After the Chernobyl accident in 1986, the environment of the region of Gävle, Sweden (about 150 km North of Stockholm) was contaminated by radioactive fallouts. With a warming climate, an increasing number of wildfires in such a boreal environment is expected. A forest fire event would result in the redistribution of man-made and natural radionuclides like ^{137}Cs and ^{210}Po in the local environment as aerosols or ashes with potential negative effects on human health. Samples of forest litter, soil, peatbog litter and peat were collected on two sites of this contaminated area. The samples were dried and combusted in a small-scale experimental set-up to investigate the fire-induced resuspension of radionuclides. The samples were combusted at different temperatures and oxygen concentrations to simulate flaming and smouldering conditions. Aerosol fractions of various particle sizes were collected on filters using an impactor system and the remaining ashes were also recovered for measurement by radiometric techniques.

Gamma spectroscopy measurements showed that an average of 71% of the combusted samples ^{137}Cs 71% remained in the ashes after the combustion. The influence of the oxygen concentration was also investigated. Calculations based on the measured activity indicate that up to 7 TBq of ^{137}Cs could be released from the peat and soil by a wildfire in this contaminated region of about 100 km^2. Measurable amounts of ^{210}Po were also observed by direct alpha spectroscopy measurement of filters recovered from the impactor containing the smallest fraction of aerosol (> 0.2 µm) which corresponds to the breathable fraction. The highest values were observed in filters of combusted forest soils which could be explained by a higher fraction of inorganic materials.

More research is currently ongoing currently in Sweden to obtain experimental results in the field using the opportunity of prescribed burns to estimate the radionuclide redistribution in boreal forests. The comparison of field and laboratory combustions will allow to assess the performances of the laboratory-based approach.

Seasonal change of concentrations of radioactive cesium and various elements in leaves of Chengiopanax sciadophylloides grown in Fukushima, Japan

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: *Chengiopanax sciadophylloides* is a woody species for the utilization of mountain vegetables in Japan. After the Fukushima nuclear disaster in 2011, a higher accumulation of radioactive cesium (Cs-137) within the plants of *C. sciadophylloides* were shown. Concentrations of Cs-137 in leaves of general woody species decreased gradually year after year; however, *C. sciadophylloides* was not decreased. Moreover, although the concentration of Cs-137 of *Quercus serrata* showed a seasonal pattern of the highest value in early spring and then decreasing gradually, the trend of C. sciadophylloides were unrevealed. The objective of this study is to elucidate the seasonal absorption pattern of Cs-137 concentrations and other elements in leaves of *C. sciadophylloides*.

Four study sites were set in Tamura City, Fukushima Prefecture, where many *C. sciadophylloides* were distributed. Based on the preliminary research, concentrations of Cs-137 were different along the slope position and accumulated more at upper slopes. We established the sites on the upper, middle, and lower positions of the slopes, and five individuals (over 3 m) of *C. sciadophylloides* were selected. From the survey in 2021, leaves of *C. sciadophylloides* were collected from the flushing to the defoliation seasons and analyzed Cs-137 and various elements.

The Cs-137 concentrations in leaves of *C. sciadophylloides* were the highest in April, especially in the upper slopes. The Cs-137 concentrations decreased in the samples after June, but a further decrease was not observed in the samples from November 1st, when the yellow leaves were just before defoliation. In addition, the concentration of stable isotope of cesium (Cs-133) showed a similar tendency. Similarly, the concentration of potassium (K), which is an alkali metal like Cs, was the highest in the sample in April and decreased in the samples after June. The value of the concentration of K in April was quite high (over 1500 $\mu mol\ g^{-1}$) compared with other plant species. Therefore, Cs and K may have similar mechanisms of absorption, and the active uptake of K may be concerned with the co-uptake of Cs-137.

Sensitivity to gamma radiation of Scots pine seedlings grown from seeds developed under elevated levels of ionising radiation

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: The Chernobyl Nuclear Power plant (ChNPP) accident in 1986 resulted in extreme levels of ionising radiation resulting in massive death of Scots pine (*Pinus sylvestris*) trees in the "Red forest" area and damage to trees in surrounding areas. The gamma and beta radiation in the Chernobyl exclusion zone have decreased by a factor of 300 and 100, respectively, but the radiation levels are still elevated and impact on Scots pine trees that were planted or regenerated naturally after the accident. The aim of the current work was to test whether elevated radiation during the seed development can possibly result in rapid adaptation or alternatively, increase the susceptibility of the progeny to radiation. Seeds were collected in 2019/20 from Scots pine trees growing in High (near Trench #22 of Red forest), Medium (near lake Glubokoye) and Low, background (Ivankiv forestry) level radiation sites. In the High and Medium radiation sites, the seeds received total dose rates of 48 and 10 $\mu Gy\ h^{-1}$, respectively. Six days old seedlings grown from these seeds were exposed under controlled conditions to 144 h of gamma radiation from a ^{60}Co source, with dose rates ranging from 1-100 $mGy\ h^{-1}$, followed by assessment of DNA damage (COMET assay), phenotyping and analyses of expression of cell cycle- and DNA damage repair genes. Interestingly, at $\geq$ 40 $mGy\ h^{-1}$ there was significantly less DNA damage in the seedlings from seeds from the High and Medium radiation sites as compared to those from the low radiation site seeds. All seedlings showed gamma dose rate-dependent growth inhibition but no significant phenotypic differences between seedlings from the different seed development sites were observed. Also, no significant effect of seed origin on expression of the cell cycle and DNA damage repair genes analysed so far has been found. Taken together, the results indicate lower radiosensitivity at the DNA level in seedlings from seeds developed at elevated radiation levels as compared to low radiation, but the consequences and background of the differences in DNA damage remain to be elucidated.

Soil-to-plant transfer of 40K, 238U and 232Th and radiological risk assessment of selected mining sites in Nigeria.

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: *One of the major route through which humans are exposed to ionizing radiation is via food chain, which is consequent of soil-to-plant transfer of radionuclides. This work reported the activity concentrations of ^{40}K, ^{238}U and ^{232}Th in samples of water, soil and guinea corn grains collected from Beryllium and Gold mining sites in Kwara, Nigeria. In-situ measurements at approximately 1 m in the air was carried out using a well-calibrated portable Gamma Spectrometer (Super Spec RS-125), while the soil, water and the guinea corn samples were analyzed using a '3 x 3' inch lead-shielded NaI (Tl) detector. The measured activity concentrations of the natural radionuclides in the soil from both mines are lower than the in-situ measurements. This was attributed to the contribution from other terrestrial materials on-site. The estimated mean transfer factors (TFs) for ^{40}K, ^{238}U and ^{232}Th are 0.21, 0.17 and 0.31, and 0.46, 0.19 and 0.28 respectively for the Beryllium and Gold mining sites. While the TFs for ^{238}U and ^{232}Th exceeds the mean value of 0.0062 and 0.0021 for ^{238}U and ^{232}Th respectively, the TFs for ^{40}K are well below the 0.74 for cereals grains provided by International Atomic Energy Agency (IAEA). The radiation impact assessment using the Monte Carlo simulations reveals values that were generally less than the global average values provided by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Hence, the risk of cancer inducement due to radiation exposure is within the acceptable limits for both mining sites.*

Ten-year monitoring of vertical distribution of radiocesium in Fukushima forest soils and tasks for future decades

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: The accident at Fukushima Dai-ichi Nuclear Power Plant resulted in the release of a large amount of radiocesium in March 2011, and forest areas were contaminated, especially in Fukushima, Japan. There is great concern about the long-term effects of ^{137}Cs remaining in forest ecosystems due to its long half-life (30 years). We have conducted continuous monitoring of forest soils (both organic and mineral soil horizons) at 10 plots with different ^{137}Cs deposition levels and dominant species, for up to 10 years after the accident. Here, we describe the temporal trends of ^{137}Cs inventories in each soil horizon, and statistically evaluate the phase shift of ^{137}Cs distribution in forests.

In the organic horizon, the ^{137}Cs inventories were exponentially decreasing at most plots. In the mineral soil horizon, most of ^{137}Cs remained in the surface layer of the mineral soil horizon (0–5 cm). In this layer, the inventories first increased and then became relatively constant. By applying several regression models for the temporal trends of ^{137}Cs inventories in this layer, the exponential offset model was selected at most plots, and we suggested entry into the "quasi-equilibrium steady-state", a relatively stable ^{137}Cs distribution in each forest compartment, over the observation period. Although we also observed exponentially increasing trends of ^{137}Cs in the lower layer (5–10 cm) of the mineral soil horizon, we concluded that the downward migration of ^{137}Cs is not significant in terms of the balance of the ^{137}Cs distribution in the entire mineral soil horizon.

Overall, most ^{137}Cs from the accident should be retained in the surface mineral soil horizon over future decades, and we should still pay attention to external exposure from ^{137}Cs radioactivity in this layer. This point is comparable to forests in Chernobyl, although climate and soil conditions were significantly different between Chernobyl and Fukushima. Meanwhile, we also observed significant spatial heterogeneity of ^{137}Cs inventories. We highlight the importance of plot- to subplot-scale (or smaller) environmental factors such as quality of organic matter in the forest floor as well as continuous multi-point investigations, to improve predictions of ^{137}Cs distribution in forests.

The effect of the suspension of potassium fertilization on the radiocesium uptake suppression by hinoki cypress

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: The effect of potassium fertilization on the suppression of radiocesium（^{137}Cs） root uptake by hinoki cypress seedlings, which were not directly contaminated, was continuously investigated in 2014 after the Fukushima accident. We reported at the IUFRO Brazil Congress that continuous fertilization was effective in suppressing ^{137}Cs uptake, based on investigations up to the third year（2017）, fertilization was suspended in half of the fertilized plots since 2017 and in all plots since 2021.

The study site is located in Kawauchi, Fukushima Prefecture with a deposition of ^{137}Cs of 360 kBq m^2 based on the third monitoring, and the soil type is Cambisol. We established eights plots of, 50×50 m in 2014; two were fertilized three times until 2016, two were fertilized seven times until 2020, and the remaining four were not fertilized as a control. Fertilization was started at 2014, and applied in spring before the start of tree growth at 100 kg K_2O (83 kg as K) per hectare with 60% KCl fertilizer ever year. Tree height and diameter were measured each year the end of tree growth, and needle leaf and soil samples were collected for analysis.

The exchangeable potassium content of the soil tended to be higher in the fertilized plots than in the unfertilized plots during the fertilization period, but decreased to pre-fertilization levels in the year following the suspension of fertilization. The concentration of ^{137}Cs in needles in the fertilized plots was significantly lower than in the unfertilized plots during the fertilization period, indicating an inhibition effect of absorption. The concentration of ^{137}Cs in the needles increased when fertilization was suspended, but the concentration of ^{137}Cs in 2022 was one-eighth and one-third of that without fertilization in the seven and the three times fertilization treatments, respectively. Similar results were obtained for the transfer factor.

It was concluded that the effect of ^{137}Cs uptake suppression continued even after the suspension of fertilizer application.

The importance of forests in the dose assessments of radioactive repositories the next 1000-100 000 years

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: In the safety assessment of Swedish geological waste repositories forest are assumed to be the dominating ecosystem above repositories during terrestrial periods. The main reason why forest was expected is that the present and future land area consists in large extent of glacial till unsuitable for agricultural land. In the timeframe of 100000 year it is assumed that the climate will temperate or warmer but still temperate. However, in this timeframe it cannot be excluded that cooler periods will occurs with a shift to a more boreal climate still forested. Even substantial cooler periods were analysed with periglacial and glacial periods partly submerged under the sea without forests.

The fate of hypothetical released radionuclides (e.g. C-14, Cl-36, Mo-93, Ni-59) from a repository were evaluated with a combined transport and exposure model (BioTEX). Even if forests dominate the landscape the major dose was obtained from mires that have accumulated radionuclides and then are drained for agriculture, because the discharges from a geological repository were simulated to be at low lying areas, i.e lakes and wetlands. The agriculture pathway also gave higher exposure because of the higher productivity potentially feeding a larger population in a concentrated area, while hunter and gatherers needed to scavenge larger areas for game, berries and mushrooms to be sustainable. This study also pinpointed that the interesting forest for dose assessment are on or close to wetlands, thus not the well-studied productive forests on tills.

Transfer of radiocesium through food webs in forest and river ecosystems

T1.14 Forest radioactive contamination: long-term dynamics and impact on ecosystem and society

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Abstract: The disastrous earthquake and subsequent tsunami on March 11, 2011, caused the Fukushima Daiichi Nuclear Power Plant to lose power and release enormous amounts of radionuclides. Of the variety of radionuclides deposited on land, ^{137}Cs is the most worrying radionuclide in the environment due to its relatively long half-life and bioavailability. The transfer of ^{137}Cs through the food web into the bodies of animals in Fukushima's forest and river ecosystems has been confirmed since the early post-accident period.

Although the transfer of ^{137}Cs through food webs focusing on either forest ecosystems or river ecosystems has been investigated, there are few examples of comprehensive investigations of these ecosystems connected by water systems. The objective of this study was to monitor the process of transfer and redeposition of ^{137}Cs accumulated in forest soils through the food web in the biocoenosis of forest and river ecosystems and to understand the amount and pathways of such transfer and redeposition.

We have collected various samples, including freshwater fish, insects, spiders, and plants in terrestrial and aquatic environments in three river basins (Ukedo River, Takase River, and Kuma River) in Fukushima Prefecture since 2020. Those river basins contained the evacuation zone.

We measured ^{137}Cs concentrations in the samples collected with germanium detectors and analyzed their feeding habitat using carbon and nitrogen stable isotope ratio analysis and DNA metabarcoding methods.

The detection of DNA from a variety of aquatic insects in the bodies of terrestrial predators suggests that insects that live in water as larvae have the ability to transport ^{137}Cs to the terrestrial food web. Carbon stable isotope ratios, an indicator of food resources, differed depending on the location of fish sampling (upstream or downstream) and fish species, and individual fish with stronger ties to the forest ecosystem via food webs tended to have higher amounts of radiocesium retained in their bodies.

The findings from this study will provide a more detailed understanding of the ^{137}Cs concentration characteristics of each species. It will be necessary to continue monitoring ecosystems in order to understand the dynamics of ^{137}Cs accurately.

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

Biological legacies as nature-based solutions to maintain protective effects in alpine mountain forests

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Protective forests play a fundamental role in mountain areas. Natural disturbances are affecting their stability and the provision of essential ecosystem services. Assessing the residual protection provided by biological legacies and forest recovery dynamics in the context of climate change is thus of extreme relevance.

A multiscale approach, from tree to landscape, adopting different techniques and data sources (field, lidar, satellite and UAV data) is implemented in this research. The aim of this study is a better understanding of the influence, potentials and actual service-life of natural disturbance legacies in protective forests against rockfall and a better knowledge towards a more ecological and effective post-disturbance forest management. The study areas are located in the North-East of Italy, which was severely affected by storm Vaia in October 2018, that caused large windthrows.

5 Years after the event, field investigations are being carried out to asses the decay status of the existing deadwood under specified conditions (altitude, species, soil). This includes applying sensors for a long term-monitoring of moisture, water content of the logs and soil, climate data, sampling of the dry-matter content and the decay status of deadwood. The final goal of this research is the enrichment of scientific data about decay-conditions, towards well-founded, practice-oriented knowledge of the “service-lifetime” of biological legacies after a disturbance event in protective forests.

Contrasting impacts of climate change on protective functions in mountain forests of the Alps

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Protection forests play a key role in protecting settlements, people, and infrastructures from gravitational hazards such as rockfalls and avalanches in mountain areas. Rapid climate change is challenging the role of protection forests by altering their dynamics, structure, and composition. Information on local- and regional-scale impacts of climate change on protection forests are critical for planning adaptations in forest management.

We used a model of forest dynamics (ForClim) to project the future development of mountain forests in the Eastern Italian Alps and their capacity of protecting against gravitational hazards, namely rockfall and avalanches. We investigated eleven representative forests along an elevational gradient (950-2000 m a.s.l.) and locations covering wide differences in tree species structure, composition, and site exposition under multiple climate change projections and current management scenarios. In additon to assessing future changes in forest structure and composition, we evaluated protective performance using protection indices.

Our findings showed that climate warming had a contrasting impact on the montane and subalpine forests. Forests in lower-montane elevations with a mild to warm climate and those located in dry continental valleys showed drastic negative changes in forest structure and composition, triggered by drought-induced mortality and maladaptation of current tree species to future climatic conditions. Subalpine forest, instead, profited from rising temperatures and longer vegetation periods with an increase in forest growth. However, impacts were highly contingent to the magnitude of climate warming, with increasing criticality under the most severe climate projections. Increased warming and drought-stress also impacted the protective functions of forests, decreasing rockfall and avalanche protection indexes for montane sites while increasing them for subalpine forests. In some cases, the most severe climate change scenario induced a complete loss of the ability of the forest to protect against gravitational hazards.

Forest management strategies require prompt adaptations to counteract the effects of climate change if protective functions are to be maintained in mountain forests of the Alps. Given the contrasting impact of climate warming, silvicultural planningt can be aided by model-based projections and local-scale assessments.

Detection and management of degraded forests to preserve protective functions: a transnational case study from European Western Alps

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Since the last few decades, in the European Alps global change has posed a severe threat to the functionality of mountain ecosystems due to an increase in the frequency and intensity of natural hazards. Furthermore, conflicting trends of depopulation of marginal areas on the one hand and mass tourism on the other pose new problems of spatial planning and management. In this context, sustainable management of mountain forests appears as a 'wicked problem', due to the multiplicity of conflicting interests that involves. Forests, due to the services they provide, are an essential element for the liveability of mountain territories: nonetheless, their slow natural dynamics can result insufficient to cope with the speed with which the climate crisis effects are manifesting themselves.

In this context, ALCOTRA project 'SylvAFoRes' (Adaptive Forestry for a Resilient Forest) promotes an approach of analysis, planning and management that increases the resilience of forests to climate change in order to ensure the provision of ecosystem services to society. The study area covers around 2100 km^2 between Italy and France (respectively in Susa and Durance valleys), in a mountain environment inhabited by more than 45 000 people.

Through a transnational approach, the project focuses on the identification of stands exposed to degradation and on their interactions with those natural hazards that increase the vulnerability of fundamental ecosystem services (protection, production, biodiversity, tourism). Early detection of degraded forests has been achieved through the application of a protocol (FORDEAD) based on open-source satellite images, which has been validated for mountain forests. Afterwards, their development trends were monitored and considered in the light of possible interactions with fire and other hazards (e.g. avalanches). From the results of the analysis, areas at greater risk of loss of functionality have been identified. Subsequently, adaptive and climate-smart silvicultural treatments will be defined and tested in several pilot forestry sites in order to slow down or prevent the degradation process.

Therefore, the results of this project will provide practical tools and experiences to replicate innovative silvicultural solutions in other mountain areas, minimizing the drawbacks of global change.

Ecology of Protective Forests

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Forests, as the main body of terrestrial ecosystems and important natural resources, play a vital role in maintaining the earth's ecological balance. All forests have certain protective functions, e.g., water and soil conservation, preventing wind erosion, stabilizing mobile dunes, and carbon sequestration. However, with the development of human society, forests have been severely damaged, destroying the ecological balance of nature. To meet the needs of protective functions due to the reduction of forest resources, protective forests, whose basic management purpose is to provide protective functions, have been planned or planted in ecologically fragile areas or areas with natural hazards or adverse climates. Protective forests, including natural and plantation forests, can be divided into shelterbelts and non-belt forests according to their shapes. The final goal of constructing and managing protective forests is to ensure efficient, stable, and sustainable ecological protection functions. From an ecology perspective, protective forest programs no longer take a single “protective forest” but a “protective forest ecosystem” as the main body. Therefore, developing the “Ecology of Protective Forests” discipline is necessary.

For natural protective forests, it should be regionalized based on the principles of dominant protection functions. However, in the ecologically fragile areas that need to be afforestation, it involves site classification, planning, and design of planted protective forests. Protective forest management should follow ecological principles to ensure the protective functions efficiently and continuously over a long time, which include the theory of protective maturity and phase-directional management, structures optimization and configuration, renewal, and mechanism underlying decline and restoration. As a bridge between the construction and management of protective forests, the assessment of protective forests can be applied to evaluate the protective forests in time to determine the degrees of protection function, identify the problems existing in the processes of construction and management, and provide feedback to the construction and management, respectively. Consequently, this can ensure the final goal of protective forest construction. Based on over 30 years of systematic research, the disciplinary frameworks of Ecology of Protective Forests have been established, including the theories and technologies of construction/regionalization, operation/management, and ecological service function assessment of protective forest.

Exploring the Influence of Vegetation Dynamics on Soil Erosion, Flood Peaks, and Landscape Dynamics in Alpine Watersheds under Climate Change

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Alpine watersheds are complex and highly engineered systems designed to mitigate flooding and debris flow risks, safeguard downstream areas, and support arable land. However, these engineered solutions often come with significant financial costs and environmental challenges. This study proposes a novel approach to investigate the influence of vegetation dynamics on soil erosion, flood peaks, and subsequent landscape dynamics in alpine watersheds, with the aim of identifying less engineered options that can yield effective results.

To achieve this, we developed an integrated modeling framework that combines a dynamic vegetation model (LandClim), the Revised Universal Soil Loss Equation (RUSLE) for soil erosion estimation, and the landscape evolution model HAIL-CAESAR. By employing this comprehensive framework, we simulated and analyzed the effects of climate change and vegetation dynamics on sediment transport and landscape evolution processes.

Our findings suggest that landcover changes have significant effects on the sediment cascade within alpine watersheds. Through simulations and scenario analyses, we observed that alterations in vegetation patterns can influence the magnitude and distribution of sediment transport, thereby impacting soil erosion rates and flood peak intensities. Additionally, considering the effects of climate change on vegetation dynamics, we found that shifts in species composition and growth patterns can further contribute to these effects.

Our results indicate that, by implementing appropriate management strategies, less engineered options have the potential to yield favorable outcomes in terms of flood mitigation and soil conservation in alpine watersheds. By recognizing the potential of natural processes and incorporating ecological considerations into watershed management, decision-makers can optimize resource allocation, reduce costs, and minimize the environmental footprint associated with conventional engineering solutions.

The implications of our research underscore the importance of considering vegetation dynamics and the impacts of climate change in the planning and implementation of strategies for alpine watershed management. By adopting a holistic perspective that integrates ecological factors, decision-makers can develop sustainable management approaches that aim to balance flood risk reduction, soil conservation, and the preservation of natural systems. While our study provides valuable insights,

further evaluation and cautious interpretation of the results are necessary to refine our understanding of the complex interactions within alpine watersheds.

Forest-based solutions for reconciling natural hazard reduction with biodiversity benefits

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Nature-based solutions (NbS) offer a way to preserve, restore and manage ecosystems to meet today's societal challenges by combining benefits for society and biodiversity. They incorporate natural features and processes into projects to ensure their sustainable development while investing in the integrity of ecosystems. Forests can be a good solution to achieve this goal. "Forest-based solutions" (FbS) can then be identified as NbS using forests for providing both human well-being and biodiversity benefits. In this paper, we intend to consider FbS as solutions reconciling natural hazard control with biodiversity benefits, and especially highlight the practice and research needs in this field. FbS correspond specifically herein to forests used or managed for mitigating natural hazard linked to gravity (rockfalls and avalanches) or to water (floods and drought), while preserving, restoring or managing biodiversity. Firstly, we review the definition and development of FbS applied to natural hazard reduction, while stressing issues concerning the design, implementation, and monitoring of these kinds of actions. Secondly, we point out the need to combine natural hazard control with restoration, preservation and management of ecosystems, by posing novel practice and research questions.

Impacts of climate change on the mechanical properties of standing trees

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: The role of forest stands in reducing natural gravity hazards has been studied for several decades and at different scales ranging from the tree to the role of the forest cover on a complete territory. At the tree level, previous studies have focused solely on the mechanical response of the trunk during an impact.

A non-destructive protocol called "Pull-Release" test has been developed to measure the mechanical properties of the different compartments of a standing tree (roots, trunk and crown). This experimentation opens new fields of research both on the role of the anchorage on the stability of the tree but also on the complete response of a standing tree to the mechanical solicitations related to various hazards. Moreover, it could allow to evaluate the effect of different types of natural disturbances (fire, pest attacks, droughts...), whose frequency and intensity should increase with climate change, on the protection capacity of a tree.

This protocol was applied on different standing trees of healthy forest stands located on an altitudinal gradient in the French Alps and on trees having undergone a disturbance (mainly fire). Seasonal variations of mechanical properties were also analyzed.

The presentation will describe the protocol used, the results of the first year of measurements and the first conclusions to account for in the management of protective forests under a changing climate.

Improving the prediction of forest wind disturbances in the alpine region by remote sensed data

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Windstorms are natural disturbances that are expected to increase both in frequency and magnitude as a consequence of climate change. In the Alps, windstorms are responsible for severe damage to forest stands, which in many areas provide fundamental protection against natural hazards. Therefore, the assessment of the vulnerability of forests toward windstorms is fundamental in the alpine region to improve forest management and avoid future losses. Different models are present in the literature assessing the critical wind speed (CWS) of a certain forest stand. However, one of the main issues in their application at a wide scale concerns the creation of the input data both in terms of stand characteristics and species-specific parameters. In this study we address such a gap in knowledge (i) developing an algorithm to derive single trees and stand characteristics from LiDAR data and (ii) improving the species-specific parameters for the most widespread forest species of the alpine region. We take advantage of one the most advanced models ForestGALES (implemented in the R environment, so-called fgr). The developed algorithm (written in the R environment) calculates the tree characteristics (height, DBH, crown radius) to create an input database for the fgr model. The stand characteristics of distance to any gap and gap size are automatically derived at a resolution of 20x20m while stem density and dominant height are calculated at the same resolution but using a moving window either of 3x3 or 5x5. Such values are associated with the tree input database (based on the tree location) and the CWSs are directly computed through the fgr model. The species-specific parameters of the most common forest species for the alpine region are derived from literature and specific tree pulling experiments, improving the representativeness of the investigated forest. The procedure has been applied in the Alto Agordino area (IT), showing promising results. The developed methodology can substantially advance the usability and accuracy of forest wind susceptibility since it requires as input the canopy height model and the species distribution. Therefore, practitioners can enhance forest management by increasing the resistance of protective forests against future windstorms.

Knowledge transfer through power strategies: the example of two EU projects on ecosystem-based and climate-adapted natural hazard management

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: In the efforts to maintain and improve the protective effect of alpine mountain forests against natural hazard risks for people and objects, current research results can make a decisive contribution to a risk-based and climate-adaptive protective forest management. However, the promotion and development of innovations through applied research programmes, such as the EU Alpine Space Programme, is not yet a guarantee for a successful implementation of ecosystem-based and climate-adaptive risk management of natural hazards in practice. Rather, the practical impact of such EU projects is low, as the implementation of research results by policymakers and practitioners fails due to the interests of the actors. To integrate such results more successfully into practice, the study aims to identify additional factors of knowledge transfer beyond participation and communication of scientific information, which the transdisciplinary approach of EU research programmes places at the centre of its selection process and project implementation. In the study, the "Research-Integration-Utilisation" (RIU) model of knowledge transfer is applied in the EU Alpine Space projects "GreenRisk4Alps" and "MOSAIC", which elaborated innovative eco-system-based and climate-adaptive natural hazard management strategies. The RIU model assumes that scientific information must be actively taken up by practitioners or policy actors and integrated into their practice, which is done in "integration forums" by interest driven actors within power networks. Within the study a mix of qualitative and quantitative methods were applied to identify additional success factors of knowledge transfer. The study examines whether the project proposal formulated in the EU Alpine Space Programme contains links to the interests and power of actors. Our results show that the transdisciplinary model of knowledge transfer in the Alpine Space Programme ignores the selection processes of scientific results by powerful actors and thus disregards highly relevant factors for the transfer of scientific knowledge. The effective use of these factors is possible in the identified and described integration forums. Based on robust data, these offer a solid foundation for the design of knowledge transfer processes by selecting the most promising integration forums. The likelihood of application of research results from EU or other research fundings could thus be significantly increased.

Long-term monitoring in the forested headwater catchment Rindbach, Austria, as a basis for an integrated natural hazard management.

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: As part of an action program launched by the Austrian federal government that specifically addresses challenges regarding protective forests, a case study has been established in the Rindbach watershed near Ebensee (Upper Austria) for long term monitoring, research and training. This torrential-model catchment will serve as a natural laboratory and as a training area for practical courses with a long-term perspective (>30 years). It is managed and organized in close cooperation with the Austrian Protective Forest Hub (https://www.protective-forest.at/protectiveforesthub.html), which serves as a competence center for nationwide coordination, exchange of information and knowledge transfer, bringing together various interest groups. The main objective of the experimental catchment Rindbach is to gain understanding about geological, hydrological, hydraulic, forestry and engineering interrelationships under natural conditions. For this purpose, also two meteorological as well as a water level and discharge measuring stations were set up in the catchment area.

Within a three-year pilot project funded by the Austrian Waldfonds (https://www.waldfonds.at/), necessary baseline data are gathered by an interdisciplinary team of scientists. The compiled data includes information on geology and hydrogeology, soil and site conditions, hydrological conditions, natural hazard processes, forest conditions and dynamics as well as technical infrastructures. In addition to the provision of all collected data, the project will further conduct "best-practice" models and first order simulations of the above-mentioned interrelationships to maintain the protection function of the forests besides other ecosystem services. The final data collection will enable comprehensive analyses of future challenges in forested catchments, for example due to climate and/or land use changes, characterised by increase in the frequency of critical precipitation events, occurrence of natural disturbances (e.g. windthrow, bark beetle infestations), influence of forest and

game management, changes in sediment availability as well as changes in the soil water balance, nutrient supply and carbon sequestration.

Maintaining the protective function of mountain forests under climate change by the concept of naturalness in tree species composition

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: In Swiss mountain areas, the protective function of forests is the predominant ecosystem service having high cultural and economic significance. It is assumed that natural forests or close-to-natural forests, i.e. forests being in the equilibrium with environmental conditions are the most resilient and resistant in regard to disturbances and hence best protecting people and assets on the long run. Here, we estimated the naturalness of the tree species composition by comparing Swiss National Forest Inventory (NFI) data with current and future potential Natural forest Site Types (NST). Based on this analysis, we identified species that are under or over-represented in protective mountain forests and derived the subsequent potential for management interventions. The urgency of management interventions is expected to be small if all predominant tree species of the idealized potential natural forests are present and only their relative portions in the stand need adjustment. In contrast, interventions are advisable, if predominant tree species of the current and future potential natural forests are absent. Based on NFI data, the tree species composition of 47% of the protective mountain forests were classified as 'natural' or 'close-to-natural', while the remaining 53% were classified as 'not natural' or 'partly natural'. Norway spruce (*Picea abies* (L.) H. Karst.) and European larch (*Larix decidua* Mill.) were the two most over-represented species under current and even more so under predicted future climatic conditions. To date, silver fir (*Abies alba* Mill.) and European beech (*Fagus sylvatica* L.) were the two species most frequently absent in protective mountain forests, in which they should prevail. Apart from European beech, the most prominent increase in prevalence is predicted for oak (sessile oak and pubescent oak; *Quercus petrea* Liebl., *Q. pubescens* Willd.) and small-leaved lime (*Tilia cordata* Mill.). These species were currently missing from more than 75% of the stands, in which they are expected to be dominant under future conditions. Our analysis indicates the need to transform tree species compositions of protective mountain forests to optimize fitness under future climates. Some of these transformations will take place naturally, incited by disturbances, others – the majority of them – will need active management interventions.

Mapping the natural disturbance risk to protective forests across the European Alps

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Mountain forests play an essential role in protecting people and infrastructure from natural hazards. However, forests in the European Alps are currently experiencing an increasing rate of natural disturbances (including windthrows, bark beetle outbreaks and forest fires) that may jeopardize their capacity to provide this ecosystem service in the future.
Here, we map the risk to forests' protective service across the Alps by integrating the risk components of hazard (in this case, the probability of natural disturbances), exposed values (current protective forests that protect people or infrastructure), and vulnerability (the probability that the forests' protective capacity is maintained or recovered after a disturbance).To map disturbance probability, we use satellite-based data on forest disturbances from 1986-2020 and fit an ensemble model predicting windthrow, bark beetle and fire occurrence based on topographic and climatic predictors. To assess forests' protective capacity, we analyze the recovery of key forest structural parameters (cover and height) over time after disturbance using spaceborne lidar (GEDI) data. Over 35 years after a disturbance, most forests maintain or recover sufficient cover and height for providing protection from natural hazards, but recovery is limited at warm, dry sites that are also particularly exposed to forest fires. Forest management interventions to reduce forest susceptibility and/or alternative protection measures should be prioritized in areas where disturbances are likely to occur, forest recovery is slow, and where people rely on forests for protection. Integrating information on disturbance probability, recovery, and demand for protection can thus help identify priority areas for risk reduction under an intensifying disturbance regime.

Planning with limited resources in mountain forests: Decision support for spatial prioritization of management activities under future uncertainties

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Mountain forest management is extremely important in Switzerland for providing protection against natural hazards and multiple other ecosystem services. Many mountain forests are however spruce-dominated and under high risk of large-scale, climate change-enhanced disturbances. Forest managers are thus challenged with allocating their limited resources (operational capacity) for an efficient management of mountain forests considering both their future protective function as well as their resistance and resilience. Because it is not possible to access an entire forest area within a planning period, a prioritization of forest areas with respect to the largest long-term management impact is urgently required.

We present a novel approach for prioritizing forest areas for management activities in mountain forests in a Swiss case study. We combine various spatial information on topography, truck accessibility of the forest road network, important areas for protection services, and new developed predisposition maps that indicate forest areas particularly vulnerable to disturbances (windthrow, bark beetle, and snow breakage). This information is used to automatically subdivide the case study into forest management units (FMU). FMUs represent spatially contiguous areas combining homogenous harvest operational aspects and management planning objectives. Based on current forest conditions and field measurements, mid-term management scenarios are defined for the main forest types. Further, the management impact is assessed on the harvestable timber amounts, the potential to mitigate disturbances and to reduce the risks for natural hazards. This allows an assessment of the potential long-term management benefits and costs of harvesting operational activities.

The gained information on benefits and economic consequences will provide a holistic assessment of management consequences on the level of each FMU. Based on cost-benefit relations a prioritization of the spatially defined FMUs will be possible for the next planning period (usually 10 years). Outcomes are aimed to support the order on how the FMUs should be accessed depending on the main management objective. Our hypothesis is that the largest long-term impacts on resistance and resilience will be achieved if management is targeted to promote mixed forests with a high structural diversity. However, this might cause trade-offs with economical management objectives.

Preserving the protective function of forests in Switzerland's high mountain regions: the crucial role of forest management

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: In densely populated mountain regions such as the European Alps, forests provide a fundamental protective function against multiple hazards such as snow avalanches and rockfall. However, climate change and natural disturbances pose a significant threat to the protective function of forests in these areas, as they often lead to decreased stand density and reduced stability. Forest management can play a crucial role in countering these challenges and enhancing forest resilience. By reducing the growing stock and promoting forest regeneration, forest management can bolster the ability of forests to maintain their long-term protective role against gravitational natural hazards.

In this contribution, we investigate the future effectiveness of forest protection in a mountainous area in the region of Davos, Switzerland, which is largely covered by Norway spruce and serves primarily as a protective function. To assess future forest dynamics, we utilize a dynamic process-based model at the landscape scale (LandClim), which is initialized with current climate data, forest structure data from stand maps and high-resolution remote sensing data. Forest structure data are derived using a representative stand type approach, where forest stands are populated with locally adapted individual tree datasets using a statistical method based on the fourth Swiss National Forest Inventory.

The model is run until 2080 under two climate change scenarios (moderate and strong), different disturbance regimes (windthrow, and bark beetle), and a suite of management scenarios, allowing tree species to migrate to potentially suitable areas. We compare two management scenarios (business as usual, and adaptation with a focus on increased resilience), defined together with local stakeholders. Additionally, we explore the impact of three levels of ungulate browsing pressure (low, medium, and high) on regeneration dynamics.

Our findings indicate that by the end of the 21st century, at these high elevations, Norway spruce will mostly persist and even expand to higher elevations, potentially maintaining the long-term protective effect against rockfall and avalanches. However, there will likely be increasing shares of deciduous tree species, especially in the valley bottom, suggesting the need for different management interventions at these locations

Prioritizing forest management under global change: a stakeholder-driven approach in spruce-dominated mountain forests in Switzerland

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: The vulnerability of mountain forests to natural disturbances is expected to rise with climate change along with increased disturbance frequency and severity. The damage caused to mountain protective forests may have negative repercussions on their ability to safeguard human lives and infrastructures. As resources for interventions are limited, prioritizing management interventions becomes crucial to anticipate and plan for potential disturbance and damage scenarios.

This study presents an approach developed together with stakeholders, aiming to provide guidance for management prioritization in spruce-dominated mountain forests under anticipated exacerbating disturbances (windthrow, snow breakage, and bark beetle) and natural hazards (snow avalanches and rockfall).

A comprehensive set of 20 spatial layers was generated to identify ‘hotspots’ for intervention for two regions in Switzerland (cantons of the Grisons and St. Gallen). Spanning approximately 1’600 km^2 (30 % forested), these layers encompassed high-resolution (10 x 10 m) forest structure parameters, and various site characteristics derived from airborne LiDAR data. The influence of each variable on each disturbance agent was weighted using the outcome of an expert survey, resulting in the assignment of predisposition values to each landscape pixel. These values were reclassified to predisposition classes and aggregated to spatially continuous disturbance predisposition maps. Map validation was conducted using stakeholder input, field forest stand data, and remote sensing disturbance data. Additionally, avalanche and rockfall models were employed to simulate large-scale hazard scenarios considering different forest covers, including disturbed forests derived from the predisposition maps. This allowed to assess the impact of disturbances on hazard potential. The simulation results were combined with data on economical and individual damage potential to perform a quantitative risk assessment at the building level.

Such predisposition maps may serve as an input to cost/benefit analyses to formulate and prioritize management actions. The expert-driven approach presented in this study serves as a model for the effective integration of research and practice, ultimately enhancing the resilience of mountain forests in the face of global change.

Quantifying drought conditions in Swiss protective forests based on 40-years inventory and satellite data

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Mountain areas are one of the many regions that are strongly impacted by climate change, leading to growing concerns about increasing frequencies and intensities of natural hazards. Thanks to the presence of forests, risks emanating from these can be avoided or reduced to an acceptable level. However, these so-called protective forests are themselves affected by climate change as well due to the intensification of disturbances such as droughts, windstorms, and bark beetle infestations. Consequently, critical changes in their protective effect are to be expected. To maintain forest resistance and resilience for the mitigation of natural hazards, forest acclimation to new and fast changing climatic conditions is the cornerstone for a successful hazard management strategy. The capacity of a forest to acclimate are determined by prior climatic regime as well as by forest dynamics legacies and related to site conditions, forest structure and species composition. In this study, we aim at characterizing the past and current status of protective forests in Switzerland in response to drought episodes by studying time-series from 1984 to 2022 of forest structure and climate parameters. Two main hypotheses will be tested: (1) relationships between forest structure and drought indicators differ with stand elevation and forest composition, (2) forests in higher elevation have been exposed to less intense drought episodes in the past and result in greater sensitivity to recent drought episodes.

Historical climatic conditions, field data from the Swiss National Forest Inventory (NFI) and forest indicators assessed by satellite data (Landsat and Sentinel) will be used to compute climatic drought indicators, forest drought tolerance proxies and forest structural parameters related to the protective effect (*i.e.* dominant species, basal area, stem density, mortality rate).

Based on observations, we will classify forest stands as acclimated and non-acclimated to drought episodes in mountain areas. Quantification of the drought legacy effect on forest structure and composition will bring insights about protective forest dynamics and their potential development in the future. Furthermore, the analysis will help identifying forest areas requiring active management to sustain their protective effect against natural hazards, visualized using maps that provide support to forest management practitioners.

Towards improved early detection of bark beetle infestations in Swiss mountain forests

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: The European spruce bark beetle (*Ips typographus*) has wreaked havoc on European forests in recent years, also thanks to the dry and warm conditions that have prevailed. These outbreaks have caused significant damage to large portions of Norway spruce forests. Rising temperatures and increasing drought frequency cause an accelerated development of *Ips typographus* while also increasing the susceptibility of spruce trees to bark beetle attacks. Consequently, spruce forests are becoming more vulnerable, raising concerns about their protective function against natural hazards, and other ecosystem services. Given these circumstances, timely planning and effective implementation of control and adaptation measures become paramount. To assist stakeholders with their responsibilities, the development of robust methods for the early detection of both vulnerable and infested trees is essential.

To address this challenge, the earlyBEETLE project focuses on improving the early detection of bark beetle damage in mountain spruce forests in the canton of the Grisons in Switzerland. The project aims to (i) Conduct a retrospective analysis and interpretation of spatio-temporal bark beetle infestations using tree rings and remote sensing; (ii) Identify suitable indices, utilizing remote sensing and field data, for the early detection of bark beetle infestations; (iii) Develop an ad-hoc database to optimize the long-term monitoring of bark beetle infestations; (iv) Evaluate and optimize management interventions and determine the most effective timing for their implementation in six different study regions.

The project utilizes satellite data to identify past patterns of 'dead' pixels and detect potential correlations with various indices related to tree stress (e.g. NDVI). Additionally, drones equipped with multispectral cameras provide individual-tree resolution images. Field observations of forest characteristics (e.g. tree height, crown length, and health status) provide ground-truthing for satellite and drone data. Pheromone traps are regularly monitored to inform management decisions and determine the appropriate timing for drone flights. Real-time data on new infestations are collected and stored in the database, which is used to inform and validate remote sensing data.

In this contribution, we will present the latest findings of the project and discuss their relevance in the context of global change impacts on mountain protective forests.

Transpiration and water use sources of poplar protective forests with different ages in a semiarid sandy region of Northeast China

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Poplar (*Populus × xiaozhuanica*) protective forests play an important role in the prevention and control of desertification in semiarid sandy land of northern China, however, these protective forests with different ages frequently suffer dieback and mortality during extreme drought years with decline in groundwater level. Nevertheless, the transpiration and water use sources of poplar protective forests with different ages and their response to drought and decline in groundwater level remain unclear. Here, the seasonal variations in transpiration and water use sources of the 7– and 20–year–old poplar protective forests were determined based on the thermal dissipation and stable isotopes methods. Environmental variables were measured concurrently over two growing seasons. The results showed that transpiration per unit leaf area averaged 1.6 and 2.3 mm d^{-1} for the 7– and 20–year–old trees during the measurement period, whereas it was 1.5 and 1.9 mm d^{-1} for the transpiration per unit ground area (E_s), indicating that water use of protective forests increased with stand age. Sensitivity of E_s to climatic variables increased with stand age, but the E_s of 7–year–old protective forest was more sensitive to soil drought and decline in groundwater level compared with the 20–year–old protective forest. In addition, the canopy conductance significantly increased with stand age, but the sensitivity of canopy conductance to vapor pressure deficit was sensitive to soil drought for the 7–year–old poplar protective forest, indicating a decrease in hydraulic conductance. Furthermore, the 7– and 20–year–old trees switched water sources from 0–100 cm soil layer and groundwater in spring to 0–200 cm soil water and groundwater in summer as the soil moisture and groundwater level decreased, but the contribution of groundwater to transpiration decreased from 47% to 32.3% and from 39.6% to 37% for 7– and 20–year–old protective forest, respectively. These findings indicated that decline in groundwater level reduced the contribution of groundwater to transpiration for 7–year–old poplar protective forest, and thus exacerbated the negative effect of soil drought on transpiration compared with the 20–year–old poplar protective forest.

Trends in growth and intrinsic water use efficiency of Pinus sylvestris var. mongolica trees under a warming and drying climate in Northeast China

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Determination of the long-term trends in tree growth and physiological performance responding to a warming and drying climate is vital for protective forest vulnerability assessment and management. Here, tree growth and intrinsic water use efficiency (iWUE) of Mongolian pine (*Pinus sylvestris* var. *mongolica*) were investigated at Fujia (FJ), Zhanggutai (ZGT), Kulun (KL) and Wulanaodu (WLAD) sites with mean annual precipitation (MAP) of 554, 479, 410 and 305 mm in the Keerqin Sandy Land for the warming and drying period 1970–2019, respectively, using annually resolved tree-ring width and $\delta^{13}C$ data. Results showed that basal area increment gradually increased and then declined or maintain constant for all study sites, showing a higher growth rate at KL and FJ sites than those at sites with WLAD and ZGT sites. Tree growth was only sensitive to spring precipitation at ZGT and KL sites owing to low groundwater levels. The iWUE displayed a significant increase over time at all study sites, showing the highest extent of increase at the ZGT site. An increase in iWUE was due to increasing atmospheric CO_2 and drying influencing stomatal conductance and photosynthetic capacity at the FJ site, whereas it was because of warming and/or drying reinforcing stomatal closure at ZGT and KL sites. However, it was possibly associated with progressive nutrient limitation at the WLAD site because of the shallow groundwater level. Negative relationships between BAI and iWUE were observed for all study sites, except at the ZGT site. These findings indicated that increasing iWUE did not stimulate tree growth at all study sites, because the negative impacts of drying on tree growth have overridden the small positive influence of rising atmospheric CO_2 at the FJ site. However, it was likely that warming and/or drying reduced the stomatal conductance and thus decreased photosynthetic rates, limiting tree growth at ZGT and KL sites, whereas it may be due to progressive nutrient limitation reducing tree growth at the WLAD site. Therefore, the predicted warming and drying climate might have a more negative impact on Mongolian pine trees at sites with low groundwater levels than with high precipitation and/or shallow groundwater level.

Unveiling the Vulnerability of Tropical Montane Forests in the Face of the Climate Crisis

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Climate change has had a severe impact on the Philippine tropical montane forest ecosystem. However, limited studies have been conducted in the country on the vulnerability of these forests to the climate crisis. This paper assesses the vulnerability of the tropical montane forest of the Cordillera Region to projected climate change using geospatial techniques. Specifically, this study determines the forest areas in the region that are vulnerable to fires and landslides using open-source satellite imageries and remotely sensed datasets. The geospatial analysis reveals that approximately 116 thousand hectares or 8.5% of the forest in the region are prone to fires. The study notes an increasing trend of fire incidents and burned areas observed in both natural and plantation forests in the region. This trend could be linked to the region's rising temperatures and extended drought. In the next four decades, a projected rise in temperature of 1.9 to 2.1°C and a decrease in precipitation (-70.42 mm) during the dry season could result in more severe forest fires, larger burned areas, and longer fire durations. Furthermore, nearly 73% of the region's forests are vulnerable to landslides on a high to extremely high level. This vulnerability is reflected in the 182 landslides that occurred in the region between 2007 and 2018. The projected increase in precipitation (341.99 mm) during the wet season could further lead to an increase in landslides in the area in the near future. The output of this study could be used in the adaptation and mitigation plans, and risk reduction activities in the region. The findings of this study highlight the need for urgent action to prevent further forest degradation due to climate change. This study also underscores the importance of using geospatial techniques to identify areas that are most vulnerable to climate change and to develop targeted adaptation and mitigation strategies.

Where mountain forests meet the sea – simulating anthropogenic changes to protection forest function at northern latitudes.

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: Norway is defined by its fjordic landscape, with steep forested slopes rising out of the sea. Due to the northern latitude, snow is common to sea level and even low altitude forests (in absolute terms) provide many of the protective functions from gravitational mass movement normally associated with mountain forests. However, the concept of protection forest management is in its infancy in Norway, where instigating a suitable national policy is complicated by the current forest structure and ownership. Large areas of protection forest are even-aged spruce forests planted from the 1950s to restore the degraded natural forests. These forests represent a large national investment to create a timber resource that is due for harvest, though today they provide many services beyond this original intention. Notably, society and its associated infrastructure have developed both downhill of and within these forests in the 70 years since their creation. The logical solution of protecting the current and future society by setting aside large areas as protection forest is a real challenge because almost all of Norway's forests are under highly fragmented and small-scale private ownership. Through a lack of understanding, many owners or harvesting companies want to maximise their short-term economic gain and instigate large scale clearcutting, which has resulted in documented mass movement and high tensions between stakeholders.

We address a national requirement to compile knowledge in a common platform to understand the implications of forest management decisions with respect to underlying gravitational hazards and climate. We combined expertise on forest management & measurement, climate, hydrology, and gravitational mass movement to build a state-of-the-art simulation framework to quantify the effects of different forest management strategies on a given forest's protective function against gravitational mass movement.

In our scenario simulations, forest cover, climate and terrain characteristics can be manipulated to investigate changes in risk zones according to different management choices. We will demonstrate this in multiple case studies representing different levels of risk and convey the consequences of anthropogenic changes on disaster risk reduction.

Will current management practices ensure rockfall protection in mountain forests under climate change?

T1.15 Impacts of Global Change on Protective Forests in Mountain Areas

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Abstract: In many mountain regions, forests have an important role for protecting human infrastructure below slopes from rockfall damages. To this end, such forests need to sustainably fulfill certain requirements, e.g., in terms of the stem number distribution over stem diameter classes and stand basal area, both of which are required to dissipate the energy of falling rocks (so-called "target profiles"). Established management practices exist to date to achieve these target profiles. However, it is unclear whether forest management will need to be adapted to sustainably maintain the protective function of mountain forests in the future under climatic change conditions.

We anticipate that key parameters of current best practice forest management can be adjusted to maintain the protective function of mountain forests without having to introduce an alternative management regime. To test this based on many simulation scenarios, we apply the dynamic, individual-based forest model ForClim to representative stands at four elevational zones in the Swiss Alps. For each stand, we first determine a sustainable achievable stem number distribution and the corresponding stand basal area, and then optimize multiple model parameters considering different climate change assumptions (current climate, RCP 4.5, and RCP 8.5). By combining dynamic forest modeling with heuristic optimization, we implement a novel method of autonomous learning. We use Simulated Annealing to estimate the extent to which adjustments of management parameters (e.g., target diameter, harvested timber volume, and intervention cycle) may be required to achieve the target profiles under climate change. We discuss the trends for each stand as proposed by the optimizer. When comparing all simulation scenarios, preliminary results indicate that the recommended adjustments to management parameters exhibit heterogeneous trends depending on the elevation and severity of climate change. In order to sustainably maintain the protective function against rockfall, the management parameters must be subsequentially adjusted several times during a simulation period.

This method of autonomous learning provides forest practitioners with a useful decision support tool. It allows to test a wide range of silvicultural options in a non-destructive manner while considering environmental changes such as climate change at long-term.

T1.16 Implementing fire-resilient landscapes

A landscape-scale spatio-temporal forest treatment and wildfire scenario model for California

T1.16 Implementing fire-resilient landscapes

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Abstract: In 2020, the state of California signed a memorandum of understanding with the US Forest Service to increase the pace and scale of forest health and fire resilience treatments throughout the state. In order to achieve the goal of reducing the impacts of catastrophic wildfires, the entities agreed to a target of 1 million acres treated per year over twenty years, beginning in 2025. Determining how to allocate treatment acres in an equitable way across an incredibly diverse socio-ecological landscape requires an extensive cost-benefit analysis based on modeled treatment impacts on forest structure and composition, fuel loading, wildfire behavior, and benefits to communities.

We developed a methodology for modeling the effects of annual forest, shrubland, and rangeland treatments on vegetation growth and change over a 20-year period. The core set of modeled scenarios consisted of a combination of three variables: treatment intensity (the number of acres treated per year), treatment prioritization (where treatments were allocated on the landscape), and treatment type (how vegetation was impacted). These variables guided the development of 108 unique treatment scenarios. The treatment scenarios were developed regionally to account for varying fire management goals and objectives across the state.

We created a reproducible workflow in Google Earth Engine to allocate the treatments on the landscape for each scenario. Next, we transitioned the forested vegetation in 5-year timesteps using the Forest Vegetation Simulator (FVS), a growth and yield model. For non-forested vegetation, we used a Google Earth Engine workflow which transitions shrub and grass vegetation over time after disturbance based on vegetation characteristics, disturbance type, and disturbance severity. We then ran a spatially explicit, probabilistic fire behavior model across the state at 1, 10, and 20-year timesteps to evaluate the impacts of vegetation treatments over time on fire extent and severity.

To evaluate the effect of the varying forest and landscape management scenarios, we use a cost-benefits framework. We provide summaries of objectives met, impacts of varying treatment scenarios, and potential workforce and funding needs to meet fire resilience goals for the state of California.

Addressing policy coherence towards integrated wildfire risk management in the European Union

T1.16 Implementing fire-resilient landscapes

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Abstract: Although forming part of the natural ecosystem, wildfires are one of the most important threats to forest areas and adjacent values and communities. Even more so since wildfire risk (WFR) has been exacerbated across the world due to climate and land use changes, favouring more severe, damaging, and extreme wildfire events not only in traditional fire-prone areas but also in unprecedented territories, with different socioeconomic, ecological and political implications. Consequently, integrated approaches tackling the root causes related to fire spread capacity (hazard) as well as the creation of exposures and vulnerabilities become determinant. Beyond approaching wildfires as an emergency, WFR reduction needs to be integrated in all sectoral policies influencing risk "(de)construction" process, such as urban planning, bioeconomy, nature conservation, green energy or within the touristic sector.

In this context, the European Green Deal responds with policies and initiatives with objectives ranging from biodiversity conservation (e.g. EU Biodiversity Strategy for 2030) to the promotion of renewable energy (e.g. EU Renewable Energy Directive), the strengthening of the bio-based sector (EU Bioeconomy strategy) and much more, all directly or indirectly impacting forest ecosystems. Many of the policies framed under the Green Deal just vaguely mention wildfires. This can create incoherences between and within policies and strategies with respect to WFRM. Policies influence environmental and socio-economic dimensions, being able to transform a territory into a more wildfire resilient one if coherence exists or into a risk-prone one if there is incoherence.

This research identifies the landscape of policies and initiatives under the European Green Deal influencing WFR in terms of hazard, exposure and vulnerability trade-offs, and analyses up to what extend they are aligned in a (in)coherent way for wildfire disaster risk reduction. Results conclude that significant dysfunctions, but also potential synergies exist to move forward to integrated WFR management under a common policy frame supported by multi-stakeholders' risk governance bodies. Key aspects that could be approached in a more coherent way along and across the initiatives and policies analysed are suggested. Moreover, the method and results offer a general frame that may be downscaled from EU to national or regional level.

Assessing Fuel Moisture Codes Before and After Fire Events using Sentinel-1 SAR C-band imagery in the case of Mediterranean Forests

T1.16 Implementing fire-resilient landscapes

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Abstract: In fire-prone Mediterranean regions, fire danger is often estimated using meteorological factors using the Canadian Forest Fire Danger Rating system. The system's fuel moisture codes are interpolated from single-point weather data. Radar remote sensing is sensible to soil and vegetation moisture content and might be a valid tool for mapping the spatial distribution of fuel moisture over time. This study investigates the sensibility of Sentinel-1 C-band backscatter values to fuel moisture over a study area of about 500 km^2 in northwestern Portugal. The fuel moisture was parametrized with the Drought Code (DC) of the Canadian Forest Fire Danger Rating System. Sentinel-1 C-VV and C-VH backscatter values from 276 images acquired between January 2018 and December 2020 were assigned to five classes depending on the Drought Code (DC) over several unburned and burned sites with full (>90%) forest cover. Confounding variables such as tree cover and incidence angle were accounted for. C-VV and C-VH backscatter values are inversely correlated ($R^2 = 0.324$ to 0.438; $p<0.001$) with local incidence angle over canopies. Correlation is significantly stronger over very wet locations (DC class = 0 to 1). C-VV and C-VH backscatter values can discriminate wet to dry forest environments, but they are less sensitive to the transition between dry (DC classes=1 to 10, 10 to 100) and extremely dry environments (DC classes=100 to 1000). C-VH is more sensible than C-VV to catch burnt areas. The VH polarization captures post-fire vegetation recovery after an average minimum period of 360 days after the fire event, although with less distinction for extremely wet fuels.

Costs, Risks, Liability and Legal Architecture of Prescribed Burns in the United States: History and Trends for the Future

T1.16 Implementing fire-resilient landscapes

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Abstract: Prescribed burns are utilized in the United States to mitigate wildfire risk as well as to enhance wildlife habitat, control pests and diseases, and provide other benefits. These burns have costs of implementation as well as risks of damage to property or personal injury. A large portion of the benefits of prescribed burns accrue broadly to society, whereas the costs and risks of burns are borne by individuals. Both the risks and the benefits of prescribed burns have become more pronounced over time with increasing population, particularly within the wildland-urban interface, and growing wildfire severity due to climate change.

This oral presentation will discuss the history and evolving trends of costs, risks, liability, and legal architecture surrounding prescribed burns on private and public lands. We will discuss long-term social trends and other drivers of the policy debate and how this has impacted the incentive structure surrounding the decision about whether or not to burn. What are the continuing challenges and what policy structure would alleviate those barriers while enhancing social benefits?

Designing Fire Resilient Landscapes in South-west France

T1.16 Implementing fire-resilient landscapes

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Abstract: In July and August 2022 almost 30,000 ha of forest were burnt in three fires in Les Landes de Gasgone Forest in south-west France. These were the largest forest fires in the area since August 1949 due to an extremely efficient prevention system with forest owners' mandatory enrolment in municipal fire prevention associations (DFCI).

The background to the 2022 fires was a very dry and hot summer with temperatures around 40 C and humidity below 10% on occasions. These unusual conditions lasted for more than a week due to an offshore easterly wind that kept moisture from the sea reaching inland and forming clouds and rain. Under these conditions when the first two fires started, both by human activity, they proved very difficult to control. Several strategies were put in place, which proved very effective to stop the fire progression included the opening of large fire breaks, tactical fires, and backfires.

With the changing climate bringing hotter and drier summers to the south-west of France the risk of large fires is likely to increase. Improved fire fighting systems are clearly not the solution to this problem and a more fire-resilient landscape is required. In this paper we present calculations using the Prometheus fire spread model (https://firegrowthmodel.ca/pages/prometheus_overview_e.html) to investigate fire movement in the landscape and the total area burnt. We investigate different landscape designs, both human inspired, and designed using machine learning (e.g. simulated annealing), with a number of constraints such as land ownership, retention of the overall percentage of forest cover and the location of roads, railways and habitation. The modified landscapes have different patterns of forest cover and a mix of other land uses including agricultural areas, photovoltaic farms, and urban areas to help reduce fire spread. We compare the levels of damage and the rates of fire propagation from the July and August 2022 fires in the current landscape and in these modified landscapes. The results could be of benefit in helping to reduce the overall level of damage from forest fires and be part of the design of a climate-resilient forest landscape in the region.

DISRUPTED LANDSCAPES: Integrating Mediterranean Wildfires into landscape planning

T1.16 Implementing fire-resilient landscapes

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Abstract: Wildfires are the main natural disturbance that affects the Mediterranean area, and it is expected to worsen in the global climate change scenario. The fire regime has changed, mainly due to climate and human activity. The international community specialized in wildfire management recognizes the inability to solve and treat the problem strictly from the field of emergencies. The classic prevention model is being questioned, since it is not an issue of extinction capacity or economic resources destined to extinction, but an issue of landscape's ability to integrate and modulate disturbances.

This investigation explores a representation methodology by mapping future scenarios in landscape architecture as a means of integrating wildfires disturbance in landscape planning and management. The case study of the Collserola mountain range in the Barcelona Metropolitan Area in Spain is developed, to test representation, planning and management methodology. The perception and interpretation we make of wildfires and disturbances is sociocultural, but in turn, disruptive, and this fact influences political and scientific positions that are not exempt from these assessments. The concept of loss of value, associated with disturbances, is analyzed, to resignify loss and disturbance through the characterization of the operation of the disturbance: intensity, frequency or regime, as well as the landscape's own capacities that are activated by the disturbance, such as resistance, resilience or transformability, proposing its integration into landscape planning and management through representation.

The case study develops a methodology for the integration of disturbances in planning and management in a specific territory such as the Collserola mountain range, anticipating the scenario of great wildfire and proposing the inclusion of disruptive change through management and of wildfires through fire regime management to reduce vulnerability.

This methodology incorporates the operability of wildfires to planning and decision making to resignify the concept of disturbance and join a necessarily transdisciplinary reflection on the socialization of value and risk.

Keywords: Landscape management; landscape planning; wildfires; landscape representation

Economic resilience to wildfires

T1.16 Implementing fire-resilient landscapes

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Abstract: Economic resilience towards wildfires is the condition of a socio-ecological system whose economic actors can continue their functions prior to the fire event. This refers to the revenue-raising function (income-generation paths through marketable products and services), but also the non-market social and ecological functions from forests and woodlands. The economic resilience requires a system that minimizes the severity of the wildfire impacts, reduces the economic impact of fire prevention restrictions, decreases the time lapse until the recovery of the economic functions, ensures the availability of restoration funds to repair the losses (e.g., insurance), or assures the feasibility of alternative methods to exert post-fire the functions.

This presentation revolves around potential and existing mechanisms that allow for static and dynamic economic resilience (*sensu* Rose, 2007), accounting for the efficient allocation of resources, to the reparation of the capital stock. This duality confronts the anticipation of future losses (avoided reparation costs or losses) with the current expenditures to achieve certain reduction in exposure or vulnerability. It follows a discussion about the acceptability of these mechanisms, confronted with the general public risk aversion and risk perception, and the current resources typically devoted to rather reactive, impact-mitigation approaches rather than to proactive, risk-reduction measures.

Normative frameworks distil the liability of each involved economic agent – from homeowner obligations (e.g. insurance), to forest manager duties, public dissuasive and punishing structures, etc. Some countries rely on subsidy schemes to landowners and/or catastrophic aids to affected agents, which reduce the incentives of agents to enter into additional pre-fire risk reduction expenses. Yet, those public funds do not arrive to the whole region, reason for efficient distribution. Businesses become disrupted both due to the wildfire impacts, but also due to losses for strict restrictions aimed at avoiding fire ignitions during the risk season. While these restrictions tend to become more frequent due to more frequent harsh summer conditions, compensation mechanisms are to be designed if these businesses are to be maintained. Also, economic opportunities emerge post-fire not only for restoration but also for the usage of the burnt material -could be channelled as chances for the disrupted businesses.

Effects of surface fire behavior on emission from Pinus koraiensis plantation–A laboratory simulation study

T1.16 Implementing fire-resilient landscapes

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Abstract: The emission of smoke from forest fires not only affects short-term respiration health of fire fighter and public, but also poses a long-term threat to human cardiopulmonary functionality. The dead surface fuel of red pine plantation forest were collected as experimental materials, and the characteristics of forest fire behavior and the emission characteristics of particulate pollutants and gaseous pollutants during forest combustion were measured by laboratory simulated combustion experiments under field conditions as the main research means. In this study, we systematically investigated the effects of forest fire behavior characteristics on the respirable particulate matter and mixed exposure ratio, and established a forest fire smoke prediction method based on easily estimated fire behavior characteristics. The result shows that: Flame length, depth, fuel consumption loading and fire line intensity are highly significant positive correlation with $PM_{2.5}$ concentration; flame length and fuel consumption loading are highly significant positive correlation with CO concentration; residence time, flame height, fuel consumption loading and CO_2 concentration are highly significant positive correlation.Based on MLR, SVM, BPNN and RF, forest fire smoke exposure characteristics were predicted using easily estimated forest fire behavior characteristics, and RF was the optimal algorithm after screening, the R^2 of predicting $PM_{2.5}$ concentration and MER were 0.88 and 0.87, and MAPE were 16.55% and 14.84%, ; flame length had the most significant effect on $PM_{2.5}$ and MER based on RDA , and the flame length explained 15.0% and contributed 42.6% to smoke exposure; when the concentration of particle pollutant and gaseous pollutant MER were exceeded limit values, the corresponding flame lengths were 28.30 cm and 20.88 cm, respectively, and when the flame length exceeded the limit value, attention should be paid to forest fire smoke protection.In summary, the forest fire behavior characteristics measured in this study were highly correlated with the collected forest fire smoke concentrations, making it possible to realize fire environment smoke predictions based on forest fire behavior characteristics.Further optimization of laboratory data parameters using actual forest combustion data in the field will significantly improve the applicability of indoor burning experiments.

Exploring Swedish forest owners' and fire and rescue services' experiences of collaboration during forest fires

T1.16 Implementing fire-resilient landscapes

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Abstract: Forest fires are now becoming more frequent due to warmer and drier summers caused by climate change. A forest fire can have a significant impact on society as they are unpredictable and do not adhere to geographical or organizational boundaries. In such situations, forest owners and the local community often gather to help, and their assistance is highly valued. In Sweden, forest owners are legally responsible for helping the fire and rescue service during forest fires and managing the post-fire monitoring of the burnt area.

To better understand the experiences of private forest owners during forest fires and their collaboration with fire and rescue services, interviews were conducted and analyzed using qualitative content analysis and the critical incident technique (CIT). The results showed that forest fires are not only a disaster in economic terms but also have an emotional impact on forest owners. Despite this, forest owners feel a sense of responsibility and express a willingness to act, which sometimes involves putting themselves in danger. They want to collaborate with the fire and rescue services in the decision-making process, and their strong and differentiated network is mobilized to accentuate specific local knowledge proven useful in fighting forest fires. To ensure a safe work environment for all involved, the fire and rescue services need a proactive plan that involves forest owners. The fire and rescue services' view of the collaboration with the forest owners and the network that gathers has an impact on the result of the forest fire. The fire and rescue services stresses that meeting the emotional needs of the affected forest owner is a prioritized action that enhances good communication and collaboration.

While a forest fire can be a personal disaster, it can also yield a positive outcome by promoting practical and structural enhancements privately and in the local community. Collaborative efforts

between the forest owners and the fire and rescue services create security and resilience that extends beyond the forest fire area and leads to better pre-disaster planning. While the fear of new forest fires will remain for generations, disasters can be turned into proactive engagements.

Fire risks and boreal forest management

T1.16 Implementing fire-resilient landscapes

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Abstract: Forests are increasingly affected by both natural disturbances and human impacts, including fires, logging and land-use change. Climate change has further altered forest dynamics, leading to novel conditions such as increased droughts and more frequent fires, making forests more susceptible to disturbances. In the boreal region, fires rank are a major factor in shaping forest dynamics, second only to human management. Millions of hectares of boreal forest burn annually, with size and frequency of wildfires increasing. Nonetheless, our understanding of how forest management effects wildfires remains limited

Intensive forest management practices, including tree planting, thinning, and clearcutting, contribute to uniform forests in terms of species and age, often disconnected from the underlying landscape. These practices, along with landscape augmentation methods such as ditching, enhance wood production but also increase the susceptibility of spatially homogeneous forests to large fires. While much research has focused on boreal forest fires in North America, where management practices are less intensive, it is crucial to expand our understanding of fire dynamics in intensely managed forests in Eurasia. As wildfires are projected to become more frequent and severe in Eurasia due to climate change, comprehending fire dynamics in these forests becomes increasingly important.

We use a cellular-automata model to simulate fire spread, combined with eco-physiological modeling for environmental factors such as fuel moisture. We consider fire spread through small regions (1-10km), and focus on two management aspects, the structuring of forest stands by logging and tree planting, and the impact of ditching on fire dynamics via soil moisture. We find that stand management, and its effect on the spatial organization of the forest landscape, greatly affects fire spread, and that small stands can be used to mitigate fire risk. This behavior interplays with other aspects of landscape management, such as augmenting the landscape to control soil moisture, and diversifying stands with different tree species. Overall we find that management practices has a substantial impact on fire risk in boreal forests, with preferable choices depending on the scale at which management choices are made.

Fire-related functions and services under global change: a simulation study in fire-prone landscapes in northeastern Portugal

T1.16 Implementing fire-resilient landscapes

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Abstract: Fire regulation capacity (FRC) by ecosystems and landscape is an ecological function that modulates fire regimes by maintaining fire frequency, intensity and spread within acceptable thresholds and mitigates the harmful effects of fires on ecosystems and people. This study applies a modelling and simulation approach using the LANDIS-II Forest Landscape Model to assess the role of ecosystems and landscape features in regulating fire and supplying the fire protection ecosystem service (FPES) in a mountainous fire-prone area in northeastern Portugal undergoing landscape change and climate change. The study was conducted for i) 1990 -2020, where we modelled the effect of past landscape changes on fire behaviour to assess FRC (using burned area and fire intensity as a proxy) and FPES (using fire impacts on ecosystems services (ES) as a proxy), and ii) 2020-2050, where we explored the combined effect of farmland abandonment and fire management strategies (FMS): business-as-usual (BAU) based on fire suppression and fire-smart (FS) strategies focused on fire prevention, on landscape dynamics and FRC under climate change scenarios (RCP 4.5 and 8.5) to predict their effects on future fire regimes and the economic value of FPES. We found that past landscape changes promoted buildup and spatial continuity of hazardous fuels in the landscape, increasing the occurrence of large fires and areas burned above the firefighting capacity, thus indicating a reduction in FRC. From 2020 to 2050, this trend continued, particularly under the BAU strategy, where a marked decrease in FRC led to a pronounced change in the current fire regime. Still, fire-smart management fostered FRC and mitigated the effect of climate on fire activity by moderating the occurrence of large and intense fires, thus preventing fire regime intensification.

Regarding FPES, we found that from 1990 on, the value of ES supplied increased, but losses due to fire also increased, which reduced the FPES supply. Likewise, from 2020 on, although the economic value yielded by ES was positive for all FMS, FS strategies outweighed BAU in both climate scenarios and were more cost-effective than BAU.

Forest fires as a factor of ecosystem alteration in the Paraná Delta, Argentina

T1.16 Implementing fire-resilient landscapes

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Abstract: The Paraná Delta is a vast network of islands, channels, and wetlands formed by the Paraná River and its tributaries. The forests settled in this area are home to a great diversity of plant and animal species, closely related to the region's wetlands. However, the pressure of various productive activities, since the 1990s, has significantly altered the forest, wetlands and produced relevant cultural and natural ecosystem services losses. In particular, deforestation, agricultural expansion, and urbanization have altered some sectors of the region, which has led to the loss of natural habitats and a decrease in biodiversity. This proposal focuses on the fire crises in the last two decades. The first of these episodes was in 2008, and the institutional response was the creation of the Strategic Plan for Conservation and Sustainable Use in the Paraná Delta (PIECAS-DP). Among its objectives, it was foreseen to solve the problems related to the DP fires and achieve a normative harmonization between environmental conservation. Between 2020 and 2022, new fire crises occurred, aggravated by an unprecedented drought, leading to conflicts in which the National Supreme Court of National Justice intervened. Also, important national and specific regulations were enacted since 2020 to reduce the situations where economic interests were behind the production of intended fires and the loss of native forests. The hypothesis put forward is that the level of institutionalization of the environmental paradigm in the Paraná Delta is low, and this is due to i) the fragmentation between divergent principles that generate tensions between individual and patrimonial interests and collective rights, and ii) the little adoption, by public institutions, of concepts and knowledge produced by laboratories dedicated to the study of aquatic ecosystems. The adopted methodology is descriptive-inductive and includes the collective case study of the Paraná Delta which has unique characteristics, natural and cultural values which must be protected for present and future generations.

Germany is becoming a forest-fire land: are we ready for that?

T1.16 Implementing fire-resilient landscapes

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Abstract: Forest fires are not new to Germany. Forest fires were a natural part of the stand dynamics before the middle ages. Natural grassland and forest were intermixed in the central European landscape, and large herbivores such as European bison roamed before the Romans arrived in Germany along the Rhine. Forest cover was depleted significantly during the middle ages and rebounded since the industrial revolution. The first scientific forestry started in Germany in the 18th century, with sustainable timber production and hunting a primary goal. The natural grassland disappeared, either converted to cropland or forest. As a result, a cultural landscape was formed where the forest ends at the doorstep of a house. Forest turned to monocultures of a few species dominated mainly by conifers in the subsequent 19th and 20th centuries. In this new cultural landscape, forest owners tried their best to suppress fire as stand-replacing large fires contradicts the normative dogma of sustainability, which fundamentally avoids the significant natural disturbance. In this presentation, I will show how the history of forest development in Germany, in combination with anthropogenic climate change impacts and lack of public awareness, is gradually turning Germany into a forest-fire land like California and Australia. I found the burned forest areas increased 400% in the last years compared to 20 to 30 years ago. At the end of the 20th century, the average size of a burning patch was less than 5 ha, and nowadays, forest fire with more than 100 ha in size is becoming common. Due to the lack of grassland between human habitation and croplands, forest fires at doorsteps increased the vulnerability of damage to human life and properties. I have detected that northeastern Germany and Rhine Valley are highly vulnerable due to increasing dryness, sandy soil with low water storage capacity, still a large portion of conifer monoculture, and a lack of mixed forests. I detected the areas for silvicultural and infrastructure improvement so that forest owners and all stakeholders get ready for the new reality and create a future forest more resilient to fires.

Impact of wildfire severity on natural regeneration of Douglas-fir in interior British Columbia

T1.16 Implementing fire-resilient landscapes

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Abstract: Wildfires are an increasingly pressing issue in British Columbia (BC) due to climate change, fuel buildup, and pest outbreaks, so understanding how forests regenerate after fire is critical for successful post-wildfire restoration. This study examines the impact of burn severity on Douglas-fir seedling natural regeneration in the Fraser variant of the Dry Cool Interior Douglas-fir biogeoclimatic (IDFdk3) subzone of British Columbia. The study site is located 10 km west-northwest of 100 Mile House (51˚ 39′ N, 121 ˚ 28 ′ W), BC. The area experienced large wildfires in 2017, resulting in mixed-severity burned stands. Plots are located in low, moderate, and high burn severity zones. Seedling regeneration data and ground cover percentages were recorded from 2019-2022, and seedling needle, twig, and soil samples were collected in each plot in late summer of 2022 for elemental and stable isotope analyses. Low burn severity plots had more seedlings per unit area, but high burn severity plots had larger seedlings. To further investigate these patterns, the results from the stable isotope analyses of needle material ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$) and twig and soil water ($\delta^{18}O$, $\delta^{2}H$) will be used to assess time-integrated water use efficiency, stomatal conductance, leaf nutrient status, and soil water uptake depth of seedlings. By incorporating this ecophysiological data with seedling growth and biomass measurements, we can investigate key growth-limiting factors (light, water, nutrients) and assess differences in seedling performance based on burn severity. The anticipated results of this study include insights into the effects of burn severity on post-fire natural regeneration dynamics of interior Douglas-fir that will help inform post-fire regeneration strategies. Given the economic importance of interior Douglas-fir in the region, understanding how to facilitate regeneration success after wildfires is a critical issue for First Nations, the forest industry, and management and stewardship agencies. This study will help inform the development of silvicultural strategies to create favorable regeneration conditions, ultimately facilitating the recovery of forest ecosystems following destructive wildfires.

Improving surface fuel maps integrating remotely sensed data, machine learning, and ecologically based concepts to support prescribed fire management

T1.16 Implementing fire-resilient landscapes

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Abstract: Spatially explicit maps of surface fuel components (e.g., litter, duff, down woody debris–DWD) across large areas are needed to implement pre-fire fuel management strategies and predict fire behavior, effects, consumption, and emissions. Remote sensing and statistical modelling offer opportunities to capture fuel heterogeneity. Light detection and ranging (LiDAR) data, for instance, are commonly used to model forest structure attributes and predict canopy fuels. Nevertheless, remote sensing data alone are inadequate to describe the highly heterogenous surface fuelbed layer, due to the low sensitivity of both passive and active sensors to discriminate the ground from surface fuels and understory vegetation.

To overcome these limitations, we recently developed a LiDAR-based, object-oriented approach to map annual tree litterfall and litter accumulation with time since fire, exploiting the evident relationship between the litter distribution and the spatial variability of overstory inputs. In this study, we expand this methodology to describe additional surface fuel components besides litter that originate primarily from the tree crowns. We investigate the relationship between observed DWD (1 hr, 10 hr, and 100 hr fuel components) and crown biomass using tree crown maps and crown attributes derived from airborne LiDAR point clouds. Specific models of crown bulk density, volume, and branch biomass of different diameter sizes will be trained using machine learning and annual DWD fall will be predicted. On the other hand, duff (partially to fully decomposed organic material) accumulates from the breakdown of litter and DWD. Therefore, we will further use the DWD and litter maps as input to estimate annual duff formation and to simulate duff accumulation

based on fire return intervals. Study sites are fire-maintained longleaf pine forests located in Florida, Georgia, and South Carolina (southeastern USA), where remote sensing and field reference data are available for testing and validating the methodology. This integrated conceptual approach will enable mapping some physical properties of fine fuels at higher spatial resolutions, partially resolving the limitations of current methods to describe the surface fuelbed layer in a spatially explicitly manner and offering fire modelers and managers the required information to support decision-making prior to and during prescribed burns.

Information and innovative technology supporting the wildfire risk management and forest resilience – Slovak case study

T1.16 Implementing fire-resilient landscapes
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Abstract: The ongoing climate change creates significant risks for forests across the globe. Under these challenges, the EU launched Horizon 2020 European Green Deal Call to bridge the scientific advances in the fight against wildfires into concrete innovation opportunities. Under the topic "preventing and fighting extreme wildfires with the integration and demonstration of innovative means", project SILVANUS was launched. Its goal is to develop an integrated technology and information platform for wildfire management. The innovative technologies and stakeholders' participation solutions in lowering wildfire risk are tested in 11 countries worldwide and across all phases of wildfire risk management: prevention/preparedness, detection/monitoring, and restoration/adaptation. Slovakia has also joined the Europe-wide initiative to fight forest fires through the SILVANUS project. On April 24-26, 2023, the Slovakian project partners demonstrated innovative solutions and technological support for all phases of wildfire risk management: 1. the results of wildfire risk assessment using a holistic and integral approach for wildfire prevention/preparation phase, 2. the technologies which outputs are real-time data supporting the decision-making process of command staff in the wildfire detection/response phase, 3. the use of the SIBYLA forest growth simulator in forest recovery phase. Specifically, the possibilities of deploying the OPTIX smoke detection CCTV system operating in 24/7 mode and allowing monitoring of the territory in a 360° radius were tested. The camera output visualized in the control centre was sent to the Fire and Rescue Service's operations centre as a text message or MMS (photos). Wildfire was verified via drones operated by foresters. Drones were also deployed to monitor the territory during the fire to support the intervention commander. SWARM of drones was used to map the fire-affected area and create a continuous orthophoto map. In problematic GSM signal locations were used a stand-alone Starlink satellite internet and a drone using Starlink satellite internet to create a local GSM network. The Colossus ground robot technology was deployed to extinguish the fire and transport the firefighting assets and injured person. To suppress the wildfires, a pond system of water transport, a helicopter with a Bambi bucket in the undercarriage, which was filled from the large-capacity FIREFLEX tank.

Innovative technologies & socio-ecological-economic solutions for fire resilient territories in Europe (FIRE-RES project)

T1.16 Implementing fire-resilient landscapes

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Abstract: Extreme wildfire events exceeding control capacity are becoming a major environmental, economic and social threat, not only in fire-prone regions in Southern Europe, America and Oceania, but also in new areas such as Central and Northern Europe. The EU H2020 FIRE-RES project (https://fire-res.eu/) aims to provide Europe with the necessary capacity to avoid collapse in the face of Extreme Wildfire Events (EWE), which are projected to increase as the result of a harsher climate. FIRE-RES is a 4-year project (2021–2025) whose scope is to effectively promote the implementation of a holistic fire management approach and support the transition towards more resilient landscapes and communities to EWE in Europe. FIRE-RES brings together a transdisciplinary, multi-actor consortium of 35 partners, formed by researchers, wildfire agencies, technological companies, industry and civil society from 13 countries, linking to broader networks in science and disaster reduction management. The project will deploy a total of 34 innovation actions across a set of eleven living labs representing different environments in Europe and Chile. Its final mission is to boost the socio-ecological transition of the European Union towards a fire-resilient continent by developing a stream of innovative actions.

Integrated Fire Management within ASEAN: Approaches to include community-based fire management and address climate change

T1.16 Implementing fire-resilient landscapes

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Abstract: Forest fires continue to significantly impact the environment, economy, and communities around the world in both direct and indirect ways. Environmental harm caused by forest fires disturbs ecosystems and alters land use inducing significant release of greenhouse gases. Climate change affects each passing fire season intensifying the severity of smoke and haze by the increasing frequency, intensity, and duration of fires. From these smoke particulates, transboundary haze has risen across the landscape afflicting the whole ASEAN region at a worsening rate thereby threatening public and environmental health. The transdisciplinary scale and transboundary impact of wildfires requires a collective and proactive approach inclusive of diverse perspectives. A series of roundtable discussions conducted in early 2022 through the RECOFTC TFD-FLOURISH project, provided lessons learned that emphasized the need for international intervention and a shift towards long-term integrated planning involving diverse stakeholders and efforts at multiple levels. The methods within this current project focus on enhancing existing strategies and technologies for greater use and accessibility for forest communities to prepare and respond to fire risks themselves. Initial study across Southeast Asia indicated that people cause most ignitions either accidentally or intentionally in cases of agricultural burning or land clearing. In implementation, project target sites in Thailand, Laos PDR, Viet Nam, and Cambodia were selected based on a range of factors including but not limited to burn scare proximity, hot spot density, land use, and transboundary relevance. This project mobilizes on the understanding that community and landscape perspectives should be prioritized in the design and implementation of forest fire management. By building trust and applying adaptive management strategies that draw on social, economic, cultural, and ecological conditions, RECOFTC facilitates the cross-stakeholder and cross-sectoral approach needed to build resiliency in fire threatened landscapes. Application of a proactive and people centered approach benefits both ecosystem health and biodiversity while strengthening landscape connectivity and sustainability of community livelihoods. Further involvement of regional stakeholders and opportunities for knowledge sharing will address the challenge of transboundary haze from the root of problem: irregular and unpredictable burning in the region.

Integrating nature-based solutions in wildfire and disaster risk reduction strategies

T1.16 Implementing fire-resilient landscapes

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Abstract: Land use changes that increase biomass accumulation at landscape scale are adding to wildfire risk conditions in many regions across the world, especially and historically in rural mountainous areas. Land abandonment and other changes are resulting in landscapes becoming increasingly hazardous, both in terms of wildfire propagation (fire velocity and intensity overcoming so-called suppression capacity) and in terms of damaging impact (increased potential of wildfires to critically impact values at risk). This trend is exacerbated by the fire-prone conditions posed by a warmer, dryer and vegetation-stressing climate, jeopardizing the adaptation capacity of risk management systems. This combination of factors is increasing the risk of extreme wildfire events and shifting the perception of wildfires as mainly an ecological phenomenon to a disaster risk management issue. While nature-based solutions (NbS) are increasingly prevalent on disaster risk reduction agendas, their application to wildfire risk has been poorly conceptualized up until now. This paper explores the consequences of the evolving wildfire risk in terms of disaster risk management, both in traditional and non-traditional fire-prone areas, and how the NbS concept can be applied as part of risk-reduction strategies. Fundamentals of fire ecology and traditional sustainable forestry practices for risk reduction, climate change and biodiversity are contrasted, exploring the boundaries of concepts such as fire-smart forestry, natural-fire regime restoration or fire-resilient landscapes, as well as conservation and re-wilding, as different options for NBS policy. Theoretical, empirical, and policy aspects are considered, delivering lessons learned (also from other natural hazards) and best practices, along with technical, financial (e.g., the role of insurance) and governance options to frame different perspectives of NbS into integrated and equitable wildfire- and disaster risk reduction.

Latest scientific insights into landscape management towards fire-resilience

T1.16 Implementing fire-resilient landscapes

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Abstract: This keynote speech will set the scene for the rest of the session, which will cover the fire-resilience topic from a multidisciplinary perspective.

This talk will review the latest advances on fire ecology, and related insights into forest management and societal adaptation and risk mitigation practices that could contribute to better prepared communities and ecosystems to tackle fire contingencies. Taking the examples from Boreal ecosystems, the talk will refer also to fire regimes and changes in the latest decades related to climate novelties. The talk will also refer to some of the following questions:

- How is the relation between fuel availability and fire severity? Which are the consequent socio-ecological impacts?
- How to achieve and maintain forest resilient structures and uses?
- How to make viable and affordable this society-forest-risk relation?
- How synergetic or competing is the wildfire risk mitigation service with other ecosystem services? (e.g. water-biodiversity-wildfire nexus).
- How to pass from effective stand-level to landscape-level measures?

Lessons from the 2023 wildfire season in Canada will be introduced as well.

Merging National Forest Inventory data with fire expert rating of fuel complexes through photo interpretation of NFI plots

T1.16 Implementing fire-resilient landscapes

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Abstract: High-quality fuel maps are needed for operational fire suppression. These are typically built on satellite scenes and other remote sensing tools, which unfortunately have limited ability to detect surface fuel conditions in closed forest. In many regions there is also very limited experimental fire data to grade various fuel complexes from a fire danger perspective. Here we analyse whether standard inventory data from the Swedish National Forest Inventory (NFI) plots can be used to grade fire danger. Five fire-experts, with long experience in conducting prescribed fire in forests, were asked to interpret a series of photos we had taken at 192 different 20m-radius NFI plots in two regions in northern and southern Sweden. The experts rated the fuel complex in each plot based on the images only, which were taken from a position 5m south of the plot centre in five directions from nadir to zenith. They rated different 'fire-danger' categories: relative drying rate of the surface fuels, relative intensity of a surface fire in high-danger fire weather, risk for fire climbing into the canopy and overall risk (all on a scale 1-10), and seasonality of surface fuel flammability (on a scale 1-5).

The evaluations of the five experts were highly consistent (no statistically significant differences). We then built regression models for each fire danger category using the NFI plot data as independent variables. The most important variables indicating high fire danger were percentile cover of dwarf-shrubs (*Vaccinium vitis-idaea, Vaccinium myrtillus, Empetrum nigrum, Calluna vulgaris*) and the proportion of *Pleurozium schreberi* and *Hylocomium splendens* in the moss layer. Also the proportion of different tree species (*Pinus sylvestris, picea abies, betula sp*., deciduous mix) had significant effects. In addition, tree height, canopy cover, tree species proportions within different canopy layers were significant variables in different regression models.

Our study show that standard NFI-data can be interpreted to grade forest with regard to fuel structure. The results can be used to refine the current fuel map of Sweden and also be integrated into forest decision support systems such as HEUREKA, for combined analysis of forest resource management and fire risk.

Multi-scale laser scanning in support of prescribed fires to maintain or restore resilient forests

T1.16 Implementing fire-resilient landscapes

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Abstract: Large fuel accumulations over decades of fire exclusion practices, especially in the western USA, coupled with longer fire seasons caused by a warming and drying climate, has increased wildfire activity, burn area, burn severity, and emissions. Fuel loadings and consumption are the two largest sources of uncertainty in estimating emissions, and improved fuel maps are needed for regional planning of forest and fuel treatments. There is broad consensus that more prescribed fires are needed to maintain resilient forests, reduce fuel loads, and restore forests where fire has been unnaturally excluded, leading to increased risks of severe wildfires. Laser scanning data collected on the ground and from aircraft and satellites provide state-of-the-art remote sensing capabilities for characterizing forest structure attributes, including biomass and fuel loads.

We estimated canopy and surface fuels at multiple scales using machine learning informed by a combination of field and laser scanning data and fire history records. We collected pre- and post-fire field and laser scanning data to model and map both pre- and post-fire fuel loads; by subsequently differencing these fuel maps, we could map fuel consumption to inform studies of fuels, fire behavior, emissions, and fire effects. In the southeastern USA, frequent prescribed surface fires are used primarily to maintain desirable conditions in surface fuels, shrub cover, and tree density and age structure in longleaf pine forests. In the western USA, where decades of fire exclusion have caused these variables to depart from historical conditions, prescribed surface fires have been reintroduced to restore dry ponderosa pine forests, and prescribed crown fires have been used to restore subalpine forests. We present a conceptual framework for inventory and monitoring of fuel loads, supported by published case studies conducted across these diverse forest types. Findings from these studies informs a strategic, multi-scale approach to regional forest and fuel monitoring

that will become increasingly feasible, practical, and useful with: 1) continued spatial and temporal infilling of airborne laser scanning collections, 2) increased instances of repeat airborne laser scanning coverage across the USA, 3) satellite laser scanning samples of fuel loads across a range of forest types and fire regimes.

Perceptions, knowledge and spiritual management of fire in Forest indigenous landscapes

T1.16 Implementing fire-resilient landscapes

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Abstract: Indigenous Peoples and Local Communities own approximately half of native forests in Colombia. These forests are important to safeguard biodiversity, to address the challenge of climate change and to conserve local knowledge. They may further contribute to address the increasing disconnection between humans and forests. This disconnection is not physical as human societies depend on the sustainability of the provision of forest products and services. It is emotional and spiritual. We do not perceive forests as the amazing organisms that enable our life on earth. Most people identify forests as an inexhaustible object or resource that provides us with materials to satisfy our individual and collective needs. The profound lack of interest that many individuals of our species show towards the extraordinary kingdom of trees has led us to place such complex ecosystems on the same level as plastic bags: on the shelf of the useful but inert. Many indigenous communities from Colombia don't perceive forests this narrow way. However, this truth is very hard to understand by forest scientists and policy makers , they do not understand that indigenous communities have this perception.

Forest and people need for live in this earth five elements one of them is fire. The concept and management of fire in land owned by indigenous communities encompasses a spiritual dimension, where fire is interpreted as a spirit that can help design and build new forest spaces as heal and rebuild living beings.

This article is a reflexive and critical approach to understanding the fire knowledge base as well as the fire-related management practices in forests owned by three indigenous communities in Colombia. The analysis of the perceptions, knowledge and spiritual management of fire of three communities offers a unique opportunity to study the biophysical and social materialization of complex multidimensional relationships and processes involved in the management of fire in their forests. Moreover, it is influential to design forest programs that may integrate information about ecological, cultural, and social values as well as traditional knowledge of Indigenous Peoples and Local Communities and thus design resilient landscapes

Quantifying emissions from megafires: Securing carbon market funds for fuel treatments that reduce wildfire severity and improve forest resilience.

T1.16 Implementing fire-resilient landscapes

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Abstract: Fuel treatments such as mechanized thinnings or prescribed burns are an effective tool to reduce wildfire severity and contribute to fire-resilient landscapes. The need to scale up these fuel treatments across the western US and beyond is increasing and acknowledged by a large contingent of stakeholders. However, fuel treatments can cost up to several thousand of USD per hectare treated as they focus on the removal of smaller diameter trees and understory vegetation, reducing surface fuels through chipping, piling, prescribed fire, or a combination of these activities. Hence, funding remains a major challenge.

We present on a new initiative based on decades-long research on the greenhouse gas (GHG) emissions implications of fuel treatments: tapping into the carbon market through Reduced Emissions from Megafires (REM). In 2023, the Climate Action Reserve's (CAR) Climate Forward program, approved the REM forecasting methodology. This methodology provides a novel mechanism for funding forest health projects by quantifying GHG emission savings by reducing the risk of catastrophic wildfires. Under the REM protocol, emissions are forecasted for project areas with and without treatment (the baseline scenario). By comparing projected emissions in the baseline and project scenarios, we can estimate the impact of treatments on GHG emissions measured in metric tonnes of carbon dioxide equivalents. The quantification of reduced GHG emissions from fuel treatments under this methodology includes accounting for forest carbon, emissions from fires, carbon in wood products, and mobile emissions, both within the treatment area and within the fireshed.

This methodology also provides a capable analytical backdrop to effectively design fuel treatment placement and types across hundreds of thousands of hectares. We have developed a semi-automated process relying on open-source vegetation, topography, wildfire history, and weather data as well as growth & yield and wildfire behavior models to explore fuel treatment effectiveness not only in GHG emission reductions but other forest resilience metrics as well such as temporary or permanent vegetation type change following high-severity wildfire.

Our presentation will provide the audience with insights in the REM methodology itself as well as its capacity to build stakeholder consensus around fuel treatment allocations.

Spurring rural economies while reducing fire emissions through a targeted fuel reduction thinning program in the western United States

T1.16 Implementing fire-resilient landscapes

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Abstract: At 64%, the Federal Government is the largest forestland owner in the Western United States. These lands provide a wide range of ecosystem services including wildlife habitat, recreational opportunities, air and water filtration as well as providing forest products and jobs in local economies. They are also the source of considerable debate as to an appropriate management emphasis. Decades of fire suppression coupled with the substantial reduction in federal harvest levels of the has led to a steady buildup of fuels, an increase in forest density, as well as escalating fire, disease, and insect epidemics. Between 1987 and 2001 the volume of timber sold from national forests dropped some 90%, followed by a modest increase since then. Mortality has increased by 388.8% in the region to the point where eight of the eleven western states are now in a situation of emitting more CO_2 than they sequester thus contributing to our national emissions. Unfortunately, the reduction of federal harvest in the 1990’s led to a subsequent contraction in regional forest products processing capacity which indirectly affects the costs and thus management opportunities of such programs. This is exacerbated by the inability to utilize any removed material as merchantability often depends on that capacity infrastructure due to the long-haul distances in the West. This study seeks to inform policy makers and market participants about the potential effects of an expansion of federal harvest in the western U.S. on national greenhouse gas (GHG) accounts and rural economies. We use spatial partial equilibrium model to explore a set of scenarios based on expanding federal harvest in the region while simultaneously expanding mill capacity to utilize the removed material. For each scenario we evaluate changes in rural economies associated with transportation logistics and merchandizing of logs throughout the region at the various manufacturing facilities. We simultaneously track GHG accounts throughout the forest and forest sector supply chain.

Stakeholder participation in fire resilient forest management and restoration outcomes in the Western Himalayan Eco-region

T1.16 Implementing fire-resilient landscapes

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Abstract: In the Western Himalayan Eco-region (WHER), communities have historically used forest fire to shape Socio-Ecological Systems (SES). However, forest fires under climate change and socio-economic transformation pose new challenges of repeated fires, increased annual burn area, and changes in fire season. Thereby threatening adaptive capacity of various forest stakeholders to resist and manage adverse fire impact. The knowledge of preparedness and adaptive capacity of the communities to forest fire is essential for improving resilience of Himalayan SESs to future scenarios of extreme fire events and related risks. Therefore, this study aims to understand drivers, factors and mechanisms affecting various stakeholders' participation and decision making in forest fire management vis-a-vis short-term and long-term actions in fire mitigation and restoration of damaged fire landscapes in Uttarakhand. Uttarakhand is one of the Western Himalayan states in India that is prone to multitude of socio-environmental risks. The majority of the forest fires in Uttarakhand arise out of human "actions and inactions". The state has a rich and complex forest management system, controlled by government departments and decentralised community forest management groups. The diversity in forest stakeholders creates a platform for potential cross and intra-stakeholder collaborations and conflicts in managing disturbed forest sites as forest fire impact is not restricted to human-made social boundaries of the forest. The existing literature has minimally investigated such complex social-ecological interactions in forest fire management in the Himalayan region. Often, fire, forest, and people are studied in silos, creating challenges in developing effective fire management policies. This study will employ the Social Ecological System Framework (SESF) and concepts of collective action to assess the multi-stakeholder perspectives. Geospatial analysis of the fire regime and expert interviews will be used for site selection. Further, various quantitative and qualitative research methods will be used to collect the perspectives of local and regional stakeholders and the preliminary results of the study will be available before July 2024. The outcomes of the study have manifold implications for further research and policy recommendation in developing indicators of resilience in fire prone SESs.

The role of nature-based fuel treatments in mitigating wildfire risk

T1.16 Implementing fire-resilient landscapes

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Abstract: Climate change has intensified the seasonal severity rating (SSR) of fire seasons and led to more intense wildfires worldwide. Nature-based fuel treatments (NbFT) provide an ecologically friendly strategy for mitigating increasing wildfire risks and maintaining ecosystem functions; however, their design and effectiveness are still unclear under different SSR conditions. In this study, we proposed a framework to assess the wildfire risk of various SSR conditions in Southwest China. Using percentiles of the SSR index, we divided the 2000-2020 fire seasons into three scenarios: low ($\leq 25^{th}$), normal (25^{th} -75^{th}), and high ($\geq 75^{th}$). We developed 17 NbFT designs involving one spatial arrangement, three modes, four treatment intensities (%), and two treatment geometric shapes. These designs were then evaluated for their effectiveness in mitigating wildfire risk under the above three SSR scenarios. Our results showed that the SSR scenarios had a significant influence on wildfire risk. Compared with the normal SSR scenario, the high SSR scenario resulted in over 50% of the study area experiencing an increasing trend in wildfire risk. In contrast, 97.6% of the study area showed a decreasing trend in wildfire risk under the low SSR scenario. NbFT with belt-shape treatments outperformed those with block-shape treatments in mitigating wildfire risk when other parameters remained constant, and their effectiveness was boosted with increasing treatment intensity. The optimal NbFTs design was determined comprehensively under the three SSR scenarios to be fuel breaks with a density of 3.9 m/ha while treating 20% of the area in a belt shape. Using this design, the proportions of very high- risk areas would be reduced to less than 0.1% and 0.2% under the low- and normal- SSR scenarios, respectively, but this percentage would still be high at 10% under the high SSR scenario. Overall, the NbFT showed limited effectiveness in mitigating wildfire risk under high fire weather conditions even with the optimal design.

Use of near real-time satellite data in forests: Applications for wildfire purposes and development towards resilient landscapes

T1.16 Implementing fire-resilient landscapes

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Abstract: Technological advances and developments within the field of remote sensing and data processing have opened new possibilities for the utilization of satellite data. Frequently acquired satellite data can be used for monitoring and change detection to ensure maps correspond to the current situation on the ground. In the case of wildfire events, it can be crucial for first responders to have updated information that accurately represents the actual conditions of the forest and landscape. Also, monitoring the state and change in the forest and vegetation can help guide decisions in the separate phases of wildfire mitigation and prevention. In this study we have reviewed the use of open satellite data for near real-time applications in forests. We have tested near real-time change detection methods and evaluated these in a test area in boreal forest in Norway and on the Greek island of Lesvos. We have used openly available data from satellites – such as from the Copernicus program of the European Space Agency – and made updates to existing maps, based on changes automatically detected in the satellite imagery. Detection of changes such as clear cuts, new forest roads and areas with dead trees were tested, and this information was included in existing online maps, indicating the areas with such changes. We furthermore used the detected changes to update a remote sensing-based high resolution fuel map, which serves as basis for fire simulations and provides valuable information for fire risk assessments

We assessed the accuracy by comparing a selection of the automatically detected changes to field observations and reviewed the impact of updated information on applications for wildfire prevention and the development towards fire resilient landscapes.

What has happened to the uppermost soil layer after 5 years of fire occurrence?

T1.16 Implementing fire-resilient landscapes

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Abstract: Fires regardless of their causes are one of the important factors that affect forest ecosystem functions via their effect on soil properties. The aim of this study was to understand the fire impact on soil chemical properties. Two similar stands of Pistachio-Almond in semi dry areas of Zagros forests were selected to estimate fire impact, one of them faced fire 5 years ago. The other one in the neighborhood was used as a control stand to compare results without burning. Soil samples were collected from 0-20 cm depth. Soil chemical properties including moisture, electrical conductivity, soil reaction (pH), organic carbon, organic matter, total nitrogen, available phosphorus, and potassium were measured by the standard soil analysis methods Results indicated some chemical properties values of soil decreased after fire including pH (2%), organic carbon (12%), organic matter (12%), total nitrogen (5%), potassium (4%), and available phosphorous (61%). While the value of soil electrical conductivity (28%) and moisture (17%) was more in the burnt stand than the control one after 5 years. Soil basal respiration did not show any big difference between burnt and unburnt soils. It seems that fire impacts in different ways on different soil properties but it is obvious that it takes a long time for the soil to recover from fire impacts.

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

A review of the occurrence and management of forest insect pests and diseases in Kenya

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: A research conservancy of the Forest Department was established in Kenya in 1934. This was absorbed in 1948 by the East African Agricultural and Forestry Organization (EAAFRO) and only came under Kenya Agricultural Research Institute (KARI) in 1981. In 1986, Kenya Forestry Research Institute (KEFRI) took over forestry research from KARI. In this study, a desktop review was undertaken of both published and grey literature on the subject of forest pests and diseases and the evolution of management options that have been followed in Kenya. Over the years, records indicate that Kenya's forestry systems have been threatened by several insect pests and pathogens since the dawn of plantation forestry early in the twentieth century, with some causing significant economic losses and limiting productivity. On exotic trees, the major exotic insect pests so far encountered include *Gonipterus scutellatus, Oemida gahani, Pineus boerneri, Cinara cupressivora, Leptocybe invasa, Thaumastocoris perigrinus* and *Glycapsis brimblecombei*. In a few cases, like that of pines and black wattle, indigenous defoliator insects have caused problems in exotic plantations but are eventually contained by local natural enemies. Local termites also attack and cause root damage to exotic tree seedlings, mostly in the ASAL areas. The major tree diseases encountered are caused by a mixture of exotic and indigenous agents. They include damping off in tree nurseries, transplant diseases, terminal crook on pines, Armillaria root rot, and a canker on *Cupressus macrocarpa* (which eventually had to be replaced by the more disease-tolerant *C. lusitanica*). Other notable tree diseases are Dothistroma needle blight caused by *Mycosphaerella pini,* Cankers on *Eucalyptus grandis* caused by *Chrysoporthe cubensis*, and Powdery mildews on Eucalypts. Integrated pest management is considered ethical and has been Kenya's preferred strategy for containing these challenges through a combination of cultural methods, pesticides, fungicides, biological control, and selection and breeding for resistance. There need to strengthen quarantine measures persists. We benefit from engagement of citizens in pest management strategies in Kenya's forestry systems and are eager to learn lessons about successful containment of various insect pests and diseases that have been recorded elsewhere.

Keywords: Review, pests, diseases, management, forestry, Kenya

A Strategy for Restoration of Lantana-Infested Forest Landscape in the State of Uttar Pradesh, India

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: *Lantana camara* (commonly known as lantana) is one of the most serious invasive alien species in tropical and sub-tropical areas in India and other parts of the world. The species occurs in forests, pastures, agricultural areas, roadsides and vacant lands in varying densities. Research has led to the development of cut-rootstock method for uprooting it. In order to prevent re-emergence of lantana, the plants of other species must immediately occupy the place vacated by it. Pilot studies have been carried out in the past in Jim Corbett Tiger Reserve (Uttarakhand), Kalesar National Park (Haryana) and Satpura Tiger Reserve (Madhya Pradesh) where lantana was uprooted in demonstration plots of 2-5 hectares followed by planting of rooted ramets or clumps of native grass species or by broadcasting seed pellets of grass species. Planting of trees could involve greater cost than planting of grasses. Research findings are available on use of chemical and biological weed control measures for control of lantana in some areas in India and abroad. However, possibility of harm to non-target species necessitates site-specific research before largescale application of those measures.

The cost of rehabilitation of a lantana infested area would depend on forest cover and other site condition. A landscape-level rehabilitation strategy must consider several factors since the extent and intensity of lantana infestation in India are quite large and variable.

The author has proposed a strategy for restoration of lantana-infested forest landscape for the state of Uttar Pradesh, India. Four treatment models have been suggested in forest landscape for the purpose depending upon the density of forest cover. The models include a combination of uprooting, assisting natural regeneration, grass planting and tree planting based on site-specific factors such as presence of other vegetation, herbivory, anthropogenic disturbance, presence of dependent population, local support for protection, availability of funds, etc. Recommendation has also been made for utilisation of lantana biomass for making furniture, handicraft, briquettes, etc. to support livelihood of local inhabitants.

Advancements in the study of Xylella fastidiosa vectors: biology and biometrics of Philaenus italosignus juveniles.

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: In this study, we explored the biology and biometrics of the spittlebug *Philaenus italosignus* (PI) (Hemiptera: Aphrophoridae), one of the confirmed vectors of the quarantine phytopathogenic bacterium *Xylella fastidiosa* (XF). PI juveniles are known to have only one host, the lily *Asphodelus ramosus*, while the nymphs of *Philaenus spumarius* (PS), the most studied XF vector, are notoriously polyphagous. Indeed, a better understanding of these spittlebugs is key for early detection of XF.

In 2019 we first reported PI in Tuscany (Italy), nearby the outbreak area of Monte Argentario in which XF subsp. *multiplex*, was found mainly associated with Mediterranean scrub. Since then, we kept studying PI's biology intending to verify its overwintering stage and the duration of the preimaginal development. Lastly, we investigated the possibility of using biometric traits of PI juveniles as an identification tool.

Insect samples, both target (PI) and non-target (PS), included nymphs collected in 2022-2023. For all five instars the head's width was measured (500 specimens for each species). Finally, DNA tests were carried out using the PI-specific Sybr GREEN qPCR assay to verify the identity of a subsample of 80 nymphs.

Our observations showed that, in Tuscany, PI first instar nymphs are found on the lily already in December and, unlike PS, they overwinter. Thus, the duration of the preimaginal development covers a total of four months, with newly emerged adults appearing in April.

Our observations on the nymphs extended the current knowledge on PS biometrics, while providing original data on PI juveniles. Moreover, by comparing measurements we showed how each instar's size differs between the two species, PI nymphs being significantly larger. Finally, molecular tests validated our claim on PI biometrics: in no case, morphological and molecular analyses gave conflicting results.

In conclusion, the size of *Philaenus* nymphs may be used to discriminate both spittlebug species. The reliability of this trait and the new data on PI's biology will allow better monitoring of the ongoing XF emergency, both in agriculture and natural environments, also in view of the prolonged timeframe during which the bacterium may be transmitted to trees by the polyphagous PI adults.

Does the immigration country determine the further spread of forest pathogens in Europe?

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: In previous works, present and historical pathways of introduction of invasive forest pathogens (IFPs) into Europe have been studied. The main means of introduction is trade of live plants which, especially in Europe, is not strictly regulated and even entry of potted plants may be allowed. IFPs enter as ‘contaminants’ or ‘stowaway’, *i.e.*, with commodities to which the pathogen is or is not biologically connected, respectively.

When plant commodities, and the organisms they harbor, cross the border, it is common that the port of entry does not correspond to the final destination: for example, most plants for planting enter Europe through the ports of Rotterdam (NL) or Antwerp (BE), but they may be immediately transported elsewhere or grown locally for a period of time and then traded abroad. In this study, based on the European IFPs database and assuming that the country of introduction corresponds to the first report country we analyzed the spread in Europe of some historical and present IFPs to discriminate whether a country-to-country pattern of spread may be identified and whether this pattern has changed over time. This information may be relevant to identify intra-European diffusion networks and take effective action on risk management in the future.

Efficacy of insecticide aerial spraying programs to reduce tree mortality during a spruce budworm outbreak (1967–1992) in the province of Quebec

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: Spruce budworm (*Choristoneura fumiferana*) is the most important pest of conifer forests in North America. The main approach for protecting forests against this defoliator is aerial spraying of insecticides. Despite the crucial role of aerial insecticide applications in the global forest protection strategy, little is known about its real effects on tree mortality or the stand characteristics that may affect its long-term efficacy. We evaluated the efficacy of the protection program that was implemented during the 1967–1992 outbreak in Quebec in tree mortality reduction. We established 422 plots in eastern Quebec based upon the following parameters: insecticide application; stand composition; drainage quality; and stand age. Unprotected plots exhibited 18 to 44% greater tree mortality than protected plots. Insecticide efficacy was affected by drainage condition. For example, protected plots that were established on sites with poor quality drainage exhibited 67.53% lower balsam fir (*Abies balsamea*) mortality than did unprotected plots. Insecticide application had no substantial effect on spruce mortality (4.63 and 4.32% white spruce (*Picea glauca*) and black spruce (*P. mariana*) mortality, respectively). A lack of strong treatment effects of spraying operations on spruce mortality may simply reflect the fact that the protection program in Quebec was designed to protect balsam fir. As a result, the dosage or timing of insecticide applications might not have been optimal to protect spruce trees. Spruce characteristics may also play a role in explaining the aforementioned response. Spruce species normally sustain less defoliation than balsam fir because of their stronger capacity to re-foliate after defoliation, late phenology, and toxic phytochemistry. Our study also found that the return on protection investment in terms of mortality reduction may decline after 7 years of aerial spraying. Furthermore, we found that it is not necessary to achieve the target protection goal (50% foliage protection) every year to reduce host tree mortality. Our results may be useful for decision-makers to decide where and when to apply insecticides during a spruce budworm outbreak and may help to determine the appropriateness of treating the forest on an annual basis depending upon the protection goals.

Forest pest management through a co-operative research consortium

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: Damaging pests and diseases pose significant threats to the two million hectares of plantation forests in Australia and the cost of re-establishment due to pest attacks is significant. Access to current effective pesticides to mitigate many of these threats remains challenging in a small pesticide market, a climate of regulatory and economic changes and imposed certification requirements. This certification requires that forest managers protect forests from damaging pests while at the same time reducing the use and exposure to highly hazardous pesticides (HHPs). About 99% of the plantation forestry pesticide spend in Australia is on herbicides with only about 1% on other products, highlighting the comparatively limited options available to control damaging pests and diseases. In 2018, the Forest Pest Management (FPM) Research Consortium was established to maintain and increase the productive capacity of the Australian forest industry by reducing the reliance on HHPs, instead shifting usage to environmentally and socially acceptable control options for pests and diseases. The Consortium is a membership-based co-operative research effort, including 19 forest plantation growers and pesticide manufacturers, that ensures the continued availability of effective and safe control options for pests and diseases. The project has conducted need-based screening and operational trials since March 2018 in response to regulatory, economic and societal trends, and supports ~90% of the forest plantation industry in Australia. The FPM Research Consortium delivers whole-of-industry outcomes for considerable overall value at a fraction of the cost that individual enterprises would otherwise be required to expend. Outcomes include i) compliance with relevant weed or pest legislation and providing expert advice to regulators and certification bodies, and ii) protecting the integrity of adjacent land uses and its users through the development of advanced application technologies to reduce spray drift and human exposure.

Forest Stewardship Council – 30 years of contribution to sustainable forest management in Sweden

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: The Forest Stewardship Council have been a tool for sustainable forest management since the foundation in 1994. One means has been the governance system based on stakeholder involvement and membership with engagement from social, economic, and environmental stakeholders. Another means has been the forest management certification, with a global framework and nationally adapted requirements. The third means is the verification system for the full value chain and a product label facilitating the market uptake and the demand for FSC material and FSC certified products.

Sweden was the first country to have a national Forest stewardship standard in 1998. A large proportion of the Swedish forests got certified early and today ca 55 % of the productive forest is certified. The FSC certification has since been a major factor in setting new practices for forest management in Sweden. The protection of Woodland key Habitats, the requirement to have 10 percentage set-asides and/or adapted management for social or environmental values, and the inclusion of prescribed burning for larger forest management units, are examples of changed practices with strong effects for biodiversity in the Swedish forest landscape.

Another example is the ban of chemical pesticides from the Swedish forestry. This was the result of FSC promoting research and the development of non-chemical treatment of seedlings to hinder damage from large pine weevil as well as encouraging integrated pest management to prevent damage from European spruce bark beetle.

FSC certification also have a strong social dimension with requirement for all workers to have collective agreements, support of the rights for the reindeer herding Sami population as well as requiring engagement with affected local stakeholders.

There are learnings to be drawn from the experiences, challenges, and development of the FSC certification scheme, how the stakeholders have been engaging in writing the standards, and how FSC certification has been a driver for change of forest management practices in Sweden.

Historical shifts in government programs for spruce budworm outbreaks in Canada

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: Spruce budworm populations are characterised by large-scale outbreaks, punctuated by periods where the insect appears to undergo local extinction. Outbreaks occur with a predictable frequency of ~30-40 years in eastern Canada, and cause widespread mortality of balsam fir and spruce. Mortality losses in eastern Canada during the 1910-1920 outbreak was estimated to be 720 million m^3. Similarly, losses in Quebec between 1967 and 1992 were ~238 million m^3 with a commercial value of $12.5 billion. When the use of spruce and balsam fir as sawlogs and pulpwood, respectively, began in the early 20th century, uncontrolled outbreaks became an economic threat to timber supply. During the outbreak of the 1940s, forest protection became a priority for some provincial governments that began large scale pesticide application programs. For example, between 1952 and 1993 97% of 6.2 million ha of forested lands in New Brunswick Canada were treated with insecticide. During this program 12 insecticides were applied as aerial sprays. The four more commonly used were DDT (1952-1968), phosphamidon (1963-1967), fenitrothion (1968-1993) and aminocarb (1970-1987). Opposition from experts, citizens and citizen groups contributed to research efforts to develop silvicultural methods to reduce stand vulnerability, behavioural and metabolic chemicals as well as naturally occurring insect pathogens to replace insecticides. Today, two insecticides are used in control programs. In 1973, broad use of *Bacillus thuringiensis* var Kurstaki (Btk), a pathogen of lepidopteran larvae, began as a foliage protection strategy to target feeding larvae in high value stands. In the early 1990s Tebufenozide, an analogue of the moulting hormone, ecdysone, was developed and is approved for use in Canada. Mating disruption from overloading male olfactory senses by spraying sex pheromone has been tested without success for practical use. Widespread moth dispersal from the current outbreak (2006-present) in Quebec into New Brunswick has put other regions at risk. An early intervention strategy (EIS), is being tested in New Brunswick since 2014 to suppress infestation hotspots with Btk and quell population growth as soon as populations begin to rise. Following eight years of tests, this strategy appears to be effective in mitigating the spread of the outbreak.

i-Tree Pest Predictor: a "crystal ball" to foretell future forest invaders?

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: All around the world, there has been an interest in fostering interconnectedness among continents that has led to rising rates of international biotic interchange that threaten the health and resilience of our global forest ecosystems. Though most result in little ecological impact, introduced insects pose a significant threat to forest ecosystems due to the small, but mighty, proportion that cause significant impacts, such as regional host mortality or functional host extinction. Robust forecasts of insects that are likely to cause substantial impacts have largely remained elusive, though they would improve biosecurity measures and could help prevent the introduction of some potentially catastrophic insect species akin to the emerald ash borer (*Agrilus planipennis*) and hemlock woolly adelgid (*Adelges tsugae*) in eastern North America. For this study, we used data from introduced insects currently established in North American forests to identify drivers of impact and develop models and a tool that can predict impact of insects that have not yet arrived in North America. We considered four submodels – (i) insect traits, (ii) host traits, (iii) host evolutionary history, and (iv) insect evolutionary history – and found that the significant submodels varied by insect host type and breadth but, overall, evolutionary history of the native and novel hosts was significant irrespective of insect host type and breadth. The significant submodels were consolidated into five composite models and built into an i-Tree Pest Predictor tool that can help forecast which non-native insects have a high probability of causing tree mortality on 360+ hardwood and 50+ conifer trees native to North America should they establish. Ultimately, the tool, now available through i-Tree, is being used to develop a risky insects database. Along with sentinel trees and other risk assessments, this tool will help predict the next high-impact insect invaders in North American forests before they invade, which will aid decision-making and help provide directed feedback to improve biosecurity measures. Similar tools can be developed for other countries or continents to better predict the risk that non-native forest insects pose to forest ecosystems around the world.

Learning from the past to better inform the future – interdisciplinary and transdisciplinary approaches to forest health

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: Biological invasions leave long-term (and often irreversible) landscape legacies with climate change and current global political and economic issues only serving to exacerbate the biosecurity crisis. Humans are a key driver in the movement and introduction of tree pests and diseases but also part of management solutions. A holistic and interdisciplinary approach to promoting forest health requires multiple disciplines and perspectives and acknowledgement that different societies will favour specific approaches, but we can learn from each other. There will be a number of factors affecting biosecurity decision-making of different actors including their values and motivations, how risks are perceived and acted upon and the push and pull of existing regulatory and economic contexts. Understanding these contextual factors and historical legacy is key to any future attempts to improve biosecurity policy and practice. We provide an introduction to the session and examples from across the globe of the benefits of bringing together different disciplinary and experiential expertise for addressing biosecurity threats in ethical, sustainable and socially just directions. We end with a call for collaborative and inclusive approaches to sharing knowledge and practices and for interdisciplinary or transdisciplinary processes to be considered essential by all key players in forest health.

New challenges, new TRIAD: investigating zoning-based forestry with functional enrichment to foster forest resilience

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: TRIAD forest management was proposed 30 years ago to reconcile conservation and exploitation by dividing the landscape into three types of zones with specific management goals: protected areas, intensive timber production areas, and extensive production areas. More recently, numerous studies in forest ecology have emphasized the importance of increasing forest resilience to uncertain future conditions by maximizing their functional diversity. In this perspective, we revisited the TRIAD management approach to add a resilience component. Using the LANDIS-II forest landscape simulation model, we tested novel TRIAD+ scenarios designed to improve forest resilience in the face of extreme disturbance events. To that end, we simulated a 4 million hectare landscape in the Mauricie region of Quebec for 200 years, with one of three extreme disturbances happening at t =100: fire, drought, or an insect outbreak. We monitored resulting changes in mature wood biomass across the landscape, and the resilience of forests impacted by the extreme disturbance via three measures: the resistance, net change and recovery time of their mature biomass and functional diversity. We then assigned to each simulation a unique combination of one of 4 management scenarios and 3 climate scenarios. The TRIAD+ management scenario used plantations to increase the functional diversity of the forests following cuts in the "extensive" zones of TRIAD. We also simulated the "classic" TRIAD and two "Business-As-Usual" (BAU) scenarios, one of which included "functional" plantations as in TRIAD+. The climate scenarios consisted of a Baseline, RCP 4.5 and RCP 8.5 scenario, impacting species growth and fire frequency in the landscape.

The new TRIAD+ resulted in a good compromise, improving the resilience, functional diversity and mature biomass of the landscape compared to the classic TRIAD and BAU without plantations, while drastically increasing the surface of protected forests. However, these improvements were relatively small, and our variables were mainly influenced by changes due to climate. As such, our study revealed important insights in the design of future forest management strategies, the practicality and efficacy of functional enrichment to improve forest resilience, and the urgent need to account for small-scale interactions at the stand level in Forest Landscape Models.

Retrospective analyses of weather-related extreme events, large-scale disturbances, and silvicultural strategies

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: Germany's forests have been characterized by intensive human use for centuries. This is still evident today in the tree species composition and the often uniform forest structures. Increasingly, forests are extraordinarily stressed by climatic development. Especially in spruce-dominated low mountain regions, large-scale disturbances occur due to storms, wet snow, and drought, which are additionally exacerbated by bark beetle calamities. With regulated forestry in the 19th century, precise documentation of forest management from planning to utilization began in Germany, so that the occurrence of large-scale disturbances and damages was also recorded. From today's perspective, these precise records of forestry operations form an extraordinary historical fund. In addition, meteorological measuring stations were established in many regions for the continuous recording of the climate and for weather forecasting. The current disturbances in forests caused by weather extremes have reached the most extreme proportions in the low mountain regions, so the question arises as to which silvicultural experiences and technical possibilities have been classified as particularly successful for reforestation in historical retrospect.

Our research project analyzes the silvicultural handling of disturbances in the forests of the model regions - Saxon Ore Mountains and Thuringian Forest - for a period of 200 years based on extensive regional archival records. We link the records of the meteorological measuring stations with the forestry records.

A look at history confirms that the spruce stands of the low mountain regions were particularly frequently and extensively damaged by climatic and anthropogenic factors. In both low mountain regions, for example, extreme storm events in 1868, 1876, 1903, and 1946 or the occurrence of drought years in 1800, 1893, 1904, and 1911 have been recorded. Despite enormous recurring damage and sound knowledge of the causes of disturbances, there was no consistent move away from pure spruce stand management. Our research demonstrates the early application of silvicultural treatment strategies such as tree species selection, specific regeneration procedures, optimization of measures via spatial order, and management of deadwood, associated vegetation, or pioneer tree species. These measures are frequently discussed even under current conditions.

Sirex woodwasp biocontrol: from Australia to the world and back again

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: Populations of Sirex woodwasp (*Sirex noctilio* (Hymenoptera: Siricidae)) on *Pinus* spp. have been largely managed throughout their non-native ranges in the Southern Hemisphere using a combination of classical (parasitoid wasps, particularly *Ibalia leucospoides* (Hymenoptera: Ibaliidae)) and augmentative (the bicyclic nematode *Deladenus siricidicola* (Tylenchida: Neotylenchidae)) biological control. Performance of this nematode can be impacted by biotic interactions with the Sirex symbiotic fungus (*Amylostereum areolatum* (Russulales: Amylostereaceae)) upon which it feeds, with bluestain fungi vectored by bark beetles, as well as by temperature, moisture, nematode inoculation technique, and pine taxon. These factors, as well as a lack of genetic diversity among biocontrol populations globally, and the legacy of a "defective strain" that arose through continuous mass rearing in Australia, are thought to have additionally contributed to limitations in achieving consistent parasitism rates by the nematode across Southern Hemisphere regions.

Here, we discuss the fascinating history of the Sirex biocontrol program pioneered in Australia in the 1960s and 70s, that was subsequently disrupted by the emergence of the defective strain in the late 1980s. Nematodes then collected from an original release site in Kamona, Tasmania, returned virulence to the program, and these were adopted by South Africa and several countries in South America. This shared resource, and possible inbreeding in culture, contributed to reportedly homozygous populations across the Southern Hemisphere, and concerns for the sustainability of the biocontrol program. More recent studies have uncovered unexpected diversity in *D. siricidicola* populations in Australia and New Zealand, including the identification of a dominant cryptic field strain (Lineage D) in background Sirex populations.

The Kamona strain has been used as an augmentative biocontrol agent, while Lineage D has behaved more as a classical biocontrol agent in Australia; having possibly originated from initial Australian releases in the 1970s or by accidental introduction via infected Sirex. It was confirmed as a sterilising strain, and has a higher reproductive rate than Kamona, and is being incorporated into release programs in Australia and South Africa. The potential of Lineage D to improve biological control of *S. noctilio* illustrates the value of characterizing the applied molecular ecology in biological control systems.

The southern pine beetle monitoring and forecast team -- a community success since 1988

T1.17 Learning from the past to better inform the future: integrated approaches to increase forest health and resilience

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Abstract: The southern pine beetle (SPB), *Dendroctonus frontalis* is among the most naturally aggressive tree-killing insects in the world. In its native regions of southeastern USA and Mesoamerica, SPB displays episodic epidemics that can kill native pines within thousands of km^2. Direct costs to forest industry are in billions of USD. Indirect effects on forests and people are profound. In 1988, Ron Billings, Texas Forest Service, organized a network of forest health professionals to sample the abundance of SPB and its specialized predator in spring with pheromone-baited traps and a common protocol. The data were mailed to Ron, who generated forecasts of outbreak risk for the participating forest areas. The forecasts were valued by participants then and now. As of 2022, even with none of the original people still active, and with no centralized financial support, the team had grown to hundreds of cooperators from dozens of state and federal institutions representing 269 forest management areas in 12 states. Now, individual cooperators enter trapping data into a cloud-based GIS system, where it is swept into www.spbpredict.com, connected with previous abundance estimates, and used to predict the probability of an SPB epidemic for each forest area in the coming summer. The growing database is publicly available and the model is open source. The system lends itself to continual improvement as knowledge of SPB population dynamics grows and data accumulate. Since inception, the model has evolved from one that emphasized cyclical dynamics due to predator-prey interactions to one that postulates alternative states of low and high abundance separated by an escape threshold. The statistical model is a zero-inflated Poisson, which matches the theoretical model of alternate states. A practical implication of there being an escape threshold is that suppression will be most effective early in a nascent outbreak, which enhances the value of short-term forecasts. Among the challenges is how to communicate and interpret forecasts that describe a statistical distribution of possible outcomes rather than predicting a specific result. A broad benefit has been to promote constructive discussions of SPB biology and management among diverse community members who bring different knowledge and perspectives.

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

A methodology to assess atypical forest stand dynamics: an application in the temperate forest of southern Quebec

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Global changes create specific conditions that most often lead to abrupt responses of the ecosystems that, in some cases, result in an ecosystem collapse (EC). This phenomenon occurs when an ecosystem changes drastically in terms of its composition, structure and function. A major challenge for current forest management is the lack of quantitative measures required to detect the occurrence of EC. We present here a new methodological approach to quantify the EC events that have occurred over the last 50 years in the temperate forest of Quebec, using the permanent sample plots (PSPs) dating from 1970. Based on transition vectors expressing changes in the composition, the structure and the function of the PEPs, we identified trajectories which are representative of the recurrent forest dynamics, and are specific to each of the most important ecological types of temperate hardwood forest. Then, these trajectories are used to identify divergent trajectories that represent either stagnation or EC. We present an application of this approach to the case of mesic maple stands (FE3). Our findings highlight that in the recent decades, some ecosystems tend to diverge more from the trajectories of the recurrent dynamics suggesting a loss of the ecosystem identity. The tools developed by this approach can be used to guide management and conservation actions in order to maintain the identity of forests as these are subjected to changing environmental conditions.

Keywords: Global change, temperate forest, forest ecosystems, ecosystem collapse, stagnation, permanent sample plots, recurrent dynamics, divergent trajectories.

Agua Salud: A long-term Research Initiative in Panama

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Long term research sites are critical to understanding global change as they allow researchers to interpret changes in reference to historical baselines and capture the effects of severe weather events like floods and droughts, events most likely to affect forest dynamics. The Smithsonian Tropical Research Institute (STRI) recently celebrated its 100-year anniversary in Panama. Under the leadership of Ira Rubinoff, STRI initiated and has maintained a tradition of long-term research sites, watersheds, networks, and plots, some for more than 40 years. The Agua Salud Project, in the center of the Panama Canal Watershed, studies the ecosystem services provided by tropical forests and how they change with land use and climate change. The project leverages basic, use-inspired, applied research, and natural history observations to address broad research questions related to land and forest management; silvicultural interventions include several forest restoration treatments targeting timber yields as well as managing for other ecosystem services. Agua Salud celebrated its 15th year of a proposed 40 plus year project in 2023. Unlike other long-term research and monitoring programs at STRI, Agua Salud is almost entirely dependent upon external resources secured through fund raising. Its core budget necessary to "keep the lights on" is $225,000 a year but could absorb over $2 million annually were it to be used to its full research potential.

In this talk we will discuss the Agua Salud experimental design and how we have leveraged extreme events and changing research emphasis towards mitigating the worst effects of global change to incorporate new research directions while still working to address the original long-term goals of the project. The necessity to remake, refocus, and repackage research questions that can be addressed in shorter time periods that will attract funders requires a full-time scientist overseeing management and the project vision, something not always recognized as valuable in the scientific community.

Digging into tree and stand dynamics: benefits from long-term yield trials – current and future perspectives

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Diverse data sources facilitate the understanding of forest ecosystem functioning and development of best management options. Among them, long term yield experiments, historically forming the nucleous of systematic forest science, provide specific advantages when questions concerning tree and stand level development affected by the interaction between environment and management activities are addressed. The presentation examplarily highlights currently emerging issues in forest ecology which are dependent on long-term observations to be solved. We show how information from unmanaged plots provide insights into maximum stand density development. Maximum stand density translates into density-productivity relations along a density reduction gradient, including mortality and prethinnings, which support the assessment of long-term growth relations between species and provenances. This is a relevant asset, when it comes to both, the decision about the most suitable and resilient species and to evaluate the effect of management activities on growth dynamics and resilience. We then emphasise the benefit of long-term observations for quantifying and understanding shifts in growth dynamics in the frame of changing environments. Lastly, we present an innovative plot design for mixed species stands that build upon the lessons learned during decades of managing long-term yield experiments. The necessity of preserving existing long-term experiments, and sustaining the scope and monitoring will be discussed.

Effect of silvicultural itineraries with contrasting objective density on forest processes to mitigate soil water deficit

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: European forests are subject to climate change with uncertain consequences. Therefore, it becomes as uncertain to predict wood production, especially for not common silvicultural practices. For example, one of adaptation option is to achieve lower objective density, to reduce evapotranspiration and precipitation interception. This mitigate soil water deficit and to increase available water for remaining trees in pedoclimatic context where water is already a limiting factor. However, these managements with lower density and reduced leaf area index raise questions about impact on ecosystem functioning or wood quality. It is becoming urgent to focus on this type of management to assess their relevance, their real potential and their limits.

In our work, we chose to study the effect of silvicultural practices with contrasting objective densities on tree transpiration and carbon storage in sessile oak (*Quercus petraea*) and Douglas-fir (*Pseudotsuga menziesii*) stands. We focus on three contrasting densities which will allow us to understand the effect of increasing competition on tree and stand functioning. First, stand leaf area index is determined. Then, tree transpiration is estimated thank to sap flow, measured with Granier sensors during early summer season. Finally, we study carbon storage through non-structural carbohydrates concentration, in three compartments, at different times in the growing season. So we can estimate carbon allocation to storage function according to forest management, at tree and at stand scales.

We work on GIS Coop networks: long term silvicultural experimental French networks in regular and heterogenous forest management systems. For 30 years GIS Coop manages 1200 plots exposed to highly contrasted stand density regimes, from open growth to self-thinning, for understanding stands dynamics for new forestry practices under a changing environment. In our study the added question is: how decreasing objective density modifies stand leaf area index, tree transpiration and carbon storage? Specific data will be collected on 2 sites, in pure and even-aged Douglas fir and sessile oak stand. We expect a decreasing stand evapotranspiration and rainfall interception with decreasing density, and an increasing carbon storage with decreasing stand density, thank to hydric stress release, but not especially a difference in carbon allocation.

Exploring the relevance of the Nelder wheels design for forest research: A case study of Pinus species interaction

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: The Nelder wheels design, originally developed for studying spacing in horticultural crops, has regained interest in forest research due to advancements in computationally affordable methods for analyzing mixed models and spatial statistics. This study examines the applicability of the Nelder wheels design to insight on intra- and inter-specific interactions among two Mediterranean pines (*Pinus pinaster* and *Pinus halepensis)* seedlings.

The experimental setup consisted of five Nelder wheels planted in Palencia, northern Spain, in 2013. This design allowed the examination of ten density levels, ranging from 1000 trees/ha to 80000 trees/ha, within a relatively small area (less than 1 ha), with the two species intercalated to create diverse mixture levels.

The advantages and disadvantages of the Nelder wheel design are evaluated, with particular attention to addressing the challenge of mortality and its impact on density analysis. Various solutions proposed by researchers to mitigate the impact of plant mortality on the experimental design are discussed, including the use of Voronoi diagrams to recalculate growing space and density.

The study also examines the survival, growth, and biomass production of the planted seedlings. Statistical models, such as Cox models, binomial logistic regressions, and mixed models, were employed to analyze the data. Findings from the study highlight the potential of the Nelder wheel design in capturing species interactions and biomass dynamics. *Pinus halepensis* exhibited higher survival rates and growth, while the mixture effects of species require further investigation to uncover the complex competition and facilitation equilibrium. Under high densities, competition and facilitation interactions were observed, with higher survival rates but reduced growth. Notably, density significantly influenced biomass dynamics for *Pinus halepensis*, with lower densities leading to higher total biomass increments but an increased proportion of root biomass compared to aboveground biomass.

In conclusion, the Nelder wheel design proves to be a valuable tool for investigating species interactions and biomass dynamics in forest research. Its ability to accommodate various density levels within a limited space offers insights into forest regeneration patterns and management strategies.

Forest conversion with beech – Back the wrong horse?

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: The summer drought in 2018/19 in Central Europe led to a massive decline in the vitality of European beech (Fagus sylvatica). Until now, European beech is the main tree species of many forest conversion programmes. Understandably, the forest administrations are very concerned about beech dieback. As a result, we want to detect the potential of European beech under rising temperature. Therefore, we use many long-term experimental plots in Germany with more than 70 years of observation. We analyze the amount of removed beech trees and the reason of removal. Based on a broad site and age gradient, we investigate the following research questions: 1. How does the amount and the proportion of removed trees changed over the time, separated by human-made thinning and natural mortality. 2. What is the influence of climatic conditions? 3. What influence does the competition have? Based on the results, we discuss possible silvicultural strategies for dealing with beech under climate change.

From evidence into practice – case Finland

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: The annual growth of the forests of Finland has more than doubled in less than a century. While the environment-induced increment increase is substantial, a considerably larger increase representing 2/3 of the change is attributed to growing stock volume and forest structure. They both have changed over time due to efficient forest management and new silvicultural regimes, elaborated based on long-term field experiments.

The earliest long-term plots and experiments were installed in the 1920s, before statistical thinking, to provide data on forest dynamics and for building yield tables. Some of the observational plots dating back to these days are still being monitored. Beginning from the 1960s, new types of experiments were established including plots with different thinning intensities as well as unthinned reference plots. The obtained data have been used for studying forest ecology and management, as well as developing silvicultural guidelines, models and decision support tools. In addition to the original aim of intensifying wood production, the long-term records on tree and stand characteristics have provided evidence on wood properties, mortality, woody decomposition and carbon sequestration, among other things.

In times of scarce resources, several experiments have been considered too expensive, outdated, or abandoned due to damage and land use or owner change. On top of that, transition to research projects lasting a few years makes long-term maintenance of the experiments challenging, not to mention establishing new ones. However, short-term projects on changing fashion topics have provided supplementary resources to dwindling basic institutional funding to maintain the experiments in time spans of decades or even century. Despite all the challenges, we still preserve a unique set of long-term experiments delivering information on retrospective changes in structure and functioning of managed and unmanages stands.

From fuel wood production to climate change mitigation – expected and unexpected answers from long-term forest experiments in Austria

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: The Austrian Research Centre for Forests (BFW) was founded in 1874 and has a long tradition in the establishment and maintenance of long-term forest experiments. At that time the experiments were mainly comprised of thinning trials in Norway spruce (Picea abies [L.] Karst.) and common beech (Fagus sylvatica [L.]) in order to study total volume production with regard to stand density. In 1892 a spacing experiment in Norway spruce was established at "Hauersteig" and measured for more than 100 years. The first results of this spacing trial were published in 1974 having a revolutionary effect on the initial spacing of newly planted stands. In 1969 the European stem number experiment was established in 14 European countries and coordinated by the International Union of Forest Research Organizations (IUFRO). In Austria this experiment was observed until 2016. Finally, at the beginning of the 1990s, a set of 5 spacing trials with cloned plant material was established in Austria. All these experiments can be considered as the core experiments of the Forest Growth Unit of BFW. They are restricted to Norway spruce, which is currently the most important tree species in Austria. In total the Forest Growth Unit of BFW is currently running 67 long-term forest experiments addressing various research questions.

The above mentioned experiments were selected because they clearly reflect how research questions evolved over a time span of approximately 100 years. Furthermore, they are imposing examples of the value and benefits that long-term experiments can have for unexpected and suddenly emerging research questions. Specifically, this contribution will show (i) how the data were used for the validation of an individual-tree growth model, (ii) how the data were used for the development of biomass equations, (iii) how the data were used for economic analyses to support decision making of forest managers, (iv) how timing and severity of thinning operations determine the vulnerability of forest stands against storm and snow damage, and (v) how wide spacing afforestation as well as thinning operations affect carbon storage and carbon sequestration of stands of Norway spruce.

Growth and yield model calibration and evaluation: the role of long-term silviculture experiment data in British Columbia, Canada

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Since the 1970s, the Province of British Columbia (BC) has invested many resources in the design and development of the Tree and Stand Simulator (TASS), its primary growth and yield model for projecting the dynamics of regenerated and silviculturally treated forest stands. Crucial to this program has been the availability of remeasured data from long-term experiments focusing on species selection, espacement, thinning, realized genetic gain, forest health and provenance which have been established and persistently maintained by a succession of committed research staff over the years, both within BC and beyond. The TASS component functions governing height increment, bole area and volume increment, wood quality attributes and crown growth are parameterized for each tree species using data collected through the destructive analysis of stems and crowns and other measurements of individual tree attributes. In a subsequent phase of calibration, key coefficients related to volume growth and mortality are re-estimated so that the simulated trends in volume and mortality conform to the magnitude and patterns of a set of guide curves for different stand densities in each species. These guide curves are a synthesis of the stand-level trends in volume growth and mortality observed in espacement trials and other growth and yield experiments. Therefore, it is highly beneficial for these field installations to be maintained as long as possible, despite the challenges. This presentation will demonstrate various approaches to generating these benchmarks. Beyond calibration, experimental installations in stand treatments continue to support evaluation of model response to thinning, pruning, fertilization, and variable retention harvest patterns, as well as the development of modules for simulating the impacts of genetic selection, forest health agents and climate change.

Influence of stand composition and thinning on drought resilience in mixed forests

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: In North America there is a growing interest in using mixed forest plantations as a silviculture strategy for improving forest resilience. Research has demonstrated that mixed forests have been beneficial for increasing diversity and in many cases, stand productivity. With predicted global increases in frequency and intensity of drought, the availability of water resources will become increasingly limiting, intensifying the inter and intra-specific competition within forest stands. Commercial thinning is an intermediate silviculture treatment implemented to manage water limitations, while at the same time, increasing the volume of residual trees. In the Pacific Northwest of North America, higher temperature heat events, and droughts are becoming more common, exposing coastal Douglas-fir and mixed forests to increased risk of reduced productivity and mortality. The objective of this study is to assess the effects of thinning treatments, coupled with tree neighborhood metrics, on Douglas-fir growth response to drought within different compositions of mixed forests. For this, several installations from the B.C. Ministry of Forests large-scale research experiment will be selected (EP703, established 1971-75). This long-term thinning study located on Vancouver Island, is a randomized complete block experiment designed to assess growth and yield in pure and mixed stands of Douglas-fir and Western Hemlock. Three installations (pure Douglas-fir, Douglas-fir - Hemlock mix, and Douglas-fir - Western Redcedar - Hemlock mix) will be compared, each with three levels of thinning treatments (0%, 20% and 35% of basal area removed). To assess the thinning responses in pure through mixed research installations, increment cores will be extracted from each treatment level within the selected sites. A multi-proxy approach will be used to assess Douglas-fir performance and survival to drought events by estimating tree basal area increment, and water use efficiency from stable isotope analysis. The results of this study will provide valuable information regarding silviculture methods for the management of Douglas-fir ecosystems that have been experiencing drought and are at increased risk of drought, while highlighting the effects of species complementarity.

Lessons learned from three long-term field experiments: impact of silvicultural practices on forest dynamics in a changing climate

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Long-term field experiments enhance our collective understanding of forest dynamics in a changing climate and lead to the successful implementation of sustainable forest management strategies. British Columbia has a long history of establishing and maintaining long-term and large-scale forest research trials. In this presentation, authors illustrate lessons learned over several decades from three long-term experiments: the Shawnigan Lake Thinning and Fertilization project, the Levels-of-Growing-Stock (LOGS) study, and the Montane Alternative Silvicultural Systems (MASS) study. These experiments were established to provide answers to a variety of research questions from several fields, including tree physiology, tree and stand development, forest regeneration, understory vegetation, silviculture, and growth and yield. More recently, these field experiments were used to address emerging research questions relevant to forest management in a changing climate and forest carbon accounting. Authors discuss their experience with maintaining and ensuring the continuity of long-term research using these field experiments. Some of the required elements include: i) dedicated forest land ownership, public or private; ii) research teams spanning multiple organizations; iii) resources for regular remeasurements and maintenance of field installations; iv) dedicated database management; v) regular field tours with research users and other interested parties; vi) educational opportunities for forestry students and the general public. Long-term experiments provide a myriad of learning opportunities, as well as baseline data to evaluate the impacts of silvicultural interventions. Current research questions on forest dynamics in a changing climate are extremely complex and require multidisciplinary research teams making full use of existing long-term experiments.

Long-term monitoring study on establishment of permanent plots for thinning effects and development of thinning models in Republic of Korea

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Accumulation of long-term data on forest is essential for sustainable forest management, but insufficient of time series data on tree growth by thinning practices in Korea. It is needed to establish the data base according to thinning practices through long-term monitoring. The final goal of the study is to develop thinning models focused on major planting species which are *Pinus densiflora(Pd)*, *Pinus koraiensis(Pk)*, and *Larix kaempferi(Lk)* in the national forests of Republic of Korea. For the study permanent monitoring plots(PMP) were established in the forest satisfied the criteria as follows;1) never thinned since plantation or passed at least 7 to 8 years since last thinning, 2) free of insect, snow or wind damages, 3) one tree species to occupy more than 80%. Each PMP consistis of three squared plots, that is, non-thinning (20m x 20m), light thinning(25m x 25m) and heavy thinning(30m x 30m) plots. The thinning ratio was 0% in the control, 20% in the light and 40% in the heavy based on the basal area. The principle for selecting trees for removal was based on the assumption that the objective of the residual stand was to produce commercial sawtimber. Therefore, thinning treatment was applied primarily to small, forked, damaged, swept, or trees otherwise unsuitable for sawtimber. Also, we considered spatial relationships between individual trees. In 2012~2015 permanent monitoring plots were installed in 45 sites of *Pk*, *Pk*, and *Lk* respectively. Inventoy factors are DBH, height, dead, species, stem quality, crown width, distance between trees etc whichwere surveyed every 3 years. A variable stand density yield model that can predict the stand volume of various densities, a site index that can diagnose the productivity of a stand, and a stocking chart that can diagnose the stock of stands have been developed. For these models to be used to predict the yield of forests considering the thinning effect and the amount of wood production by stem grade or use, it is necessary to construct a database by longer term and prevent the study site from a damage, especially anthropogenic damage.

Long-term, large-scale silvicultural experiments of loblolly pine plantations: new concepts and new findings

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Loblolly pine (*Pinus taeda* L.) is the most commercially important species in the southern US. Intensive silvicultural treatments such as site preparation, competing vegetation control and fertilizations are commonly used to enhance wood production and reduce the rotation length of loblolly pine plantations. Numerous studies have focused on young stands and reported the increased early growth through the use of intensive silvicultural practices. However, results for young plantations are not necessarily good predictors for the treatment responses at later developmental stages. Furthermore, forest landowners and managers are now shifting their interest from short-rotation production of fiber to long-rotation management for integrated objectives including high-value solid wood products, biomass for energy, and carbon sequestration. To effectively manage long-rotation plantations, it is necessary to understand the long-term effects of silvicultural treatments on forest dynamics. Based on our comprehensive analysis of nine long-term large-scale experimental studies of loblolly pine plantations across the southern US, we will discuss some new concepts and new findings. (1) There exist maximum productivity and maximum response to silvicultural practices for loblolly pine in the southern US, and the maximum response is inversely proportional to the base site quality. (2) We can define and estimate stand-level maximum BA and maximum SDI to provide a realized carrying capacity for individual stands, which is critical for developing stand-specific thinning regimes. (3) High site quality, more intensive silviculture, or high planting density generally increased stand foliage biomass and thus increased stand aboveground net primary production (ANPP) at early ages (i.e., before reaching the maximum ANPP); thereafter, ANPP could decrease from the maximum values more rapidly or slightly, or even did not have obvious declines, mainly depending on how silvicultural treatments, initial planting density and site quality affect stand biomass mortality. These findings have refreshed and expanded our knowledge about pine plantation ecosystems and provide a basis to calibrate growth and yield models and inform integrated climate-smart forest management.

Pre-commercial thinning in naturally regenerated European beech (Fagus sylvatica L.): effects of thinning and pruning on tree growth and stem quality

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Pre-commercial thinning in naturally regenerated stands of European beech is often expensive and must be justified by improved development of the remaining crop. Based on a field experiment established in two 14-year-old naturally regenerated beech stands in Denmark, we investigated some effects of pre-commercial thinning and pruning on future crop tree growth and stem quality. The treatments included (1) no thinning, (2) moderate to heavy strip thinning, with or without subsequent selective thinning, and (3) extremely heavy strip thinning in two perpendicular directions (checkerboard thinning), with or without subsequent selective thinning and with or without pruning. The resulting residual stand densities ranged from 10^5 to only 200 ha^{-1}. Treatment effects were evaluated on one potential future crop tree for every 100 m^2. Potential future crop trees were selected 32 years after germination based on spatial distribution, growth potential and stem quality. Total crop tree height was unaffected by strip thinning, but reduced by checkerboard thinning. Stem diameter at 1.30 m above ground level increased with decreasing stand density but, for checkerboard thinning, was reduced by pruning. The lower live branch was located at a lower position with heavy strip thinning and with checkerboard thinning without pruning. The frequency of crop trees with a forked stem was largest with checkerboard thinning and these forks were located at a lower position. Stem tilt and stem bend (stem straightness) were essentially unaffected by thinning practice. However, pruned trees tilted less and had straighter stems. The initial formation of epicormic branches on crop trees was unrelated to thinning and pruning practice, but crop trees that had been pruned for these were less prone to subsequently develop epicormic branches. In summary, moderate to heavy pre-commercial thinning had no effect on stem quality, while extremely heavy thinning without pruning resulted in unacceptably low stem quality. The no-thinning option resulted in acceptable growth and stem quality of the crop trees and this remains a viable management alternative for young beech.

Preserving institutional knowledge: lessons learned from a spacing experiment established in 1957 in British Columbia, Canada

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Long-term silviculture experiments have been established around the world over the past century and played a vital role in advancing our understanding of forest management practices. We learned many lessons by trial and error from the first generation of field experiments and used these insights to improve the establishment and measurement protocols for many of the experiments that were established in the last part of the 20th century. Since then, funding sources to establish new experiments have become scarce in many regions. With the retirement of experienced researchers who were involved in establishing past experiments, there is a concern regarding the potential loss of invaluable institutional knowledge related to the establishment and analysis of silviculture experiments. Consequently, there is a possibility of repeating past mistakes from the earlier parts of the 20th century. To mitigate this risk, it is crucial that we take proactive measures to document the existing knowledge on successful practices and lessons learned. In this study, we draw from a spacing experiment established in British Columbia, Canada, in 1957, to highlight the challenges faced when analyzing the data collected over more than 60 years. Some of these challenges include design features of the experiment, changes in measurement protocol and measurement standards over time, as well as limited documentation regarding establishment details and procedures. It is also important to highlight the successes and positive aspects that emerged throughout the lifetime of the experiment in terms of institutional collaborations and additional measurements that were added to address emerging research questions and needs. Even though, the analysis of the experiment was limited due to some of the design and data challenges, the results of this long-term experiment contribute substantially to the collective knowledge spacing and provide input for model building and decision-making processes. Therefore, we must continue our commitment to invest in the maintenance and remeasurement of existing trials. In addition, it is important to pursue the establishment of new experiments to answer emerging research questions and to incorporate the lessons learned in order to continually enhance our understanding of silviculture impacst on forest dynamics over time.

The Scots pine and Norway spruce growing dynamic of differenet thinning regime stands

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: The aim of this study is to relate initial stand density and thinning intensity to tree diameter, height and volume increment, based on continuous 30 m observations in thinning experimental stands of Scots pine (*Pinus sylvestris L.*) and Norway spruce (*Picea abies L. Karst.*). The thinning experiments of Scots pine and Norway spruce were established in 1990 and 1992 and experimental scheme in each trial comprised from five density variants: control, first time reduced density up to 3.0-4.4, 2.0-2.4, 1.0-1.2 and 0.5-0.6 thousand trees per hectare. Since the establishment, only the dead trees were removed in control plots and other density variants were thinned according to predefined thinning program. Number of trees per hectare (N), stand level competition index (CI), mean diameters (Dq), mean heights (Hq), standing volume (V), gross volume yield (GY), mean annual increment in diameter (id) and mean annual volume increment (MAIv) and productivity were analysed for each thinning variant and experiment.

Our study shows that the lowest increment in diameter was in control plots and the highest in the most intensive thinning plots (9-10), which had a 1.5 higher increment in diameter than 1-2 plots. The average volume increment is 2,5 – 3,5 times higher in 9-10 plots compared with control plots. The intensification of thinning and the signs of stabilization of growth in the control stands cannot guarantee them the position of highest productivity and cumulative volume in the future. The average diameter of the trees in a stand, as well as the diameter/height ratio and the resilience of the stand, increases steadily with decreasing stand density.

Thinning increases drought resilience of oaks at the northern edge of their distribution

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: Drought can impact forests directly causing a decrease of forest growth, but also increase the vulnerability of trees to secondary pests and pathogens or fire, causing an additional loss of productivity. To develop new silvicultural strategies, it is crucial to understand if thinning can promote resistance and resilience of residual trees to drought by reducing moisture stress. Given projected drier summers, the aim of the study was to determine how oak (*Quercus robur* L.) tree growth is affected by severe summer droughts under different thinning intensities. Oak is distributed across large parts of Europe. However, the relationships between stand density and tree drought susceptibility in oaks has not yet been studied in the northern edge of its distribution in Scandinavia. This is likely in part due to the scarcity of thinning experiments in oak. We used a well replicated long-term study planted in 1952 with one- and two-year old seedlings of oak in southern Sweden, where oak is an important species economically and culturally. Three different treatments were established in 1991 following a randomized block design with two blocks, each containing three residual density levels. We collected tree cores to reconstruct past tree diameter growth before and after specific droughts occurring after thinning. We observed that heavy thinning increased drought resistance and decreased recovery time from drought, especially for stands with an initial low basal area. Positive effects of thinning on resistance, recovery and resilience dissipated over time, particularly for high thinning intensities. Our results suggest that heavy and frequent thinning interventions would be an appropriate forest management pathway to alleviate drought stress in pure oak stands at the northern edge of their distribution, by reducing competition for water.

Tree growth and forest degradation over 15 years in the Baikiaea woodlands of southern Africa

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: The dry Baikiaea woodlands are a fragile ecosystem at the geographic and climatic edge of the forest biome in southwestern Africa. They are subject to a combination of disturbances, mainly browsing, logging, fire and drought. Variations in the frequency and intensity of these disturbances, for instance due to climate change or changing human land use practices, can lead to forest degradation and forest loss. Currently, however, there is little long-term quantitative data on forest composition and woody biomass to assess the severity of Baikiaea woodland degradation and loss. Moreover, little is known about the growth and population dynamics of the dominant tree species in the Baikaea woodlands, limiting future wood volume and biomass projections. Long-term monitoring is hampered by many logistical challenges. This study evaluates the challenges encountered and inventory data collected over 15 years in three permanent sample plots in Namibia's state forests, representative of the western Baikiaea woodlands. The objectives are to (1) detect changes in forest structure, species composition and carbon pool, (2) assess if changes can be linked to natural disturbances, (3) determine rates of tree growth, mortality and recruitment across species and demographic groups, and (4) highlight challenges for long-term monitoring of forests in an African context. Species richness and indicators are determined for upper- and understory, while diameter distributions allow for assessing forest structure. Woody biomass and carbon are estimated with pantropical and regional allometric equations. Global climate databases and MODIS data are used to identify droughts and fires. The results contribute to determining sustainable timber harvest rates, regional carbon sequestration, and are relevant to the Great Green Wall initiative recently launched by SADC. Long-term international support is however required to expand forest monitoring infrastructure and perform repeated inventories, which can be facilitated by global plot networks such as SEOSAW.

TRENDS OF INDIVIDUAL TREE CORK INDUSTRIAL QUALITY ALONG THREE SUCCESSIVE DEBARKING OPERATIONS

T1.18 Long-term experiments to study the effects of silvicultural interventions and climate change on forest dynamics

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Abstract: In 2012 the trade of raw cork accounted for 0.159 Mtons. This value was 29% of the total traded value, since the higher added value of the cork supply chain is generated from the cork stopper production. The industrial cork quality (ICQ) is determinant for the material physical properties and therefore its final usage. ICQ varies from 1 (best) to 7 (lowest quality). The perception of stakeholders is that ICQ is getting worse in the last decades. The objective of the present work was to evaluate, at the tree level, the trends of the ICQ along three consecutive cork debarking operations and the drivers of those trends. The data set used includes cork samples collected in 37 permanent plots in three consecutive debarkings between 1996 and 2010. The data set therefore includes paired data. Each sampled was classified for ICQ following the industrial procedure. The final data set included 809 pairs of observations: 417 pairs from the 1st to the 2nd debarkings, and 392 pairs from the 2nd to the 3rd debarkings. The McNemarBowker test (MBtest) allowed to test the symmetry of the contingency tables produced. Dendrometric, stand management and climate variables were tested as explanatory factors for the trends observed. Results from the MBtest for the full data set confirmed the decrease in the quality from the 1st to the 2nd debarking (p-value<0.0001), but the same was not observed from the 2nd to 3rd debarking (p-value = 0.6628). When observed at the plot level, distinct trends between plots were observed. Dendrometric and management variables showed no significant relationship with the trends observed, with the exception of a small effect of the tree diameter, suggesting larger trees to have a higher probability of decreasing cork quality between consecutive debarking. The effect of climate, assessed by indicators such as SPEI and SPI, showed an interaction with the plots effect. Tree effect, namely due to genetics, was significant. Further research is needed regarding ICQ evolution using long term permanent plot data and more samplings. On the other hand, the effect of management practices should be researched by the installation of specific controlled trials.

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

A Wildfire Resilience Decision Support Tool for Planners and Managers

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Planscape is an open-source wildfire resilience decision support tool for planners designed to bring the best available state and federal data and science together in a user-friendly, accessible format. Currently, Planscape is being developed in partnership with the state of California to provide free, accessible planning options to various user groups throughout the state. Planscape helps regional planners prioritize landscape treatments to mitigate fire risk, maximize ecological benefits, and help California's landscapes adapt to climate change.

The state of California is committed to increasing the pace and scale of forest, shrubland, and rangeland treatments from a current average of 250,000 acres per year to 1 million acres per year starting in 2025. However, the state noted that there was little guidance on how to prioritize projects to achieve the state's goals for achieving wildfire and climate resilience. The mission of Planscape is to empower regional and forest unit planners to prioritize resilience treatments across the landscape and fund the most impactful projects.

Planscape uses a range of open-source datasets developed by the state of California as the base data for planning. A user interface allows planners to explore the data layers individually, as well as overlaying roadways, administrative boundaries, and past fire history. The modeling framework that Planscape uses to prioritize areas for treatment is derived from ForSys, a scenario planning tool developed by the US Forest Service for exploring landscape management scenarios and optimizing decisions in terms of where and how to achieve landscape restoration and fuel management goals. Planscape provides an intuitive, user-friendly interface which enables managers to harness the power of ForSys. In addition to providing treatment scenario optimization, Planscape is also able to provide cost and revenue estimates for forest health treatments and to prioritize treatments based on cost constraints.

As Planscape development progresses, we plan to include a full suite of ecosystem service estimates based on treatment type and treatment intensity. This framework will allow practioners to leverage a vast array of data and information technologies in effective and meaningful ways, and lead to well-informed, objectively-prioritized project planning activities.

Analysis of the development of new governance approaches for the provision of forest ecosystem services. Six case studies in Europe, China & Colombia

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: This research presents the results of applying a systems-based analysis approach to the identification of the factors that most influence governance innovations, the relationship between system dimensions and factors in order to shed light on innovation processes/patterns and compile recommendations for forest policy and. Forest systems are conceptualised as socio-ecological-technical systems that pose particular conditions for novel governance approaches in private, community owned, and state-owned forests. Accordingly, we analyse these contextual conditions in five different regions of Europe and explore how they influence the emergence and development of governance approaches. Examples include new payment schemes and compensation approaches for the cases of the Habitat Bank in Finland, Vida Manglar in Colombia and Forest Share in Germany, as well as new partnerships and actor networks for the cases of Forest and Pasture Management in Italy, Love the Forest in Sweden and a Sustainable Forest Value Chain in Austria. The results show that the governance approaches studied are closely influenced by the context conditions in which they emerge, and vice versa. While we observed common patterns in the influencing factors that seem to play a key role in all the cases analysed, we were also able to identify particular conditions for the design and work of governance. These relate to their individual historical development, disruptive events, local context, knowledge sharing, policies and incentives. The key impact lies in assisting the management of governance innovations, shedding light on their emergence and potential for future development.

(It is currently planned to apply the framework to additional 10 cases in a Horizon Europe Project in China and Europe at the second half of 2023)

Assessing Habitat Quality of West African Forests: Trade-offs and Opportunities for Sustainable Land Management in Agricultural Landscapes.

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: The expansion of agriculture in West Africa drives forest fragmentation, biodiversity loss and a decline in ecosystem services. To guide effective land and natural resource management decisions in the region, it is essential to evaluate and quantify ecosystem services. This study uses quantitative and qualitative data and employs the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model to assess the impacts of land-use change on the ecosystem services' capacity of nine forest patches in four West African countries: Togo, Benin, Nigeria, and Cameroon. The focus is on provisioning (e.g. crop production), regulating (e.g. carbon sequestration), supporting (e.g. habitat quality), and cultural ecosystem services (e.g. sacredness and spiritual contributions), which are vital to the local communities residing near the forest patches. The analysis covers a 20-year period from 2000 to 2022, revealing recent trends. The land use change analysis shows an increase in agricultural land, particularly in areas where cocoa production serves as the primary income source for communities. However, this expansion of farmland results in a decrease in carbon sequestration due to forest conversion. Additionally, some forest patches under formal and informal protection status demonstrate improved habitat quality for tree species considering their diversity and density. While provisioning services is generally very important to the local communities, cultural ecosystem services predominate for sacred forests, showing the differentiated capacities of the forest patches to supply ecosystem services in their mosaic landscapes. Given their rate of change, we explore the potential of the forests to maintain or enhance their ecosystem services over time. These preliminary findings highlight that progressing towards sustainable management of these forests requires a differentiated approach that considers the importance of their varying ecosystem services to the local communities.

Keywords: Land-use change; Forest fragmentation; Ecosystem services; InVEST model; Agricultural landscapes, Rural livelihoods; Tropical forests

Balancing Ecology and Economics: Exploring the Benefits of Thinning in Japanese Cypress Plantations

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Managing stand density in forestry plantations is known to have positive effects on various ecosystem services. It is crucial to assess the cost-effectiveness of such management strategies, considering limitations in human and economic capital. The objective of this study is to simulate the effects of thinning on regional-level forest ecosystem services (habitat supply, water purification, climate regulation, forestry profits) over the next 10 years and estimate the associated labor and costs. We conducted simulations to predict the growth and density of each stand for each year and identified stands in Japanese cypress plantations with tree densities above a certain threshold for thinning. We then evaluated ecosystem services based on these simulated management and stand structures. Habitat supply for terrestrial organisms was assessed using understory vegetation cover, inferred from upper stand density that influences the light environment. Water purification was estimated by predicting soil erosion using the Revised Universal Soil Loss Equation (RUSLE). Climate regulation was evaluated by estimating carbon emission reduction through biomass power generation utilizing thinned wood as a substitute for petroleum fuels. Additionally, overall revenue was calcurated by deducting costs, such as labor, from the income generated through biomass sales. The results indicate that appropriate stand density management has positive impact on understory vegetation cover at the regional scale, leading to enhanced biodiversity. Moreover, this management approach was found to reduce soil erosion into rivers by over 10% and achieve a carbon emission reduction of at least four tons or more in terms of carbon dioxide equivalents. Furthermore, even when considering the costs of additional employment, the revenue generated from fuelwood sales was projected to be profitable. In conclusion, thinning practices have the potential to enhance the supply of ecosystem services at the regional level. The labor and costs required to implement these practices are within a realistic range. The findings of this study provide valuable evidence for policymakers aiming to formulate strategies that promote regional economic development and enhance ecosystem service provision.

Case study on Management option for securing multiple ecosystem services in Kalash valley dry temperate forests in Pakistan

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Context: Kalash valley has community owned dry temperate forests with great potential to manage for multiple ecosystem services. These are high value forests having timber, non-timber forest products(NTFPs), unique wildlife, and high significance for eco-tourism. However in the last six decades, the timber based management system, these forests have been degraded, and the various related products, services and functions have been drastically reduced. In order to restore these degraded forests and bring back the ecosystem services, the GEF financed Chilgoza Project started the resources assessment with local communities. A number of nature based solutions were also implemented including assisted natural regeneration. The payment for the ecosystem services(PES) was also implemented to generate financial resources for the re-investment in these unique forest ecosystem.

Method: To assess the resource and its value both tangible and non-tangible, a "Restoration Opportunity Assessment Methodology" (ROAM) was used. This tool utilized the GIS and RS technology for the resource assessment. Local consultation and focus group discussion were also held. Based on the results of the ROAM survey a robust management plan was formulated, where the multiple ecosystem services was the top priority for the management. In addition, the project also established plots for taking the regeneration data over 3 years period.

Results: 1)Due to the grazing exclusion, the assisted natural regeneration contributed significantly to the restoration of the degraded forests

2) There was a significant increase in the non-timber forest products

3) The negative impact of the climate change and other natural disasters were reduced

4) The integrated natural resource management approach was the successful one

5) The payment for the ecosystem services was a sustainable financial tool

Conclusions: 1) The community involvement proved a successful approach for the ecosystem services restoration

2) The natural based solutions are the key for the climate resilient forests

3) Due to the increased in production, there was evidence of the empowerment of the marginalized people

4) The women got more revenue from the utilization of non-timber forest products

5) The local communities are now in the process of registering their products as Global Indication (GI)

Comprehensive evaluation of forest assets and ecological products values based on satellite-ground data integration in Ewenki Autonomous Banner

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Forest ecosystem is the most important component of the terrestrial ecosystems, and its ecosystem service value evaluation is the key link of realization ecological products' value. However, how to establish a spatialized forest ecosystem service value evaluation model has always been a difficult point in forest resource value evaluation research. On the basis of systematically summarizing the theory and practice of natural resource value evaluation at home and abroad, this study elaborated a comprehensive system of methodology to evaluate forest resource assets and ecological products values based on satellite-ground data integration. Several data, including the basic geographic information, multi-scale remote sensing meteorological, socio-economic and ground survey data, were integrated to evaluate the forest resource assets and ecological products value and figure out its spatial distribution pattern in Ewenki Autonomous Banner in 2021. The results showed that: 1) The value of forest resources assets in Ewenki Autonomous Banner was 67.912 billion CNY, consisting of forest land assets (17.604 billion CNY), forest assets (29.954 billion CNY), and forest carbon assets (20.354 billion CNY). 2) The value of forest ecological products in Ewenki Autonomous Banner achives 42.945 billion CNY, consisting of timber/wood products (2.572 CNY) and forest ecosystem services (20.354 billion CNY). The value of each function was ranked as water conservation (17.013 billion CNY), carbon fixation and oxygen releasing (11.566 billion CNY), soil conservation (8.859 billion CNY), biodiversity protection (2.283 billion CNY), and wind erosion prevention (652 million CNY). 3) Spatially, the value of forest resource assets and ecological products in Ewenki Autonomous Banner both showed an increasing trend from northwest to southeast. The above distribution characteristics were related to local topography, climate and of vegetation distribution. The research results provided scientific basis for promoting the transformation of green water and green mountain into Jinshan Yinshan mountain, and were of great significance for promoting high-quality and sustainable development of regional forestry.

Conserving and restoring Quercus forests for spring shed management and spring revival to reduce water woes in Uttarakhand India

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Climate, demography and development are mega drivers resulting in loss of Himalayan forests. Different Quercus (Oak) species have been keystone for moist temperate mixed broadleaved forests in Central Himalayas. Quercus forests are home to high biodiversity, soil organic matter, and water holding capacity that supports subsistence of marginalised local communities. Historically thousands of springsheds new major water source for locals supported by healthy natural forests. Relevance of Oak forests has been highlighted in the Springshed conservation efforts by Government of India and their is focus on protecting and restoring catchment areas dominated by Oaks for reviving springs. Over the years deforestation, forest degradation in the region has also affected spring sheds. Many of these have either dried or are projected to dry worsening the water woes. Loss of forests, arrested natural regeneration and changed forest successional patterns were crucial in in loss of springs and necessary ecosystem services for well-being. Paper presents the impact of natural and human induced pressure on Banj Oak forests and how it has affected the structure and functions. Decline in regeneration of Banj Oak and relevant associated species due to human induced pressure is reported that further worsened due to impact of climate variability on the ecological niche of the species and is projected for 84-99% decline in its potential habitats by 2050 & 2070 respectively. Long term research on Oak dominated forest identifies deforestation to be more of a socio-ecological challenge that requires customised, integrated, multi-sectoral and interdisciplinary approach for protecting springsheds. Study presents a climate sensitive forest landscape restoration by involving diverse knowledge systems, community and women involvement for improve water provisioning, reducing disaster risks and interlinked women drudgery.

Designing a process framework for estimating the supply, trade-offs, and synergies of local forests' regulating ecosystem services

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: The supply management of ecosystem services of local forests is an essential issue as it is linked to the ecological welfare of local residents. This study aims to estimate the supply, trade-offs, and synergies of local forest regulating ecosystem services using a land cover classification map (LCCM) and a forest types map (FTM). Rigorous literature reviews and Expert Delphi analysis were conducted using the detailed variables of 1:5,000 LCCM and FTM. Land-use scoring method and Getis-Ord Gi^* Analysis were utilized on detailed variables to propose a method for estimating the local forest regulating ecosystem services' supply, trade-offs, and synergies. The analysis revealed that the rank order (1st to 5th) of supply of regulating ecosystem services was Erosion prevention, Air quality regulation, Heat island mitigation, Water quality regulation, and Carbon storage. When analyzing the correlation between the city's defined services, almost all services showed a synergistic effect. However, when analyzing locally, trade-off effects (Heat island mitigation – Air quality regulation, Water quality regulation – Air quality regulation) appeared in the eastern and northwestern forest areas. This suggests the need to consider not only the synergy and trade-offs of the entire forest between specific ecosystem services but also the synergy and trade-offs of local areas in managing the regulating ecosystem services of local forests. The study result can provide primary data for the stakeholders to determine the initial conditions of the planning stage when discussing the establishment of policies related to the adjustment of the supply of regulating ecosystem services of the forests with limited access. Moreover, the study result can also help refine the estimation of the supply of the regulating ecosystem services with the availability of other forms of data.

Economic valuation of a native forest of the Humid Chaco Ecoregion in Yaguaron, Paraguay.

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Native forests, through sustainable management, can generate economic income that could avoid deforestation or degradation of forest remnants and could also be attractive for income diversification for private land owners of these areas. The objective of this study was to economically value a native forest remnant located in the Guarapi Private Natural Reserve, in the district of Yaguarón, Paraguay, corresponding to the Humid Chaco ecoregion (Dinerstein et al., 1995). A permanent plot of 10,000 m² was installed where tree species with a Diameter at Breast Height (DBH) ≥ 10 cm were recorded and identified, and the following dasometrics parameters were evaluated: DBH, commercial height and total height. The direct use valuation (VUD) was performed by calculating the marketable volume of trees categorized in utilization classes according to Resolución del Servicio Forestal Nacional 04/92 (SFN, 1992) and the indirect use valuation (VUI) by calculating carbon (C) and carbon dioxide equivalent (CO_2 eq) (Sanquetta et al., 2018), via the method based on market values. The following scenarios were studied: 1) VUD considering the implementation of forest management plans (FMP), 2) VUI through the value of CO_2 eq, taking as reference the 2020 average annual price of the European Union Emission Allowances (EUA) value reflected in the Clean Development Mechanism (CDM) European CO_2 Trading System Exchange and 3) combination of scenarios 1 and 2. The total economic value of direct use assets, with a forest management plan, for case 1 was US$ 828.21, 2) US$ 54.65/ha with the EUA market value and for scenario 3) a value of US$ 882.86/ha was obtained. The forest has an estimable value in the Humid Chaco ecoregion and the data obtained could encourage private landowners to develop sustainable management plans or other economically profitable alternatives for the better use of forest resources.

Ecosystem Service Valuation in Lower Petchburi Watershed of Thailand

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Evaluating ecosystem services plays a vital role in the sustainable management of watersheds and natural resources. The ecosystem service valuation (ESV) in Petchburi watershed has been operated using value transfer or simple benefit transfers process. The land use patterns in 2009, 2014, and 2019 were classified using Landsat and Sentinel imageries interpretation. Then, land use change and prediction to 2029 were also classified using CA-Markov model. It was found that grassland, paddy field, and mixed deciduous forest tended to be decreased. Meanwhile, agricultural land including pine apple, rubber plantation, and orchard tended to be increased. The ESV of forest and rangeland tend to be decreased from 97.49 and 21.11 million USD per year, in 2009, to become 94.15 and 16.13 million USD per year, in 2029, respectively. Whereas, the ESV of agricultural land and water bodies tend to be increased from 146.41 and 23.91 million USD per year, in 2009, to become 150.70 and 28.47 million USD per year, in 2029, respectively. The study findings indicate a decrease in the overall ecosystem service value within the Lower Petchburi watershed, primarily due to changes in land use such as deforestation.

Keywords: land use change, land use projection, ecosystem service valuation

ECOSYSTEM SERVICES AND AGRICULTURAL DATA: TERRESTRIAL ARTHROPODS SURVEY IN A PINE FOREST MINING AREA IN THE PHILIPPINES

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: This study presents the methodologies, results, and conservation recommendations for a terrestrial arthropod survey conducted in Lepanto Consolidated Mining Company, Mankayan, Benguet, during the dry season in December 2021 and wet season in June 2022. Foliage-dwelling arthropods were sampled along a one-kilometer transect line, with four sampling points at 250-meter intervals. Ground-dwelling arthropods were sampled using pitfall traps, with ten traps randomly set-up in each sampling plot. Additionally, opportunistic sampling was performed by collecting visually observed arthropods within the sampling plots. Specimens were preserved in 95% ethanol and identified up to the nearest taxa possible then subjected to diversity analyses, which provided insights into the dominance of certain species, overall species diversity, species richness, and evenness within the arthropod communities. Two types of farms were compared within the sampling sites: rice farm and crucifer farm. Results showed that the rice farm has significantly higher diversity than the crucifer farm for both wet and dry seasons, and more arthropods were collected during the wet season for both farms. This survey revealed the functional guilds of arthropods present in the area, including decomposers, pollinators, seed dispersers, insect pests, and natural enemies, wherein they play vital roles in ecosystem processes such as decomposition, nutrient recycling, pollination, and biological pest control. Moreover, most of the collected species were considered agricultural pests. Their presence in agricultural areas highlighted the economic challenges faced by farmers, who heavily rely on pesticides for pest control. Conservation strategies were proposed, emphasizing the importance of ecological pest management (EPM) in agricultural areas. EPM promotes the use of diverse crops, resistant or tolerant varieties, soil health improvement, crop rotation, stress on pests, and enhancement of beneficial insect populations. These contribute to the balance of biodiversity, pest regulation, and sustainable agricultural production. Understanding the intricate relationships among biotic and abiotic components within ecosystems can provide valuable insights for conserving terrestrial arthropods and promoting sustainable land management practices. These findings contribute to the establishment of baseline data and conservation recommendations for terrestrial arthropods in Lepanto Consolidated Mining Company and similar ecosystems.

Enhancing Forest Multifunctionality: Embracing Diverse Management Alternatives to optimize for Ecosystem Services' provision

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: To meet the demands for multiple ecosystem services, forest managers need to prioritize the multifunctionality of their landscapes. National sectoral policies, at the same time, drive management towards their specific objectives, which are often developed in non-coordinated processes. In this study, we used a multi-objective optimization approach to investigate the potential multifunctionality cost stemming from national sectoral policies in four European study regions. Then, in each region, we developed three different scenarios to find the optimal distribution of management practices for each sectoral policy, and we added an additional scenario that aimed to maximize multifunctionality. In this way, we analyze the spatial trade-offs between forest ecosystem services and biodiversity in each of these scenarios. All case studies showed that the highest multifunctionality, i.e. provision of multiple ecosystem services, was provided by combining integrative management regimes with a proportion of forested land allocated to specific uses. We identified trade-offs between different ecosystem services, thereby emphasizing potential bottlenecks or reinforcing effects that may either hinder or facilitate the adoption of multifunctional-oriented management strategies. Finally, we observed that sectoral policies that addressed a greater number of services were closest to the maximum level of multifunctionality. In conclusion, it is crucial for forest policies to adopt a comprehensive approach that encompasses diverse objectives to foster multifunctionality. However, it is imperative for these policies to acknowledge and tackle the conflicts and synergies among ecosystem services, aiming to optimize management efficiency. With regard to management strategies, promoting continuous cover forestry and implementing climate adaptation-focused management regimes across all studied regions is essential. Nonetheless, to

realize the full potential of multifunctionality, it is also important to incorporate elements of intensification and allocate a substantial proportion of set-asides.

Exploring the Impact of Alternative Forest Management Methods on Greenhouse Gas Fluxes from the Forest Floor

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Forest and forest management strategies have a significant role to play in mitigating the effects of the ongoing climate change. The values of the ecosystem services our forests provide are of ecological, economic, and social importance. Products from forestry are a renewable but limited resource, so the management must be done efficiently. The common management method in Sweden is through clear-cut, a method that have long term impact on both the biodiversity and the carbon fluxes from the soil. We need to learn more about alternative management strategies to limit the negative impacts on biodiversity and maximize the carbon sequestration. In our study we examine how forest management methods affect fluxes of greenhouse gases from the forest floor. We compare three management methods of a mature spruce forest on mineral soil: clear-cut, continuous cover forestry and no harvest. Flux measurements of carbon dioxide and methane through chamber measurements started the year before planned harvest and continue 3 years after harvest. While previous research has focused mainly on forest management through clear-cutting and measurements during the growing season, we focus on alternative management methods and measure fluxes all year around, to get the full picture of how fluxes of greenhouse gases are affected by how the forest is managed. Our first results show changes in the biogeochemistry of the soil after harvest for both management methods. The loss of trees on the clear-cut area resulted in increased soil moisture the first winter, which led to a deep ice layer in the soil, affecting the microbial processes in the soil during winter. The gaps created in the continuous cover forest allows more light to reach the forest floor and an increase in the photosynthesis within the field layer, resulting in lower carbon dioxide flux from the soil. The long term results of these measurements will give us deeper knowledge of how to best manage a forest and keep the carbon in the soil.

Forests and Sustainable Development Goals (SDGs) – assessing their relationship through the use of Soft Operational Research

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Problem Structuring Methods (PSMs) are a collection of interactive and participatory modeling techniques for handling unstructured complex problems that are characterized by the presence of multiple actors with divergent viewpoints and competing interests, trying to find potential solutions in an uncertain environment. PSMs are a type of Soft Operational Research, they are fundamentally different from traditional operational research. Soft Systems Methodology (SSM), the Strategic Choice Approach (SCA), and Strategic Options Development and Analysis (SODA) are popular Soft OR methods, that have been applied in different fields. Forests and Sustainable Development Goals (SDGs) have a complex interaction, with many synergies and trade-offs. Methods that bring more dynamic and holistic approaches are better indicated to address this relation. This study proposes the use of Soft operational research, more specifically Strategic Options Development and Analysis (SODA) to investigate forests' relationship to Sustainable Development Goals (SDGs). The main goal is to find a common approach, among the multiple actors involved, to strengthen the forest sector's participation towards SDGs by 2030, and strengthen the importance and participation of the forest sector in this agenda.

Global optimisation of wood production and carbon storage

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Climate change mitigation and wood production are considered perhaps the most important ecosystem services from forests of world. Maximal biomasses and growth rates vary depending on climate. Despite of this, global optimisation of carbon storage and wood production is rarely discussed. The objective of this research is to optimise land use globally to mitigate climate change and produce wood. To reach this objective, a new physiology-based mechanistic stand development model is developed. The methodology is based on an energetic approach to forest biomass accumulation. The focus is on lowland humid forests of the world, and gross primary productivity is assumed to be influenced only by air temperature and sun elevation after canopy closure. The maintenance cost, which includes maintenance respiration and growth needed to sustain a given biomass, is assumed to be related to both temperature and biomass. The difference between gross primary productivity and maintenance cost is available for growth and growth-related respiration. The proposed research is based on published datasets. It is likely that wood production could be increased tremendously without impact on carbon storage if production were concentrated in regions with high growth to maximal biomass ratio (tropics) and carbon storage to regions with low growth to maximal biomass ratio (maritime temperate and boreal biomes).

Green Infrastructure for Forests and Trees: Policy Perspective for Multifunctional Green Infrastructure in Changing Climate

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: The Green Infrastructure for Forests and Trees (GIFT) project focuses on green infrastructure, emphasizing the importance of forests and trees. Green infrastructure can provide many ecosystem services related to biodiversity, climate, water, erosion, landscape, human well-being, etc. The aim of the project is to develop an innovative cross-sectoral approach to the design of green infrastructure of trees and forests and to promote their connectivity in different landscape types by introducing them into policy documents of different sectors and achieving an integrated cross-sectoral approach to policy planning. This requires knowledge of green infrastructure, biodiversity, ecosystem services and climate change among policy makers and professionals.

The innovative approach of the GIFT project aims to improve European regional policies by raising awareness that sufficient tree and forest cover is the first requirement to stop biodiversity loss and mitigate climate change. The communication strategy focuses on disseminating new management models for the multifunctionality of green infrastructure. The project builds on the multi-stakeholder partnership approach and involve policy makers in regional stakeholder groups.

In Slovenia, the project focuses on Gorenjska, a very forested region with inhabitants that traditionally recognise the importance of trees and hedges. Nevertheless, there are only isolated and small remnants of forests in the lowlands, which limit their function as ecological corridors. Pressure on the existing green infrastructure in the lowlands is increasing. Urban forests or larger forested landscapes are rare in suburban/urban areas, as well as smaller green spaces with shrubs and smaller tree species. Green infrastructure, especially forests and trees, is not sufficiently strategically embedded in policy, which is important for climate change mitigation and adaptation.

In our presentation, we will outline the project’s approach for creating systemic solutions for integrated management of green infrastructure not yet developed and established. With appropriate policies to support green infrastructure development and a broader range of interventions, the intensity and management of urban/suburban green spaces and agricultural lands could be adjusted to achieve better green infrastructure connectivity.

10 partner institutions from 9 European countries are cooperating in the GIFT project, which is funded by the Interreg Europe financial mechanism of the European union.

Installation of cocoa agroforests in the forest landscape of DR Congo: Implications for biodiversity conservation and climate change mitigation

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Biodiversity decline in the tropics requires the implementation of comprehensive landscape management where agricultural systems are an integral element of biodiversity conservation. Benefits carried out within agroforestry systems have played a significant role, especially for tropical crops such as cocoa. Cocoa agroforests (C-AFS) can help developing sustainable land use since they are able to support a large array of ecosystem services while theoretically providing rural households with income and contribute to food security. This study describes the typologies, woody biodiversity, structure and carbon stock of cocoa agroforests in the main cocoa producing landscape of DRC. That landscape is located tropical rainforest of northeast, in provinces of Tshopo and Ituri. A botanical inventory is carried out in 120 plots (50 x 50 m) of C-AFS of different ages, installed in homogenous units of C-AFS. Additional information as C-AFS's size, previous ecosystem and quantity (kg) of cocoa beans harvested per year are obtained from C-AFS owners. Diameter and height of cocoa associated identified plants from 5cm of diameter and cocoa trees are measured. Using surveys and bibliography cocoa associated plants' succession guild, leaf-life span, farmer's use and IUCN status are documented. Aboveground biomass of trees are estimated using the pantropical allometric equation of Chave et al. (2014) and specific equations are used for other plants. Taxonomic diversity of plants in C-AFS is estimated at plot level (alpha diversity) and at landscape level (beta diversity) using various diversity indices, while functional diversity is estimated by farmers' assigned uses and some functional traits. The key results of this study are: Carbon stock , diversity , factors determining diversity and above-ground carbon stock, structure and composition of C-AFS in forest landscapes of northeastern DRC; diversity and carbon stock of different C-AFS typologies; main species that store more carbon and their use by farmers. These results allow us to determine the ecosystemic and socio-economic value of each C-AFS typology, and can be used as a tool for developing a sustainable C-AFS and are crucial for integrating cocoa into REDD+ process and the biodiversity conservation agenda in DRC.

Keywords : Cocoa agroforest, Biodiversity conservation, Climate change mitigation, RDC

Integrated consideration of private and public ecosystem services provided by forests – Pathways to multifunctionality

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Forests provide ecological, economic and social values. These values are, however, not always compatible, resulting in conflicts over forest use and management. The increasing impact of ongoing climate change has accentuated these conflicts, both by increasing the need for forest-related ecosystem services like climate regulation and biomass for bioenergy, and by posing direct threats to the functioning of forest ecosystems through changing temperatures and precipitation patterns. One approach to address these conflicts is to strive for multifunctional forests, where trade-offs are minimized by optimizing the spatial arrangement of different forest managements and compromises are achieved that maximize the overall utility of the multiple ecosystem services supported by forests. However, the concept of forest multifunctionality is highly debated, primarily due to conflicting objectives of maximizing private goods (e.g., fiber and energy production) versus preserving public goods (e.g., regulating and cultural ecosystem services), where solutions that maximize total utility may lead to costs or missed opportunities for landowners.

In this study, we have gathered an interdisciplinary team to enhance our understanding and provide a conceptual framework for multifunctionality, focusing on areas with a high proportion of private landowners in Northern European forests. We have focused on four values: biodiversity, forest production, climate change mitigation, and support of perceived quality of life. A critical aspect of our analysis has been the consideration of these values in the decision-making process, aiming at finding ways to minimize trade-offs between them. Our framework links biodiversity, forest production, climate change mitigation, and perceived quality of life aspects to the forest structures influenced by forest management practices. We reason around how trade-offs can be adjusted and currently little prioritized benefits can be improved through spatial planning of management. We present drivers and barriers to management changes to achieve multiple goals from the landowners point of view, and discuss existing and potential policy instruments to overcome barriers, while considering legislative obstacles and incentives for landscape-scale planning. Finally, we identify areas where further research is required.

Integrating trees for sustainable coffee production in the Andean zone of Colombia: a model for climate change mitigation and rural development

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Proper land management and the implementation of nature-based solutions can contribute to mitigate the effects of climate change. In the Andean zone of Colombia, coffee production is an important economic sector that has traditionally been grown under open solar exposure to maximize yields. However, recognizing the need for sustainable practices, over the past decade, coffee organizations in the department of Cauca have initiated to promote the planting of trees as shade for coffee crops. By mid-2023, approximately 3,200 coffee-growing families have adopted these practices, resulting in the establishment of nearly 1,250 hectares of coffee plantations that include 380,000 trees comprising 40 different species, implemented through different planting models such as of agroforestry systems, tree planting, and live fences. The project engages rural development promoters who register the beneficiaries, provide continuous technical assistance, and monitor and systematize the survival and growth of the trees over time. The main objective of the project is to contribute to the sequestration of up to 9 million tons of CO_2e over a 40-year period, thereby mitigating the impacts of global climate change. It also aims to restore degraded areas, conserve natural forests, protect water sources, enhance the diversity of native species, and improve habitat connectivity throughout the coffee-growing landscape. These efforts are especially beneficial to small-scale coffee-growing families, the majority of which have farms of less than two hectares. Consequently, this project serves as an adaptive strategy to climate change while generating new sources of income for coffee-growing communities. The outcomes of this project, which integrates agroforestry systems and sustainable practices, are expected to serve as a replicable model for other coffee-growing regions in Colombia.

Landscape-level forest ecosystem service outcomes of uneven-aged forest management

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate
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Abstract: Most forest ecosystem services research is conducted at scales that are either highly localized or national in scope. This makes it difficult to compare across studies and identify broad forest management strategies to support operational decision-making at the landscape level. There is also a need for tools to help decision-makers identify, value, and compare cost-effective ways to enhance a range of forest ecosystem services within a given region. To address this, we develop an integrated assessment methodology that links a forest landscape model with economic and policy data and assumptions within an optimization framework. The model is applied to 3 million hectares of primarily uneven-aged, naturally regenerated commercial forests in Maine, USA, and includes nearly a dozen silvicultural treatments. We conduct 30 scenarios to evaluate the impacts of varying ecosystem service policy objectives and forest management on economic returns, carbon sequestration, timber supply, and several biodiversity indicators from 2020-2100. Results show a consistent tradeoff between increasing forest carbon sequestration and timber supply, but these impacts diminish when management can shift towards a land sparing approach largely comprised of permanent set asides and intensive plantations. However, our scenario analysis found it was not possible to simultaneously enhance all biodiversity indicators, as each depended on conditions created by often competing silvicultural treatments. Our study can help decision-makers achieve a subset of ecosystem service-related objectives, provided landowners have clear policy, social, and economic signals that enable them to vary their management strategies.

Multi-criteria decision analysis as a pathway to sustainable forest management: A Swedish case study

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: The sustainable management of forest landscapes is a challenge, especially when faced with conflicting objectives and stakeholder interests. Today, forests are expected to provide favorable conditions for biodiversity, timber production, recreation, and other important ecosystem services while simultaneously contributing to climate change mitigation through the substitution of fossil fuels and carbon sequestration. Consequently, forest owners and other decision-makers face complex circumstances when choosing between alternative pathways for forest landscapes. These circumstances can necessitate the adoption of robust decision-making tools. One such tool is multi-criteria decision analysis (MCDA), which provides a systematic framework for evaluating and prioritizing alternative management scenarios based on multiple criteria and stakeholder perspectives. By integrating scientific knowledge and stakeholder preferences, MCDA facilitates a comprehensive assessment of the ecological, social, and economic dimensions of the forest landscape.

In this study, conducted within the SPARC project, we evaluate the effectiveness of MCDA in developing stakeholder and science-based solutions for reconciling conflicting demands placed on the forest landscape. To do so, we conducted a case study using a municipality-owned forest property located in southern Sweden. Stakeholders with diverse interests evaluated different management scenarios that were developed using Heureka, a decision support system for multi-functional forestry. We found that MCDA has great potential for promoting sustainable forest management, by enabling decision-makers to better consider trade-offs and synergies. This will result in more informed and balanced choices that better align with ecological conservation objectives and societal needs. Furthermore, the participatory nature of MCDA fosters collaboration and trust among stakeholders and thereby offers a valuable toolset for forest owners and decision-makers. While challenges exist, careful consideration of stakeholder engagement and other factors can address these challenges, and MCDA can contribute to a more effective and inclusive planning processes aimed at achieving consensus-based and sustainable forest management.

Optimal multi-criteria land-use scenarios in an Ecuadorian mountain forest landscape: a spatial explicit approach

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Designing landscapes that can meet the needs of human populations while enhancing their capacity to provide valuable ecosystem services might be crucial for managing land resources in the face of ongoing environmental change. Over the past few decades, optimization models have emerged as a promising tool for assisting in decision-making related to land-use allocation problems, which often involve multiple conflicting objectives crucial for satisfying the complex population's demands. In Ecuador, Knoke *et al*. (2020) applied a robust optimization approach, considering various ecological and socio-economic indicators to determine the optimal land-use allocations that satisfy all objectives while accounting for uncertainty. The findings of this study offer valuable insights into the prospective landscape composition required to achieve multifunctionality, as well as potential trends of forest development. However, the model does not explicitly determine the landscape configuration. In other words, it does not provide the precise locations for implementing these land-use changes nor the anticipated forest conversion. Thus, the present study builds upon the study developed by Knoke *et al.* 2020 to generate optimized spatial scenarios of forest development at a landscape scale. This model upscaling will be attained by coupling the robust optimization approach with heuristic techniques to simulate land-use change by integrating real-world constraints. To this aim, probabilistic deforestation models have been constructed considering the diverse factors influencing forest conversion such as the steepness of the terrain, and the distance to roads or economic centers, among others. The machine learning tool, Random Forest, was used to build the deforestation model as a first step to determine the potential change in forest coverage. Results from this model will be implemented as input in the heuristic technique, along with spatial transition rules and constraints to develop scenarios of forest development. These scenarios will offer an overview of possible directions of landscape configuration, which may serve as a planning tool for policy and decision-makers to find compromise solutions to efficiently allocate land resources and design effective mitigation/adaptation responses.

Knoke *et al.* 2020. Accounting for Multiple Ecosystem Services in a Simulation of Land-Use Decisions: Does It Reduce Tropical Deforestation? *Global Change Biology* 26: 2403–20

Quantifying the impacts of forest management strategies on ecosystem services under climate change: A country-scale modeling approach

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Forest stewardship in the face of climate change presents significant uncertainties for forest managers, who are increasingly challenged to adapt conventional management strategies. To aid this transformation, decision support tools that integrate quantitative data on forest development under different treatments and climate scenarios are crucial. However, generating consistent and locally accurate model simulations required by such tools at a national scale is a challenging task.

This study proposes a comprehensive forest modeling approach using the process-based forest landscape model iLand to simulate forest trajectories and a range of ecosystem service indicators for Germany. The initial step involves replicating the forests of Germany through multiple representative landscapes that encompass the country's soil and climate conditions, as well as tree species and age class distributions. While being generated, each landscape encapsulates forest and environmental conditions for a given eco-region. Subsequently, diverse management strategies are compiled for each major forest type based on publicly available recommendations and are subsequently implemented in iLand. These strategies encompass the selection of climate-resilient tree species, as well as varying levels of forest adaptation intensity and speed.

By simulating all possible combinations of climate and management scenarios, accounting for abiotic and biotic forest disturbances until the end of the century, a comprehensive database of potential forest trajectories and ecosystem service indicators for timber, carbon storage, and biodiversity is generated. This database can then be incorporated into decision support systems to quantify the consequences of forest management decisions on the provisioning of ecosystem services.

In this contribution, we introduce the data assimilation approach employed to construct current forest conditions for the simulations. Additionally, we outline the process of synthesizing forest management alternatives at a national scale. Furthermore, we discuss the results of the simulations at both the country and regional levels, emphasizing the effectiveness of forest management in mitigating the impacts of climate change on ecosystem service provisioning in Germany's forests.

Recovery of coastal dunes in an area affected by invasive species in Playa Guanal, Isla de la Juventud, Cuba

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Our work refers to the elimination of invasive species in a sector of Playa Guanal, located in the Protected Area of Managed Resources South of the Isla de la Juventud (RAMSAR Site), administered by the Company for the Protection of Flora and Fauna Silvestre of the Isla de la Juventud, with the aim of recovering the dune invaded by the invasive species *Casuarina Sp*, by incorporating characteristic species of the place, using the Assisted Natural Regeneration method, relying on the Ramal 595 Standard, the Methodology for the restoration of the coastal dunes and Decree Law 358. The method of elimination of the coastal casuarina was established and as a result, stability has been restored to this ecosystem through the restitution of the vegetation cover, and the capacity to withstand the inevitable changes has increased environmental conditions that occur in the coastal zone, associated with the elevation of the average sea level, the increase in the frequency of tropical storms and their ability to self-recover due to the effects of climate change in 9 kilometers of beach, being increasingly resilient marine-coastal ecosystem.

Sustainability indicators for forest management under climate change: what do we need and what can we do?

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: World-wide changes in conditions (e.g., global warming) and in societal expectations on forests have led decision-makers to rethink both purpose of and feasible system(s) for forest management. Forests in Sweden already play several vital functions for people such as environmental protection, provision of goods, services, and other societal structures. Climate change mitigation is on top of these multifunctional expectations on forests in Sweden, based on future projections of increased global temperatures, rising of natural hazard events, and prioritization of the nation to become a bio-based society by 2050. Stakeholders' perspectives on sustainable forest management (SFM) can be critical to change future forests management systems for the country. To evaluate different forest management strategies, however, decision-makers require adequate information about upcoming effects in relation to sustainability indicators. As part of the SPARC project, aiming at finding SFM solutions at the landscape level, this study presents an overview and evaluation of a) SFM indicators used in different research studies, and b) the type of SFM and climate-smart forestry indicators that can be modelled with a forest decision support system (DSS) as well as become useful for stakeholders' involvement in the planning process. To achieve those targets, an examination of previous literature review of indicators for SFM and climate-smart forestry was conducted to identify patterns/differences among the parameters used within different publications. Additionally, the application of the Swedish system Heureka as a standard for long-term planning and analysis allowed us to assess the potential for indicators to be quantified and forecasted with a DSS. Preliminary results suggest that a broad range of indicators are needed; however, social aspects may be challenging to model. The oral presentation will also include a summary of findings and concluding remarks about stakeholders' thoughts on sustainability indicators.

The Predictive Role of Species Diversity on Above-ground Carbon through Functional Diversity and Functional Dominance, Southwest Ethiopia

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: *As both biodiversity and carbon storage are threatened by deforestation and climate change, it is imperative to understand the relationships between species diversity and carbon storage in tropical forest ecosystems of Yayu Coffee Forest Biosphere Reserve, Southwest Ethiopia (herein after referred to as the "YCFBR"), which helps to inform conservation policies intended to mitigate greenhouse gases emissions. Therefore, evaluating the response of above-ground carbon (herein after referred to as the "AGC") to effects of species diversity, functional diversity, as well as its direct and indirect effects interact to maintain AGC in the YCFBR, were the designed objectives of this study. Plot size of 20 m × 20 m was used to collect vegetation data from core and buffer zone, while 30 m x 30 m plot size was designed for transitional zone based on expected density of woody species in each zonation. Different, but proportionally 90 plots were systematically distributed for core, buffer and transitional zones as 40, 25, and 25 plots, respectively. For functional trait diversity estimation, traits relevant to plant-life strategy, competition ability, response to disturbances and climate change were selected; these were wood density, specific leaf area and tree maximum height. Structural Equation Models (herein after referred to as the "SEM"), was performed to evaluate the direct and indirect effects of species diversity, functional diversity and their interaction effects on AGC using R software. Overall results of this findings showed functional diversity and functional dominance were significant predictors of the AGC (21 %) in the YCFBR. Results from structural equation model indicated full mediation model and partial mediation models showed the effects of species richness on AGC are mediated through functional diversity and functional dominance and best predictor for AGC. Collectively, from a practical point of view, this findings suggests conserving species diversity would be the alternative choices for maintaining higher AGC in tropical moist Afromontane forests of YCFBR, Southwest Ethiopia. Further studies should focus to show the extent to which weighting variable for functional diversity and functional dominance contributions for AGC of forest ecosystem functions for climate mitigation measures.*

Use and Stakeholders' Perception of Value of Temple Forests in South Korea

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: As the society becomes more industrialized and urbanized, the demand for ecosystem services provided by forests changes. Temple forests in Korea, of which the origin dates to the 7th century, have been used by the Buddhist communities. Main functions of temple forests are two-folds; supply of timber for building and renovations of temple and fuelwoods and provides esthetical environment for Buddhist monks to practice Buddhism there.

The public visits temple forests which provide recreational services. With this new demand could temples to generate revenue by charging fees to ecotourists who visit temple forests. The government of South Korea made a commitment of reducing the country's greenhouse gases emissions by 40% by 2030 compared to the emission level in 2018. The forest sequestration is included in the accounting of greenhouse gases emissions as an offset. The carbon sequestration of temple forests can be considered as an investment option for ESG projects of corporations. In 2022, the Government introduced a direct payment scheme for forest owners to promote their income and enhance ecosystem services resulting by forest management. Managing forests for more ecosystem services beyond the traditional uses, including carbon sequestration, is a new option of temple forest management.

The objectives of study are: 1) to find out under how the temple forests have been used by temples and the public and 2) to identify the perspectives of temple stakeholders including monks, Buddhism believers and the public. We interviewed 40 stakeholders living in the temple and supporting temples and conducted a survey of temple forest's main function with a sample of 200 visitors to the Jirisan National Park where a few of temples are situated.

The main findings include:

The main functions perceived by Buddhist monks and believers are different from that of the public.

Buddhist monks and believers consider temple forests as a place where they can practice their religious activities.

The main functions of temple forests perceived by the public are ecological, educational, and recreational.

The public prefers temple forests to be managed for biodiversity and recreational services rather than supple of economic goods.

Variation in orchid species diversity across forest disturbance gradient in West Mau Forest, Kenya

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: Variation in orchid species diversity across forest disturbance gradient in West Mau Forest, Kenya

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ABSTRACT

The family Orchidaceae is the most diverse, widespread, and second largest among flowering plants. Despite having diverse socio-economic and ecological value, its spatial distribution across forest disturbance gradients is not well understood, particularly in tropical montane forests. We assessed the influence of forest degradation on orchid species richness and abundance in West Mau Forest, Kenya. Stratified systematic sampling was adopted across three different forest disturbance regimes, i.e., relatively intact forest, moderately disturbed forest, and highly degraded forest. Data collection entailed recording habitat types, morphological features of orchid species and host tree species. A total of five orchid species were recorded from nine host-tree species. The intact forest had seven host tree species with five orchid species. The moderately degraded forest had four host-tree species with two orchid species, while the highly degraded forest had no orchid species. The results suggest a strong negative correlation between orchid species richness and forest degradation status. The degradation of montane tropical forests appears to destroy orchid habitats leading to the decline in orchid species richness and diversity. Findings of this study suggest that resource offtake levels in these forests should be managed in order to secure orchid species populations.

Keywords: Orchid species; montane forests; habitat degradation

Vegetation healthy under high demand of mulch in context agroecology practices in south Togo

T1.19 Managing Forests for of Multiple Ecosystem Services under Changing Climate

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Abstract: The need for stakeholders to contribute to SDG2 achievement is no longer in question in the context of climate change, especially in sub-Saharan Africa. This study conducted in southeastern Togo, more precisely in the landscape located within a 10 km radius around the Donomade model farm, aims to assess the health status of the vegetation of ecosystems and agrosystems, including their capacity to produce biomass for agroecological practices. Thus, sentinel-2 sensor data of 2015, 2017, 2020, and 2022 years following were preprocessed and submitted to the normalized index of the ratio of vegetation fires (NBR), of the severity of vegetation fires (dNBR), and the CASA-SEBAL model computation. From these different analyses, it is found that whatever the year of the time series, vegetation stress level increases across the landscape. The highly stressed land areas are estimated to be 9952.215 ha, 10397.43 ha, and 9854.90 ha, respectively 2015, 2017, and 2020 years. The analysis of the level of interannual severity reveals the availability of areas with a high photosynthetic proportion having undergone stress. These areas, which are likely subjected to agricultural practices, are estimated at 8704.871 ha (dNBR2017-2015), 8253.17 ha (dNBR2020-2017), and 7513.93 ha (dNBR2022-2020). The total available biomass estimated by remote sensing for 2022 years is equivalent to 3741715 ±119.26 kgC/ha/y for an annual average of 3401.55 ±119.26 kgC/ha/y. On the other hand, the fraction of healthy vegetation is estimated to be 4594.43 ha, 4301.30 ha, and 4320.85 ha for the years 2015, 2017, and 2022. The correlation coefficient R2 is evaluated at 0.96, thus raising the acceptability threshold of the study area's net primary productivity (NPP) to 96%. The Skewness coefficient (0.81±0.073) indicates a mosaic landscape comprising productive and functional ecosystem components but very dispersed. Given the results, there is a strong opportunity to popularize agroecological practices. Mulching, by considering the reconversion of plant biomass consumed by accidental vegetation fires or slash-burn agricultural practices, may be an excellent alternative to enhance whole ecosystems services as target SDGs.

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

A concerted effort to understand and manage emerging needle diseases of loblolly pine in the southeastern United States

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: For nearly a decade, public and private land managers in the Southeast United States have reported stark increases in the frequency and severity of fungal needle disease outbreaks in loblolly pine (*Pinus taeda*) forests. Prior to the recent outbreaks, needle diseases were not considered a major threat to the health and productivity of these loblolly pine stands, which represent the region's primary timber resource. However, these diseases now affect large tracts of land, and the combination of high infection rates, and mortality of mature trees in extreme cases, has prompted calls for research to identify management solutions. In collaboration with academic, industry, state, and federal partners, we have initiated research on the issue considering multiple angles: identifying the fungal causal agents, developing inoculation procedures for a wide array of needle pathogens, optimizing resistance screening protocols, evaluating long-term impacts of biotic defoliation on tree survival and stand productivity, and prospecting for the use of phenotypic and genetic markers to aid resistance selection to needle diseases in widely deployed loblolly pine families. We utilized molecular methods to identify fungi associated with needle disease symptoms, coupled with the isolation of potential pathogens and validation of their ability to cause disease. *Lecanosticta acicola*, the causal agent of Brown Spot Needle Blight (BSNB), and other potential pathogens were identified on trees from outbreak sites throughout the region. Inoculation techniques are currently being optimized to test the pathogenicity of these species and develop an operational protocol to be implemented at the USDA Forest Service Resistance Screening Center. We are also screening improved loblolly pine families for chemical and genetic markers of resistance to BSNB using near-infrared spectroscopy and sequencing of disease-resistance genes. Finally, we are assessing the loss of leaf area index due to the presence of needle pathogens and modeling the resulting change in stand productivity. This endeavor represents a unified effort across sectors to protect Southeastern forests against emerging needle diseases.

Analyses of the Swiss Forest Protection data reveal interesting emergence patterns for pine foliage diseases

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Swiss Forest Protection was created 1983 to diagnose, record and address forest health problems in the context of the so called forest dieback ('Waldsterben'). Over the years, Swiss Forest Protection has collected a huge dataset of geographically referenced occurrences of pests and diseases affecting trees. Although the service first focused only on forested areas, it quickly expanded to include urban greens. Here we provide an overview of the most commonly diagnosed pests and diseases, focusing on temporal and geographical aspects of pine diseases. Pine trees are distributed worldwide and represent important ecological as well as economical players in forests. However, pine trees suffer from numerous pathogens that reduce their growth rates or even threatens their survival. Some of these pathogens have a quarantine status in Europe like for example the pine pith canker caused by *Giberella circinata* or the pinewood nematode (*Bursaphelenchus xylophilus*). Some others are not under quarantine but can be quite aggressive under climate change conditions like for example the *Diplodia* tip blight (*Diplodia pinea*) leading to huge losses in *Pinus nigra* stands in combination with severe drought. A huge data collection of tree disease diagnostics in Switzerland enables an overview of the dynamics of pine diseases over time. Out of more than 1000 records, first occurrence and abundance evolution of different pine pathogens is addressed in this study. Further, we will retrace the emergence/introduction of *Diplodia* tip blight of pines (*Diplodia sapinea*), as well as of the regulated pine diseases *Dothistroma* and *Lecanosticta* needle blight in Switzerland. These examples confirm the importance of urban areas as hotspots for introduction and emergence of pests and diseases to forest trees.

Can the phenological traits of a Norway spruce genotype predict its risk of needle pathogen infection?

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: A taxonomically diverse community of phyllosphere fungi inhabit leaves of plants, and the assembly of these communities are governed by different ecological and physiological processes. Although the assembled needle mycobiome in Norway spruce (*Picea abies*) tend to vary across environments, recent work indicates that Norway spruce genotypes harbors different mycobiomes derived from the local air spore communities. Norway spruce genotypes with higher genetic similarity had a more similar mycobiome. Previous studies has also shown that the presence of pathogenic fungi in the mycobiome can be associated to genetic variation in the host tree. In short, not all trees are equally likely to become infected by pathogens present in the local air spore communities. These observations may be driven by phenological variation between the tree genotypes among other traits encoded in the host genome. In this study, we aim to investigate the relationship between the trees phenological traits and colonization by phyllosphere pathogens present in the local air spore community hypothesizing that the timing of budflush will protect trees from pathogens with a short period of spore dispersal but not from pathogens who has a continuous presence in the local air spore community. To test this we set up a study that will run over multiple seasons focussing on the timing of budflush and the assembly of the phyllosphere mycobiome with special focus on needle pathogens. The timing of budflush at tree level is determined using manual observation in combination with remote sensing data collected with UAVs. The local air spore community is collected on weekly intervals with spore traps and shoot samples are collected from Norway spruce clones at defined stages of budflush and shoot development. The needle samples from the Norway spruce clones (needle community) and spore traps (air mycobiome communities) are characterized by high-throughput sequencing of the ITS2 region. The results from the first season of sampling will be shown, and discussed in the context of risk for infection of needle pathogens in Norway spruce.

Climate and pathogen-pathogen interactions in native pine forests

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Climate change is favoring the upraise of different diseases in pine stands. However, we lack insights into how different diseases may cause compound impacts. Pathogens may compete because they occupy the same niche, but may also facilitate each other as they weaken the host. In native forests, diseases may simultaneously affect adult and regenerating trees of the same species, and may indirectly favor other non-susceptible tree species. In Southern Europe, *Pinus nigra* is simultaneously affected by a needle disease caused by *Dothistroma pini* and a shoot disease caused by *Diplodia sapinea*. It represents an interesting case to study how two diseases interact with each other, as these two pathogens affect canopy trees and recruits differently, and have different climatic and microsite constraints. In general, it looks as if both diseases could cause additive impacts on the canopy while competition tended to be more present in the recruits. No signs of facilitation were observed. *Dothistroma pini* was causing defoliation all over the studied area, both in cold mountainous areas and in the warmest areas down the valleys. Climate restricted *D. sapinea* to the warmest pine forests where it also contributed to defoliation. Pathogen spill-over from the canopy to recruit trees occurred all over the studied area. However, *D. sapinea* shoot blight dominated on the recruits of the warmest areas while *D. pini* needle blight tended to prevail on the recruits on the coldest sites. The combined effects of both diseases were affecting tree growth increasing crown transparency and killing conspecific regeneration. Alarmingly, diseased forests tended to show higher bush growth in the understory and therefore a more fire-prone stand structure than healthy forests.

Comparative genomics reveal species-specific variation in the mitochondrial genomes of Dothistroma septosporum and Dothistroma pini

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Mitochondrial genomes have been used in phylogenetic studies, population genetics, and tracing the relatedness of populations. *Dothistroma pini* and *D. septosporum* are the two pathogens that cause Dothistroma needle blight (DNB): a disease that affects pine species and which is globally distributed. The pathogens cause the same symptoms and are morphologically very similar yet genetically they can be distinguished based on several nuclear gene regions and differences in the mating type genes. This study aimed to determine if there were any species-specific variations in the mitochondrial genomes of the DNB pathogens that could, in future, be used for population and evolution based studies. The two isolates from each species included in the study were selected based on differences in mating types and geographic origin. Illumina sequencing was used to obtain short-read genome sequences for isolates of *D. septosporum* from Canada and South Africa, and for *D. pini* isolates from North Dakota and Hungary. PacBio sequencing of the *D. pini* Hungary isolate and *D. septosporum* South African isolate was used to obtain long-read sequences. Contigs were assembled from the reads to form single chromosomes and the mitochondrial genes on these contigs were identified using various bioinformatic tools. The assembled *D. pini* mitochondrial genomes were 34.7 Mb and those of *D. septosporum* 33.4 Mb. The increased genome size of *D. pini* was due to large intergenic regions (over 8.2 kb) with the addition of three homing endonuclease genes of type GIY, that were lacking in *D. septosporum*. All the genomes had the 14 protein-coding genes that are typically harboured on fungal mitochondrial genomes. An exception was observed in the *D. septosporum* isolates in which the *nad3* gene was duplicated. Analysis of the duplicated genes revealed that one of the copies was a pseudogene. There was also re-arrangement of *cox1* and *atp9* genes across the species. The large amount of species-specific variation observed in the mitochondrial genomes would need to be validated in populations, but could be useful in future population studies to determine the evolutionary history of these, and other closely related species.

Comparison of Illumina vs Nanopore sequencing technologies for detecting pine needle pathogens from native and exotic Pinus sp.

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: In Sweden, the vital forestry species Scots pine (*Pinus sylvestris*) is severely threatened by new and emerging foliar pathogens that are often manifested as needle cast diseases, many of which exhibit highly similar symptoms making it difficult to determine the causal agent without involving expert plant disease diagnosticians. Current detection methods that combine culture-based and molecular diagnostics have proven insufficient, costly and involve complex steps towards accurate diagnostics. Better tools that are more efficient both in terms of capacity and rapidity for disease diagnostics, are needed to be able to quickly deploy measures for disease control. Nanopore sequencing technology has several useful advantages over present 2nd generation sequencing methods like Illumina, and it has tremendous potential applicability to plant health protection especially if it can be utilized for on-site detection in nurseries, ports-of-entry and remote forest sites; essentially bringing the lab to the field. In this study, we compared the widely used Illumina platform with the nanopore sequencing platform to ascertain its feasibility for wider adoption in practice. DNA from samples of symptomatic and healthy pine needles collected from a variety of locations (forests, nurseries, ornamental plantings) across Sweden were sequenced using the MinION and Illumina sequencing platforms in parallel to examine: 1) differences in fungal community diversity and richness, 2) resolution for assigning taxonomic identification at the species level, 3) an optimal workflow for nanopore sequencing in terms of cost, time and simplicity, and 4) its feasibility for detecting potentially harmful fungi in eDNA tissue even on asymptomatic tissue. This work underscores the importance of evaluating different perspectives of cutting-edge molecular methods available for identification of plant pathogens, which focus on high-throughput identification at the species level for improving routine diagnostics.

Development, comparison, and validation of qPCR and LAMP assays as an early-warning tool for detection of conifer plant pathogens

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: In Sweden, Scots pine is one of the most important commercial species: it has an annual net export value in forest products that exceeds more than 100 billion SEK, represents about 10% of total Swedish exports, and accounts for about 3% of the national GDP. Today, Scots pine has several damaging pathogens present in Sweden and more are spreading from other parts of Europe. There has already been considerable damage to some pine forests due to a wide variety of fungal pathogens that differentially affect the needles, branches, trunk or roots. For example, pine needle pathogens like species of *Gremmeniella abietina* (economic loss of more than one billion SEK), *Rhizosphaera kalkhoffii* (Christmas market losses), *Neocatenulostroma germanicum* (a new invasive pine blight pathogen in Sweden), *Lophodermium spp.*, *Dothistroma* spp. and *Diplodia* pine pathogens are becoming more and more problematic, probably as a result of changing climate which makes conditions more favourable for pathogen development.

Early detection tools that can quickly identify new and emerging threats can significantly reduce the window of time between when a pathogen can be identified and response to implement mitigation measures that can reduce losses. The aim of the project was to develop three different loop mediated isothermal amplification (LAMP) and qPCR assays for the rapid and early detection of three pine pathogens (*G. abietina, R. kalkhoffii, N. germanicum*) both in DNA extracted from axenic culture and in infected plant tissues. The LAMP assay was conducted using genomic DNA from pure cultures and tissue samples. Primers were designed using LAMP Designer software (OptiGene Limited, Horsham, UK) on the basis of the ribosomal RNA gene (ITS1-5.8 S-ITS2), available sequences of the elongation factor (EF1- α) and beta-tubulin (β-tub2) genes belonging to targeted species in Genbank, and considering other closely related species. This work presented that LAMP assays as diagnostic tool can provide a simple and portable solution and the utility of this for forest managers and advisors for quickly detecting disease agents at even remote forest locations.

Does invasive pathogen Lecanosticta acicola affect the fungal diversity on needles of Pinus species?

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: The relationship between the ecological success of needle pathogens of forest trees and species richness of co-inhabiting endophytic fungi is poorly understood. One of the invasive and dangerous foliar pathogens of pine is *Lecanosticta acicola*, which is a quite recently spread to northern Europe. We sampled two *Pinus sylvestris* and *Pinus mugo* sites in Estonia in order to analyse the relations between the abundance of *L. acicola* and overall fungal richness, specific fungal species composition, time of season and needle age. For identification of fungi, the rDNA gene region ITS1-5.8S-ITS2 was amplified using the PacBio third-generation sequencing platform.

The overall species richness of fungi was highest in autumn, showing a trend of increase with needle age. The overall species richness was higher on the second-year needles when compared to young first year needles of *Pinus*, and the trend was also visible in different birth years of needles. The fungal species richness in *P. sylvestris* and *P. mugo* needles was largely affected by actual presence of *L. acicola* on the needles.

Dothistroma pini in Slovenia – a ten-year update

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Dothistroma needle blight (DNB) has been known in Slovenia since 1971. In the last two decades, the occurrence of disease symptoms has intensified, and the DNB is now believed to be widespread in Slovenia. In the years 2011 and 2012, the DNB in Slovenia was found to be tied to both phytopathogenic *Dothistroma* species: *D. pini* and *D. septosporum*. At the time, both mating types were found for *D. septosporum*, while for *D. pini* only MAT2 was reported. After 2012, the DNB survey continued with varying intensity, and samples from new locations were obtained and analyzed. DNA extractions from conidiomata or necrotic bands directly from infected needles were performed, with presence of *Dothistroma* species and mating type determination done through PCR-based analyses. The obtained data shows broader distribution of *D. pini* in Slovenia, with both mating types present. To determine the impact of the pathogen on its hosts, crown damage assessments are currently underway at those locations where *D. pini* was initially confirmed a decade ago.

Dothistroma septosporum - three decades of research, from toxins to cross-kingdom effectors

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Dothistroma needle blight is a global problem in both natural and planted forests worldwide. One of the main causal agents,*Dothistroma septosporum*, has been studied in New Zealand for several decades, despite being a clonal population in that country. An overview of key aspects of this research will be presented, ranging from progress in understanding the role of dothistromin, a polyketide toxin produced by *D. septosporum*, to discoveries made through analysis of genomic and transcriptomic data. Recent work focusing on secreted effector proteins, some of which are potential virulence factors and some of which elicit plant defence responses, will be described. Some effectors are highly conserved and we identified two sets of effector proteins common to three pine pathogens - the fungi *Dothistroma septosporum* and *Cyclaneusma minus* and the oomycete *Phytophthora pluvialis* - that could potentially be used to screen for broad-spectrum resistance. Comparisons of the predicted tertiary structures showed a remarkable level of structure conservation among the three pathogens for each of the two sets of cross-kingdom effectors. Both sets are also highly conserved across fungal and oomycete species, including other pine pathogens. The ability of these effectors to elicit defence responses was then determined by infiltration into the pine host and *Nicotiana* spp.. model plants. One set induced up-regulation of PAMP-triggered immunity which is considered the first line of defence in plants. The second set of effectors elicited cell death in both pine and *Nicotiana* spp. and induced expressed of hypersensitive response, defence signalling and PTI marker genes in the model plant. Using CRISPR-Cas9, the*D. septosporum* orthologues of these genes were disrupted and their virulence to *P. radiata* assessed.There was tentative evidence for a role of these genes in virulence on pine. The identification of pine host targets of highly conserved cross-kingdom pathogen effectors that can elicit strong defence responses could ultimately assist in screening for increased broad-spectrum disease resistance.

Effects of Lecanosticta acicola infection and spread on the growth of Pinus taeda L. (loblolly pine)

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Loblolly pine (*Pinus taeda* L.) is vital for economic stability in the southeastern United States and is the most abundant tree within Alabama, USA. Recently, loblolly pine has been threatened by rapid defoliation due to the pathogen *Lecanosticta acicola*, the causal agent of brown spot needle blight. The study objective was to determine tree response to the disease by assessing tree vigor, plot characteristics, and climate conditions using 16 forest health plots established in loblolly pine plantations around the state of Alabama. Preliminary results show that trees with more severe disease had shorter shoot lengths, shorter needles, and more oleoresin production than trees with less severe disease. Since the installation of plots, tree crowns have become more chlorotic and defoliated with each month of infection. In addition, other foliar pathogens (*Sydowia polyspora*, *Rhizosphaera kalkhoffii, and Lophodermium spp*.) have been recovered in stands with severe symptoms. The knowledge produced by this project will be used to develop best management practices for areas affected by needle blight. It shall also help direct future research actions, especially when little is known regarding the impact of the pests/pathogens associated with loblolly pine in the southeastern United States.

Emerging diseases in forest tree seedling production

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: More than 400 million tree seedlings are produced in Sweden annually to replant harvested forest areas. These seedlings are cultivated in a highly industrialized manner, in which large monocultures of densely grown seedlings are subjected to intensive cultivation practices. Heavy fertilization and irrigation do create optimal conditions for their growth, but these practices may also stress seedlings and create conditions for the development of fungal pathogens. The use of chemical pesticides can also cause further plant stress making them even more susceptible to fungal infections.

The availability of effective fungicides in the European Union have been steadily shrinking during the last decades, thereby challenging the production of forest tree seedlings. Recently, there have been an emergence of previously neglectable diseases in Swedish forest nurseries, most notably the species from the genera *Phoma* and *Cladosporium*.

Currently, there is a lack of knowledge regarding both their infection biology and the possible reasons of their outbreaks. Changed cultivation practises, a warmer climate or new adaptations by these pathogens could all be possible explanations to the increased disease pressure. Other unknown factors should not be excluded as well. The objective of this research was to gain a better understanding of the species complex, population structure and infection biology of *Phoma* and *Cladosporium* to develop solutions for their control in forest nurseries.

Facilitating the selection of brown spot needle blight resistance in loblolly pine through the development of a high-throughput screening protocol

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Brown spot needle blight (BSNB), caused by the fungal agent Lecanosticta acicola, is a severe needle disease of pine affecting plantations in Asia, North America, Europe, and parts of Central America and Africa. Over the past few decades, both the geographical and host range of BSNB has been expanding continuously and rapidly. In the United States, an increase in disease incidence and severity on loblolly pine (Pinus taeda) has been reported by foresters. Given that loblolly pine is the main commercial timber species in the Southeastern United States, and that it has not historically been impacted by BSNB, the forestry industry and government agencies have made it a priority to manage both BSNB and other needle diseases. Prior assessments of outbreaks have suggested that loblolly pine families vary in their susceptibility to BSNB; however, these observations are still only preliminary and there have been no attempts at formal screenings of families. The US Forest Service Resistance Screening Center (RSC) has functioning protocols to screen pine families for resistance against pitch canker (Fusarium circinatum) and fusiform rust (Cronartium quercuum f. sp. fusiforme) and is therefore an optimal site for creating and deploying a high-throughput screening protocol for BSNB resistance. As a first step for protocol development, we isolated L. acicola from three sites in the region, which will be utilized for inoculation trials at the RSC. During the first inoculation trials in the summer of 2023, we aimed to test the impact of seedling age, incubation conditions and duration, and inoculum concentration on BSNB disease development. Subsequent trials will develop and refine parameters for evaluating disease incidence and severity on seedlings. The completed protocol will be scaled up for the high-throughput screening of 120 seedlings per family, the results of which will be compared with prior field assessments. These results will also be utilized in the assessment of host defense mechanisms against BSNB. This project, along with further genetic and molecular characterization of the families, strives to advance the formation of a breeding program for BSNB-resistant loblolly pine.

First report of current season needle necrosis (CSNN) caused by Sydowia polyspora on Abies grandis in Sweden

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Current season needle necrosis (CSNN) is a foliar disease, infecting manly firs and pines, but is also reported in several other conifer genera. The disease is in particular a problem for Christmas tree plantations, as it causes necrosis and premature foliage shedding, resulting in significant economic and esthetic devaluation. The disease has notably been a problem of fir plantations in the Pacific Northwest of the USA but has also been present in some Nordic and Central European countries. Certain species associated with this disease are also capable of infecting tip branches, needles, cause injury-related sapstain, and reduce seedling emergence. In September 2022, CSNN symptoms were detected on 10-year-old *Abies grandis* trees on a plantation located in Southern Sweden. To identify the causal agent of the needle necrosis, symptomatic and healthy needles were collected from several trees approximately 100 meters apart. After surface sterilization of necrotic needles, fungal culturing, microscopy, and molecular diagnostics, one of the potential causal agents was identified as *Sydowia polyspora* – a saprophyte, endophyte, and opportunistic pathogen. To test this hypothesis, Koch´s postulates were applied to prove microbial causality, and field surveys were conducted to ascertain the extent of disease severity at the stand level. Fifty *A. grandis* seedlings were inoculated with *S. polyspora* conidial suspension and incubated in conditions of high relative air humidity and temperature. After 2 weeks and the initial CSNN symptoms were observed, *S. polyspora* was successfully re-isolated from the surface-sterilized necrotic needles. Damage assessment of the infected *A. grandis* stand showed that most trees had up to 25% infected crown (upper and lower) and that similar symptoms are also present in a nearby grand fir stand. This is the first time *S. polyspora*-related CSNN disease has been reported on *A. grandis* in Sweden. The reason for the surge in disease symptoms caused by *S. polyspora* and possible management implications will be discussed.

Keywords: *Sydowia polyspora*, *Abies grandis*, needle necrosis, CSNN.

Foliar fungal communities in native and exotic pine from arboreta and botanical gardens: implications for invasive species introductions.

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: The genus *Pinus* includes some of the most ecologically and economically significant forest tree species in Northern Hemisphere, and is also commonly planted in the southern hemisphere in industrial plantations. Because of this importance, pines are the focus of considerable research including mycological work to determine fungi associated with all parts of the trees, including mutualists, pathogens and endophytes. In recent years, several pine pathogens have increased in importance, including needle diseases such as Dothistroma needle blight or Brown spot needle blight, and *Diplodia sapinea* causing tip blight of pines. Knowledge of the diversity and biogeographic distributions of needle inhabiting fungi, as well as the role of these organisms and factors shaping foliar fungal communities remain limited. While arboreta and botanical gardens play crucial roles in preserving and showcasing plant diversity and providing educational opportunities for the study and conservation of plants, these sites also serve as potential pathways for the introduction and spread of invasive tree pathogens, which can have devastating impacts on both cultivated and natural ecosystems. In this talk, I report on different collaborative investigations in arboreta and botanical gardens in North America, Europe and Western Asia to define the fungal species diversity and richness associated with healthy, symptomatic and killed needles of native and exotic pine, and to ascertain possible novel host-pathogen associations. Methods deployed include both classical and eDNA analysis to acertain fungal taxa associated with needles and address determinants of fungal diversity and biogeographic patterns. These smaller investigations reveal a relatively large number of pathogenic fungi causing disease on exotic plantings of pine, several of which are new first reports. The findings underscore the significance of arboreta and botanical gardens as a significant pathway for the introduction of invasive tree pathogens and also highlights the need for increased awareness, improved biosecurity measures, and collaborative initiatives to minimize the risks associated with invasive tree pathogens.

Metabolic processes occurring and secondary metabolites present during infection of conifer Lophodermella needle diseases

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Despite increasing incidence and severity due to climate change, conifer needle pathosystems are understudied which also limits our ability to design efficient management strategies and to grasp their potential as threats in forest ecosystems. Characterizing these complex host tree-microbe interactions in changing environments is important for deciphering mechanisms to improve tree resilience and to develop sustainable strategies for forest disease management. To add to our understanding of tree-microbe interactions among emerging needle diseases, we examined (1) gene expression profiles of the host and the microbiota (bacteria and fungi) within the Lophodermella needle cast pathosystem to determine the variation in metabolic processes and secondary metabolites during colonization on Lodgepole pine needles by two species of *Lophodermella*. Obtained data showed an over-expression of pathogenicity-related genes in symptomatic needles suggesting metabolic activities driven by *Lophodermella* pathogens as they dominate the mycobiota and colonize the needle tissue. Our results also suggest that members of the bacterial community are also associated with disease development and associated metabolic activities. Results from this study provide valuable insights into the pathogenicity mechanisms of *Lophodermella* pathogens and associated microbes present in this needle cast pathosystem.

Population genomic analyses to reveal the evolutionary history of the pine pathogen, Dothistroma pini

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: *Dothistroma pini*, one of the causal agents of Dothistroma needle blight, is an important foliar pathogen of *Pinus* spp. in the Northern Hemisphere. *Dothistroma pini* has a more limited distribution compared to its sister species, *Dothistroma septosporum,* and has been documented on both native and non-native pines in Europe, central and eastern North America and western Russia. Population studies conducted on *D. pini* from Europe and Russia showed evidence of human mediated movement of the pathogen across the continent and populations that were both well established and newly emerged. Comparative studies on populations from North America are lacking. The aim of this study was to investigate the population genetics of *D. pini* in the entire Northern Hemisphere and to determine the historical migration pathways of the pathogen. Isolates of *D. pini* from most of the countries where the pathogen has been recorded were selected for whole genome sequencing. Selection was based on microsatellite haplotypes, mating types and different hosts in these countries. Single Nucleotide Polymorphisms (SNPs) were determined for 91 *D. pini* genomes, and these were used for downstream population genetic analyses. Preliminary results indicated three genetic clusters. The first cluster contained isolates from central and eastern United States, Canada and all the isolates from Europe. The second and third clusters were very distinct, only containing isolates from North Dakota in North-central USA and isolates from Arkansas in South-central USA, respectively. These clusters will be used to model historical migration scenarios of *D. pini* by conducting an Approximate Bayesian Computation (ABC) analysis. This is the first study to consider the population structure and diversity of *D. pini* and determine the migration patterns in the Northern Hemisphere using genomic data. These findings will highlight possible areas of risks for future introductions of the pathogen into areas where it does not yet occur, especially in the Southern Hemisphere where its distinct absence remains an enigma.

Susceptibility of South African pine material to infection by Dothistroma septosporum in Colombia

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Dothistroma needle blight (DNB) is one of the most important pine needle diseases in the Southern Hemisphere. In Colombia, outbreaks of DNB have been observed on Mesoamerican pine species including *Pinus patula*, *P. tecunumanii*, *P. maximinoi* and *P. oocarpa*. Two distinct clonal populations of *D. septosporum* have been identified, of which one appears to be highly aggressive. In South Africa, the same Mesoamerican *Pinus* spp. are increasingly being planted. The aim of this study was to evaluate the possible threat that Colombian *D. septosporum* strains could pose to the South African pine planting stock. This was achieved by assessing the natural tolerance to *D. septosporum* of five South African *Pinus* species and two hybrids under field conditions and where disease severity was measured over a two year period. In addition, the genetic diversity of the *D. septosporum* population isolated from the newly infected trees was investigated using microsatellite markers. The trial was conducted on a forestry farm having high levels of *D. septosporum* inoculum on surrounding trees. The first signs of infection were observed on six-month-old trees. The hybrid *P. patula* x *P. tecunumanii* (Low Elevation population) as well as pure *P. tecunumanii* LE, *P. patula* and *P. maximinoi* exhibited high levels of tolerance to infection, while *P. oocarpa* was highly susceptible. Microsatellite data showed unexpectedly high levels of genetic diversity in the *D. septosporum* population including unique alleles and haplotypes not previously found in Colombia. The results suggest that there have been new introductions of the pathogen into Colombia. These continued introductions and emergence of new haplotypes that are able to infect Mesoamerican pine species highlight a potential risk to the South African forestry industry, and other countries, planting these pine species. Broadly, the study emphasizes the risks associated with global pathogen movement and the need for continual pathogen screening in pine breeding programs that should incorporate field as well as molecular data.

Swiss needle cast in coastal Oregon and SW Washington, USA: variation in aerial detection, foliage retention, and disease severity

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Swiss needle cast (SNC) is widely regarded as the most important foliage disease of Douglas-fir (*Pseudotsuga menziesii*) and is caused by the fungal pathogen *Nothophaeocryptopus gaeumannii*. The distribution and disease severity of SNC were evaluated using a regional network of 106 plots located within an area that extends beyond the range of susceptible coastal forests in Oregon and Washington. Plots were measured at the time of establishment in 2013-2015 and remeasured five years later in 2018-2020. Foliage retention was found to be negatively correlated with disease severity and positively correlated with tree growth. At individual sites, needle retention and disease severity has varied between sampling periods. Aerial detection surveys have been flown since 1996, and most recently in 2022 and 2024 following north-south lines separated by 2 miles to identify geographic areas symptomatic for SNC within the coastal forests of Oregon. The 2022 survey showed the highest total area of symptomatic Douglas-fir forest recorded to date at 266,030 ha. The SNC outbreak has remained within a well-defined geographic area, yet within this area, there has been significant variation in disease impacts.

The population structure and diversity of Dothistroma septosporum in Cantabria and Valencia indicates several introductions of the pathogen into Spain

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: *Dothistroma septosporum* and *D. pini*, the causal agents of Dothistroma Needle Blight (DNB), are important fungal pathogens of *Pinus* species. DNB was first reported in Spain in 1933 but severe disease outbreaks have only occurred in the Spanish Atlantic region in the past decade. In 2015, a needle blight disease was observed in Cantabria in stands of *P. nigra* subsp. *nigra* and *P. nigra* subsp. *salzmanii* planted alongside each other, and a third site of *Pinus nigra* subsp. *corsicana* planted seventeen kilometres from the others. In 2016, a needle blight disease was also observed in Fredes and Boixar in Valencia on *Pinus* species. The aim of this study was to identify the pathogen/s present on the affected trees, and to determine the population diversity and structure of a collection of isolates from three planted stands in Cantabria and two locations in Valencia using 12 microsatellites and species-specific mating type markers. In total, 150 isolates, all representing *D. septosporum* were obtained. The consensus between the DAPC and STRUCTURE analyses, as well as pairwise genetic differentiation, showed that there are two genetic clusters in Cantabria of which one cluster is also present in Fredes in Valencia. Furthermore, a unique cluster is present in Boixar in Valencia suggesting an introduction from an unsampled source. Although both mating types were detected among the isolates, sexual recombination was not statistically supported in any of the sites. The high genetic diversity observed in Cantabria suggests that the pathogen is not recently introduced into the region as is the case in Valencia where the population is clonal.

Validation of a universal pathogen identification tool to diagnose needle pathogens of Pinus taeda in the southeast United States

T1.20 Needle diseases of conifers: a globally rising threat to natural and planted forests

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Abstract: Little is known about the fungi causing needle diseases on *Pinus taeda*, loblolly pine, which is the primary timber species in the southeast United States. Foliar diseases have traditionally been regarded as secondary problems leading to defoliation and reduced growth, but seldom tree death. However, current reports from industry and government forest managers indicate a recent and stark increase in the incidence and severity of needle diseases in commercially managed pine forests throughout the region. This calls attention to an emerging problem for which the causal agents are poorly understood. Preliminary work has identified several fungal pathogens infecting symptomatic needles sampled throughout the region, including *Lecanosticta acicola*, the causal agent of brown spot needle blight. While *L. acicola* is likely the major pathogen responsible for outbreaks in the western part of the region, no single organism has been identified as the sole causal agent in the eastern states. Previous investigations suggest that multiple organisms result in symptom development and have highlighted the importance of identifying the pathogens in this system. Traditional diagnostic approaches such as isolations failed to identify all fungi, and metabarcoding did not provide species-level identification at an effective cost for use in routine diagnostics. For this reason, our goal is to establish a metagenomics platform to rapidly screen the microbial communities associated with diseased needles and precisely identify fungal pathogens associated with the outbreaks. To meet this goal, we have adapted a Nanopore-based platform that uses the enrichment of fungal DNA to greatly enhance sensitivity and generality with the sequencing of entire diagnostic genes. By this method, DNA samples are first barcoded followed by enrichment achieved through hybridization-based capture of multiple complete diagnostic loci, which are then amplified and sequenced in parallel using third-generation technology. The platform is being optimized using samples from diseased forests, generating species-level fungal community profiles associated with symptomatic *P. taeda* needle samples, thus providing information on the occurrence and proportion of pathogens across affected sites that may be used to develop disease management prescriptions.

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

A pan-European way out of the ash decline crisis: are we yet prepared for rescuing vital genetic diversity in two of Europes´ keystone forest species?

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: Ash dieback (ADB) has been threatening the European ash population for almost three decades, which already resulted in a dramatic loss of ecosystem, species-, and genetic diversity across the continent. Although recently much knowledge has been gathered and permitted us to better understand various aspects of the disease, a pan-European vision for actively safeguarding vital genetic diversity in the European ash population is at present non-existent. However, given that the ash dieback crisis in Europe will certainly be exacerbated in the very near future due to westward expansion of the emerald ash borer as well as to future climate change impacts, developing a cross-border perspective is urgent and vitally important. During this presentation, we suggest a proposal for a European initiative aiming to safeguard genetic diversity in European ash species by combining several approaches in concert. We discuss classical and novel opportunities for resistance breeding and genetic conservation, thereby saving time and costs mediated by knowledge transfer and joint conservation infrastructures. To avoid errors from the past, we compare the current crisis to the Dutch elm disease (DED), where the lack of resources and collaboration led to a steady and non-reversible decline in elm populations. By analyzing data from systematic long-term forest monitoring and mortality observation networks (> 400 observation plots from the ICP level I crown defoliation dataset), we estimate the time remaining to put such a European conservation initiative into action. Our conclusion is that joint European efforts can still make a difference to the level of genetic diversity loss in ash species due to ADB, provided resources are made available in the very near future.

Bark-beetle infestation patterns after storm and drought-induced outbreaks

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: In the recent decades, Norway spruce forests (*Picea abies*) in Europe have been subject to large-scale tree mortality caused by the spruce bark beetle (*Ips typographus*). The outbreaks were induced by storm-felling events and periods of drought, which are becoming increasingly frequent due to climate change. Because storms and droughts spatially affect forests differently, the infestation patterns and configuration of the bark beetles might differ between storms and drought. In this study, we examined local and landscape factors associated with bark beetle-caused tree mortality after one storm (2005) and one drought event (2018) in southern Sweden. The following infestations were compared regarding differences in infestation occurrence and size and associated forest structures and climate. Based on our findings, we discovered that the allocation of infestation patch sizes for the two outbreaks were quite similar with a large proportion of small groups (≤ 10 trees) greater than 0.6. However, the outcomes from this study demonstrate that the drivers behind the spatial configuration of bark beetle infestations can differ considerably between outbreaks triggered by storms and droughts, and the main cause seems to be linked to the spatial distribution of susceptible trees. The most consistent differences for both occurrence and infestation size were that storm-induced infestations increased more with spruce volumes and area of nature reserves in the landscape; whereas for the drought-induced infestations, occurrence and size increased more with clear-cuts in the landscape and spruce heights across spatial scales. Soil moisture and mean drought index were important for both outbreaks but were more important for the infestation sizes after droughts than after storms and may involve a time-lagged effect.

The reasoning behind the differences between storms and droughts may be that during storm-induced outbreaks, when the wind-felled trees are removed or not suitable anymore, bark beetles needs to find specific susceptible standing trees, while after droughts all trees are more or less stressed, which results in a selection of large trees in dry and warm landscapes. Finally, we show that locally the previous infestation size influenced the later infestation size negatively and this seems to be related to host-tree depletions.

Early response of the undergrowth to mass spruce dieback after bark beetle outbreak in the Białowieża forest

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: Spruce-dominated forests are commonly exposed to disturbances associated with mass occurrences of the European spruce bark beetle (*Ips typographus*). Canopy reduction triggers a number of physical and chemical processes in the ecosystem resulting in rapid changes in the vegetation of the lower forest layers.
Our aim was to determine the response of understory vegetation to the dieback of Norway spruce (*Picea abies*) in the first years after disturbance. Our study area was the Białowieża Biosphere Reserve covering the Polish part of the Białowieża Forest, in total 597 km^2. The main data source was 650 phytosociological relevés obtained from the Natural and Cultural Inventory of the Białowieża Forest conducted in 2016–2018 – the peak years of bark beetle gradation.
Shade-tolerant forest species, e.g. *Dryopteris filix-mas, Carex sylvatica, Lathyrus vernus,* and *Anemone nemoros*a, as well as some forest-edge species, showed a decrease in the frequency of occurrence or cover in the plots with dead spruce stands. While the retraction of the former seems understandable - it was probably due to the increased access to light, the reaction of the latter is not clear.
In turn, the presence of light-demanding species associated with non-forest semi-natural communities (meadows, grasslands, swamps) and species characteristic of the class *Epilobietea angustifolii* has also increased. Interestingly, some typically forest species, such as *Stellaria holostea, Galeobdolon luteum, and Milium effusum* were also more abundant after disturbance. Particularly interesting is the reaction of *Oxalis acetosella* - the most common undergrowth species in the Białowieża Forest. Its cover increased dramatically right after spruce dieback, and in the following 3-4 years gradually decreased to the pre-dieback level. A similar course of change, although to a lesser extent, was also observed in the case of *Calamagrostis arundinacea* and *Impatiens parviflora*.
We showed that early response of the undergrowth to pest-related forest disturbance selectively affects individual elements of the phytocoenosis, and it is usually extended over time, unlike, for example, fire-related disturbance. The response of individual species can be divided into directional reactions (positive and negative trends) and non-directional reactions, i.e. fluctuations. We also demonstrated that mass spruce dieback temporarily increases plant biodiversity (α-diversity).

Emerging new diseases in the Cryphonectriaceae: hidden pathogens and unexpected host jumps

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: The Cryphonectriaceae is best-known for the *Cryphonectria parasitica* and chestnut blight that has devastated native *Castanea* populations in Europe and North America. These fungi are less well known in other parts of the world. For example, *Cryphonectria* (now *Chrysoporthe*) *cubensis*, an aggressive canker pathogen of trees in the Myrtaceae with a biology very similar to *C. parasitica,* is relatively poorly understood in terms of its global relevance. This is firstly because the canker disease caused by *Chr. cubensis* and its congeners including *Chr. deuterocubensis* and *Chr. doradensis,* have affected mainly *Eucalyptus* plantation forestry and are not yet known to cause serious disease problems in natural forest ecosystems. Research spanning approximately four decades and more recently capitalizing on DNA-based techniques has shown that the Cryphonectriaceae includes many aggressive tree pathogens of mainly, but not exclusively the Myrtales. Other than those in *Chrysoporthe*, species of these pathogens reside in genera including *Auropex*, *Celoporthe*, *Immersiporthe*, *Myrtoporthe* and others. Some of these fungi have undergone host-jumps from native Myrtales to infect plantation-grown Eucalypts and surveys both in plantations and natural ecosystems are revealing new examples. As these pathogens expand their host range, in some cases utilizing plantation-grown trees as bridgeheads in their pathways of movement, the likelihood that the could cause of new and serious disease pandemics in natural woody ecosystems will increase. Every effort should be made to prevent their movement, particularly across continents of the tropics and southern hemisphere.

Exploring the Growth-Differentiation Balance Hypothesis (GDBH) in trees. Evidence from Dutch elm disease.

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: Trees are long-lived organisms suffering attacks from many pathogens during their lifetime. Disease results from timely combination of a susceptible state of the tree, the presence of a virulent pathogen and favourable environment over a sufficient time period. Under adaptive equilibrium, it is environmental changes favouring the pathogen that lead to disease. Conversely, when an alien pathogen is introduced, disease may occur under optimal conditions for the tree. This is the case with European and American elms, which are devastated by a virulent and invasive fungus, which causes Dutch elm Disease (DED). Nevertheless the trees show a strong and surprising seasonal variation in susceptibility against DED, demonstrating an inherent ability to resist infection. The period in which elms can become diseased is generally restricted to a few weeks in spring. DED occurs because during this time the vector beetles emerge and inoculate the pathogen. The reason for this window of susceptibility is not well understood, but sporadic studies indicate a link to tree growth rate and morphogenesis.

To investigate how these relationships may determine the expression of a susceptibility response, an in-depth study of the time course of primary and secondary growth including meristem reactivation, leaf area and wood development, was run in combination to assessment of susceptibility through repeated artificial inoculations from late winter to summer in a reference elm clone.

The study revealed that three growth patterns, predetermined, free and by successive flows, coexist in the elm. Each of the growth types had a specific temporal and spatial distribution in the architecture of the plant, which corresponded to different wood anatomy patterns and responses to DED inoculation. Maximum susceptibility coincided with an initial growth phase, during which expanding leaves were net carbon sinks, and spring wood was formed. The first reduction in susceptibility occurred with transition to a later growth phase when intense photosynthesis was ensured by an increasing number of mature leaves as energy sources. The results are in agreement with the GDBH, which predicts that any slowdown in growth rate that does not reduce the rate of photosynthesis can increase the resources available for defence.

How soon before we know the worst?

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: Examples of accidental introductions of pest and pathogens are well documented, with some proving to be highly invasive and damaging. Opportunities for such introductions have grown hugely in recent decades because of the vast increase in global trade, particularly trade in living plants and timber products, as well as more frequent international travel by individuals. Although most introduced organisms are unlikely to establish when transferred to new regions, the potential for damage is large if they do and their impact on habitats and ecosystems is long-term and usually irreversible especially if long-lived woody perennials such as trees are affected. To counter introductions, plant health measures tend to rely on prior identification of high risk organisms combined with inspection to intercept them and surveillance to ensure their continued absence. Drawbacks to this approach are that in their native range, pests and pathogens associated with co-evolved hosts may be cryptic or, if they are known, they are not recognised to pose a risk elsewhere. In addition, surveillance may fail to discover high risk pests sometimes for decades after their arrival, due to the difficulties of detection in heterogeneous natural environments, or because of the novel host/pest/pathogen combinations that some introductions make. Drawing on examples, we will explore how long the lag phase is between arrival and detection can be, what influences this and whether plant health measures can meet these challenges.

Lessons learned from the white pine blister rust and Dutch elm disease outbreaks

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: White pine blister rust, caused by the fungal pathogen *Cronartium ribicola* J.C.Fisch. (Basidiomycota), and Dutch elm disease, caused *Ophiostoma novo-ulmi* Brasier and *O. ulmi* (Buisman) Melin & Nannf. (Ascomycota), have caused two of the deadliest forest disease outbreaks in the world. In planted and regenerated white pine stands of North America, mortality can reach nearly 100%. The Dutch elm disease has killed billions of elm trees in North America and Europe. These diseases have not only caused vast economic losses but also irreversible changes to forest ecosystems. The pathogens that cause these diseases are biologically very different, yet they have in common that they are caused by alien pathogens that were introduced accidentally to Europe and North America. They also have in common that the hosts that they attack in their introduced range have very little natural resistance due to the absence of coevolution. Much has been learned about these diseases since their introductions over a century ago. Recent exploration of the genomes of these pathogens has opened a new window into their biology, epidemiology, adaptation and reproduction. The introduction, colonization and dissemination of these pathogens have left a signature in their genomes that can now be deciphered. Our understanding of the routes and pathways of introduction and spread has improved with population genetics and genomics studies. Anthropogenic transport is evident and there is support for multiple or repeated introduction events of both pathogens. Hybridization and introgression appear to play a role in the success of the Dutch elm disease pathogens. Hybridization between the white pine blister rust and a native pine rust is on-going, yet with unpredictable outcomes. We are also discovering genomic signatures of adaptation to temperature of host defense compounds that could provide some clues about invasion success and ability to overcome host defenses. The development of genomics biosurveillance systems promises to change the way we conduct monitoring by identifying variants and hybrids and assign intercepted samples to putative sources. Although such tools and analyses may not be helpful to resolve past pandemics, they can improve our ability to identify patterns and prevent future outbreaks.

Population Genetics and Structure Analysis of Cronartium pini in Northern Sweden

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: The young Scots pine forests in Fennoscandia are increasingly facing numerous abiotic and biotic challenges, with Scots pine blister rust being one of the most devastating fungal diseases. This pathogen, caused by the rust *fungus Cronartium pini*, significantly reduces the value of timber due to decreased radial stem increment, deformed branches, and excessive resin, and can even lead to the death of entire trees. Surveys conducted in 2021 and 2022 revealed the widespread presence of Scots pine blister rust, affecting 80% to 90% of forest stands in Northern Sweden.

In this study, we utilized microsatellite markers developed from the *C. pini* genome to investigate the genetic diversity and population structure of *C. pini* samples collected from northern Sweden. Our comprehensive analysis unveiled significant genetic variation within and among *C. pini* populations, indicating the existence of diverse genotypes and multiple genetic clusters. Moreover, we examined the genetic variations and structures between the heteroecious form, *C. flaccidum* and the autoecious form, *P. pini,* shedding light on their distribution patterns and disease severity.

Notably, our findings identified three distinct multilocus genotypes (MLGs) associated with *C. pini* in multiple counties, suggesting the establishment of MLGs and their corresponding clusters as potential contributors to the ongoing Scots pine blister rust epidemic in northern Sweden. These insights into the population genetics of *C. pini* provide a foundation for evidence-based management strategies, including targeted breeding programs and disease surveillance, aimed at mitigating the impact of pine blister rust on vulnerable pine ecosystems.

By enhancing our understanding of population genetics dynamics in forest pathogens, our study contributes to the development of sustainable strategies for forest conservation and ecosystem resilience in the face of emerging threats. The knowledge gained from this research is vital for implementing effective forest management practices that safeguard the health and productivity of Scots pine forests in northern Sweden.

Resilience of conifer trees to environmental stressors

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: Forest trees play crucial roles not only for mitigating effects of the climate change but also for their considerable economic and ecological value. Forest trees are equally vital as an alternative bioenergy source and play important roles in pollution abatement and the maintenance of biodiversity. Timber and its associated products from forest trees contribute substantially to the revenue generation of many countries of the world. The demand for wood and forest products is expected to continue to increase for the foreseeable future. However, major threats to the sustainable supply of forest tree products are adverse climate, insect pests and diseases. Although many microbes associated with forest trees play fundamental roles in the health of trees, influencing their vitality and productivity, others cause severe diseases. In the last century, some notable pathogenic infections of trees have been recorded and forest pathologists have contributed to tackling several of such severe diseases including chestnut blight, Dutch elm disease (DED), sudden oak death (SOD), *Heterobasidion* root rot and recently ash dieback etc. Despite all the efforts undertaken to control the spread of tree diseases, emerging and invasive pathogens still pose a threat to sustainable supply of forest tree products. Economic losses caused by phytopathogenic fungi every year are estimated at several billion US dollars. Today, the need to increase and safeguard those resources of renewable materials and bioenergy as well as to sustain timber quality together with the demand for novel wood bioproducts present major challenges for forest and tree health biotechnology programs. In this presentation, I will highlight the important components of resistance strategy of forest trees against pathogens using *Heterobasidion*- conifer pathosystem as a case study. I will show the application of genomic tools for identification of other vital traits including microbiomes in disease resistance, which are not usually included in tree resistance breeding programs. I will also discuss novel conifer wood property traits and metabolic pathways which we identified and considered important for resistance against necrotrophic pathogens such as *Heterobasidion* spp. I will outline and discuss the intractable challenges to unravelling resistance mechanisms in conifer tree pathosystems.

The Global Forest Health Crisis: A Public-Good Social Dilemma in Need of International Collective Action

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: Society is confronted by interconnected threats to ecological sustainability. Among these is the devastation of forests by destructive non-native pathogens and insects introduced through global trade, leading to the loss of critical ecosystem services and a global forest health crisis. We argue that the forest health crisis is a public-good social dilemma and propose a response framework that incorporates principles of collective action. This framework will enable scientists to better engage policymakers and empower the public to advocate for proactive biosecurity and forest health management. Collective action in forest health features broadly inclusive stakeholder engagement to build trust and set goals; accountability for destructive pest introductions; pooled support for weakest-link partners; and inclusion of intrinsic and nonmarket values of forest ecosystems in risk assessment. We provide short-term and longer-term measures that incorporate the above principles to shift the societal and ecological forest health paradigm to a more resilient state.

Uromycladium falcatarium, the Falcataria mollucana rust fungus – potential bio security threat for some leguminosae in the Pacific Islands

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: *Uromycladium falcatarium* is an rust fungus caused extremely damaging disease on sengon (*Falcataria moluccana*) in Indonesia. The rust gall fungus has spread across the commercial sengon plantations of Indonesia, Malaysia and the Philippines causing economically significant damage to timber production. The fungus causes growing tissues of sengon trees to form large twisted knots and gall on the leaf, stem, branch, canopy, and which can lead to the death of young trees and damaging of all ages. The fungus spore are able to infect the seeds, survive inside the embryo or in the taste, become seed borne or seed transmitted pathogen. In the other hands *F. mollucana* were to be extremelly invasive weed on the entire Pacific Islands and need to be supress or control intensively in order to prevent the ecosystem changing. The research were conducted a series of experiments with this fungus on a suite of Fabaceae species from Hawaii, i.e. *Acacia chinensis, A. koa, A. koai, A. contorta, A. lebbeck, Leucaena leucochepala*. Plants were exposed to fungal spores under laboratory, greenhouse and natural field conditions. Although several non-target test plants showed signs of initial infection in the laboratory there was no disease progression in any plants other than the target *F. moluccana*. Galls and spores were only formed on the target plants in deliberately inoculated pathogen greenhouse conditions. Field tests have not shown any signs of non-target impact. The results of these experiments suggest that this or other strain of *U. falcatarium* may be suitable candidates for further research as potential biological control agents. We also discuss how our study can help address concerns about the biosecurity threats posed by *Uromycladium* species. The lesson learned and anticipated the gall rust diseases outbreak from the past for the future.

What do we want and where do we want it? Social acceptability of 'lost' tree species restoration in Great Britain

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: Resilience is recognised as a priority for 21st century forestry. Tree health is an essential component of resilient treescapes, as demonstrated by continuing crises such as *Ophiostoma novo-ulmi* and *Hymenoscyphus fraxineus*. We argue that resilience should be social and personal as well as ecological.

There are many different management methods with potential to restore resilient tree species, yet social acceptability in this context is poorly understood. The importance of social acceptability in land management is widely accepted, but tree health presents unique barriers to stakeholder engagement. Recent outbreaks have brought tree health into the headlines, but understanding is still limited. This project sought to harness recent interest in tree health and species loss by engaging stakeholders with opportunities for resilient treescapes. The aim was to explore 'lost' species restoration by focusing on elm in Great Britain, which is now largely absent in its original form but holds strong potential for restoration.

We examined the feasibility of elm restoration by assessing the cultural significance of once widespread species, *Ulmus glabra* and *Ulmus minor;* exploring current values, attitudes and experiences related to elm loss; and identifying stakeholder expectations for elm restoration, including testing the social acceptability of different management scenarios.

We determined that environmental, industrial, and personal perspectives have changed since the outbreak of *Ophiostoma novo-ulmi*, largely due to the decline in availability of elm resources, the loss of large trees, and influential memories held by older individuals. Interviews with stakeholders identified different concepts of restoration and management options with varying philosophical, practical and policy approaches. Recent publicity around tree health crises may provide an opportunity to harness wider public support for resilient treescapes, but effective management requires careful consideration of local contexts, regional differences, and sensitivities, with generational divides and misaligned organisational priorities identified as major constraints. Questions over biosecurity and ecological integrity, combined with concerns for nature equity and cultural identity, encourage us to conclude that the road to restoration may rely on emotional connection alongside environmental and policy decisions. These results have implications for how we engage the public and other stakeholders around current and future tree health issues.

When and where to take action against new invaders of forests.

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: At the very early stages of an invasion by a pest or a pathogen the eradication of an potential invader should be relatively cheap; limited distribution and small units to destroy. The challenge is to detect the invader when it is present in low incidence. This reqires high alert systems that come with a high cost. At later stages erradication is often not possible and the golden rule is to work towards containment in restricted areas. If containment fails a massive and potentially devastating attack to one or several host species could be the result. At the later stages of tan invasion process, the detction of an invader is normally straight forward but the costs for controlling the attacks are multiplied. The trade off between detection and control has a pivotal point somewhere in the invasion process. When considering the optimal effort one should also include the stakes that are involved, this include economical losses as well as loss of habitat for biodiversity that is dependent on the threathened host(s). Examples will be discussed where early detection and late stage management have been successfully deployed.

Winner and loser of spruce budworm outbreak: Pine stands as a study case

T1.21 Never waste pandemics: lessons learned from past forest disease outbreaks

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Abstract: In Canada, red and white pine stands are drastically declining due to forest harvesting during the last 3 centuries. Their conservation is essential to provide socio-economic, cultural and spiritual benefits. In this context, sustainable forestry practices have been developed in order to restore their natural dynamics by emulating the effects of natural disturbances. In pine stand, secondary disturbances such as spruce budworm outbreaks (SBW) are rarely consider while most of these practices focused on emulating surface fires due to its importance in pine establishment. Without fire, balsam fir colonizes the understory which prevent pine establishment and increase the probability of a SBW outbreak. SBW is the main defoliator of conifer trees in North American boreal forest and affected mainly balsam fir and spruces. This disturbance has major impact on forest dynamic in term of productivity and affected area. Given that the frequency and intensity of these outbreak tend to increase with climate change, it is vital to learn more about the effects of this insect on the dynamics of pine regeneration in order to maximize the management strategies. We aim to evaluate the role SBW outbreak in the natural dynamic of red and white pine. Specifically, we evaluate the impact of this insect on natural regeneration on seedlings.

An experimental design was established in twelve pines stands in Temiscamingue (Québec, Canada), where six stands were affected by SBW and six stands were not affected. Within each stand, we establish 28 4 m^2-plot where each pine and balsam fir seedling have been recorded and their height have been measured. Balsam fir defoliation have also been estimated. Pine seedling establishment varied between undefoliated stands and defoliated stands. Our results showed that pine establishment and growth increased during a SBW outbreak. Natural regeneration is a key component of forest management, given its major role in persistence and resilience of forest ecosystems. This study demonstrates the importance of SBW outbreaks in pine forest dynamic, providing insights for forest management.

T1.22 New challenges for forest soil resources in the face of growing global demands for forest products and the need to limit global temperature increase.

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

Are the critical limits for N in soil solution of European forests still exceeded?

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: The anthropogenic emissions of nitrogen dioxides and ammonia resulted in elevated nitrogen inputs into large parts of European forests. Based on empirical evidence, critical limits for total inorganic nitrogen (nitrate and ammonium) concentrations in soil solution have been defined regarding adverse effects on ground vegetation, fungal communities, trees nutrient balance and effects of elevated nitrate leaching.

Concentrations of major nutrients in soil solution have been continuously monitored on the ICP Forests Level II intensive monitoring plot network since the late 1990s. Evaluations of the data of the first years showed that critical limits had been temporally or permanently exceeded at about one third of the plots, typically at forests exposed to high atmospheric deposition of nitrogen. Since, measures taken to reduce air pollution in Europe and elsewhere started to show an effect and atmospheric deposition of nitrogen decreased by about 30%.

In this study, we investigate the temporal evolution of the exceedance of critical limits for nitrogen in soil solution of European forests between 2000 and 2020 based on measurements on approximately two hundred Level II plots across Europe. Preliminary results show that the share of samples with exceedance of critical limits of nitrogen in soil solution has decreased in all soil depths, however not on all plots. We will present results on geographical patterns and trends and potential factors affecting these patterns and trends.

ATMOSPHERIC NITROGEN DEPOSITION IN BROADLEAF EVERGREEN MEDITERRANEAN FORESTS: UPTAKE, CANOPY PROCESSES AND CYCLING

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: The implementation of emission reduction policies in Europe has led to a significant decrease in air pollutant emissions in many countries. In the case of Spain, a reduction in NO_x emissions has been observed; while NH_3 levels have remained relatively stable. However, evidence of nitrogen (N) enrichment and exceeding of N empirical critical loads has been reported in certain Spanish ecosystems, such as *Quercus ilex* (holm oak) forest. Holm oak is a broadleaf evergreen sclerophyllous species present over a wide range of environments and representative of the Mediterranean region.

To comprehend the effects of N deposition, it is important to understand and complete the N cycle in the ecosystem, including the input of wet and dry N deposition, the retention and transformations that occurs within the canopy, plant absorption and remobilization, and losses as soil gases emissions or leaching. To assess whether these ecosystems exceed critical loads and to check whether there has been a reduction in N deposition over the last decade, intensive monitoring has been carried out in three peri-urban *Q. ilex* forests located near major cities: Barcelona, Madrid, and Navarra. These sites represent forests with different climatic conditions and sources of pollutant emissions. Air pollutant gases and particle concentration, wet and dry deposition, meteorology, soil humidity and temperature, have been measured in 2011-2013 and 2020-2021. Dry deposition was quantified combining the empirical inferential method for surface deposition of NO_3^- and NH_4^+ with modelled stomatal uptake of NH_3, HNO_3 and NO_2. Also, the biological transformations occurring at the canopy level during the last period have been measured.

Throughfall results show the existence of seasonal biological processes at the canopy level such as N uptake and/or biological transformation. Holm oak leaves were able to absorb both oxidised and reduced N compounds, with higher rates of NH_4 absorption. Dry deposition represents a significant proportion of the total N deposition in these ecosystems. There is a seasonal variation an asynchrony between inputs of N and biological demand, leading to leaching pulses. Soil N_2O fluxes were detected under the canopy and in open areas and with no clear seasonal pattern.

Biomarkers of nitrogen availability in tree species from a Brazilian Atlantic Forest fragment

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Nitrogen (N) is an essential nutrient, but it can be harmful to plants and biodiversity as a whole when in excess. N deposition in forests can be caused by several factors, including the input N through the addition of chemical fertilizers in surrounding croplands. Nowadays, most of the Brazilian Atlantic Forest is composed of forest fragments surrounded by crop fields. This study aimed at evaluating changes in the N metabolism of tree species native to the Atlantic Forest in areas exposed to the application of nitrogen fertilizers. The following species were sampled: *Croton floribundus* Spreng., *Heliocarpus popayanensis* Kunth., *Astronium graveolens* Jacq., *Cabralea canjerana* (Vell.) Mart., *Aspidosperma polyneuron* Müll.Arg., and *Guarea kunthiana* A.Juss. We collected leaves and xylem sap of trees close to agricultural cultivation (considered the border adjacent to agriculture – BAC) and individuals close to a reforestation site (considered the reforestation adjacent border – BAR). The following parameters related to N metabolism were analyzed: nitrate, ammonium and amino acid levels in the xylem sap and leaves, the activity of the enzyme nitrate reductase (NR) in the leaves, and leaf protein content. For most tree species, the results indicated alterations in the N metabolism of individuals in the BAC that suggest greater N availability compared to the BAR, such as higher NR activity, higher nitrate transport in the xylem sap, higher nitrate and protein accumulation in the leaves. Furthermore, in another monitoring of N compounds in leaves of trees along a transect in a forest fragment near a maize field, we saw an increase in the content of nitrate in *G. kunthiana* located near the BAC (at up to 50 m of distance from the BAC). The leaves of *G. kunthiana* trees more distant to the BAC, from 50 to 250 m, showed a lower content of that N compound. Overall, these data suggest that N-metabolism traits from trees could be used as biomarkers for monitoring N deposition in forests, in addition to the widely used leaf total N content.
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Combined effects of climate extremes and atmospheric deposition on forest growth and water-use efficiency

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Forests remove about 30% of the human-induced increase in atmospheric CO_2,thus playing a crucial role as a nature-based solution to mitigate climate change. However, the persistence of forest carbon sink capacity depends on how well they cope and adapt to more frequent climate extreme events and concomitant changes in the atmospheric chemistry, e.g., increasing atmospheric CO_2 and nitrogen and sulphur deposition. Recent pan-tropical and global analyses showed that the CO_2 fertilization effects on physiological and productivity metrics, such as water-use efficiency (the ratio between photosynthesis and transpiration, WUE), tree growth and forest carbon uptake have slowed down (or even decreased) over the recent decades due to increasing moisture or nutrient limitations and/or to increases in tree mortality. Moreover, earlier studies conducted in the 1980s identified acid deposition as the main driver of increasing tree mortality in Central Europe. The legacy of sulphur deposition, albeit the latter significantly decreased since the 1980s, could still affect soil processes (e.g., soil acidification, soil inorganic C loss and cation leaching) and the trade-off between carbon uptake and water loss through transpiration (WUE). Despite the long history of assessing air pollution and drought effects on forests, we still lack a unifying framework to assess the interactions between extreme climate events and atmospheric deposition. We will present results from literature review and meta-analyses we are conducting within the WG2 of the COST Action CA21138 CLEANFOREST CLEANFOREST- Joint effects of CLimate Extremes and Atmospheric depositioN on European FORESTs. Specifically, we will assess how climate extremes and atmospheric nitrogen and sulphur deposition interact and affect the ecophysiological responses (in terms of WUE and growth) of European forests to increasing atmospheric CO_2. Moreover, we will address to what extent atmospheric deposition mediates sensitivity to drought events and which mechanisms are involved. Lastly, we will discuss how processes at the different scales (leaf, tree, ecosystem) are linked and integrated both at temporal (e.g., in terms of magnitude of changes) and spatial (at the European) scales.

Community stability and airborne pollutants effects in European forest understorey vegetation

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: While the deposition of atmospheric pollutants is widely recognised as a disturbance factor for forest understorey vegetation communities, it can be challenging to quantify and track the impact of disturbances on community stability over time. Community stability and resilience are often conceptualised using the idea of a ball rolling in a well of attraction, but while intuitive, this does not (in itself) give quantitative results. Ordination methods, on the other hand, are often used to visualise community composition and changes, giving quantitative results, but are not directly linked to the insights of resilience theory. We used data from long term monitoring sites that are part of the ICP Integrated Monitoring network to first summarise community composition using ordination methods, and then track the movement of plots in ordination space as a measure of community stability, linking the patterns that emerged to concepts in resilience theory. We further used stability as the response variable in statistical models, to investigate the influence of factors including the deposition of atmospheric pollutants (with a focus on oxidised and reduced nitrogen). Disturbances, particularly those concentrated in relatively short periods of time such as storm damage (so-called pulse disturbances) could clearly be seen in strong directional movement in ordination space (i.e., reduced stability), while the impact of atmospheric pollutants was more subtle.

Contribution of rime to nitrogen deposition in middle elevated mountains in Central Europe

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Nitrogen (N) deposition, an important process of atmospheric self-cleaning, represents an important pathway for nutrients and pollutants to ecosystems. Enhanced N deposition flux contributes to acidification, eutrophication and loss of biodiversity. Hence, the correct and reliable quantification of N deposition is of the utmost importance for forest management.

Rime is an under-researched pathway of the atmospheric deposition of ecological and environmental relevance, in particular in mountain regions. Rime alongside with snow were sampled and assessed for $N\text{-}NO_3^-$ at ten border mountaintop sites across the Czech Republic (CR) in the three consecutive winters of 2009–2011. Our observations indicated significantly higher nitrogen (N) contents in rime as compared to snow at all sites. The highest N contamination was found unexpectedly in the relatively unpolluted Southern portion of the CR. The measurements were put in context with data driven geo-spatial modelling results of annual wet vertical (rain and snow) and occult (fog and rime) deposition. We have found, that despite relatively low hydrological input of rime, it contributed significantly to annual atmospheric deposition. Modelled results showed that mean winter rime deposition corresponded to about 6–25%, and mean winter snow deposition made up 25–72.5% of mean annual $N\text{-}NO_3^-$ wet-only deposition. Model $N\text{-}NO_3^-$ occult deposition estimated from throughfall and total (wet and dry) deposition is highly uncertain, however: N throughfall is not a relevant proxy for estimation of realistic total N deposition due to N exchange between the tree canopy and atmosphere. Considering the fact that wet-only deposition is a year-long phenomenon, whereas rime forms under the climatological conditions of the Czech middle elevated mountains during only a few (2–3) months a year, we can conclude that the rime deposition pathway should not be neglected in quantifying the real atmospheric deposition flux in mountain regions as it might contribute to the real deposition flux substantially even in mountains of medium elevation, as was observed in the CR.

Cool to be poor? How to preserve oligotrophic forest legacies in affluent industrial societies

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Intersection of lists of forest species, Ellenberg indicator values for nutrients and red lists of vascular plants highlights eutrophication as one of the chief threats to woodland biodiversity in Central Europe. A review of temporal and spatial patterns in the loss of oligotrophic forest habitats suggests that it is not solely a result of nitrogen-immissions from agriculture and combustion, but equally one of self-melioration in the course of primary and secondary succession. Acknowledging the importance of historical legacies (the "ghost of degradation past") has crucial implications on the preservation, restoration and management of forest ecosystems and their functions.
I suggest a baseline model of N-supply and soil acidification during postglacial vegetation history, whose epochs have each added characteristic legacies to the species pool, which call for complementary management paradigms in the face of eutrophication. I review effectiveness and feasibility of primary succession (postglacial), no-intervention reserves (prehistorical), conservation of species and habitats (preindustrial) and function-oriented silviculture (industrial reference period) for the conservation management of oligotrophic forest sites and their biotic communities.
In the face of continuing high N-immissions from agriculture and combustion, measures to reduce deposition and increase uptake and storage in forests must be supplemented by local conservation-oriented N-extraction through biomass (coppicing, wood pasture and litter removal) and topsoil as already practiced in grassland management and restoration.

Effect of Nitrogen deposition on plant physiology, nutrient uptake and antioxidant enzyme activities in subtropical species

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: With the rapid economic development and the frequent human activities in recent decades, there are induced climate and environmental changes globally, such as the elevated atmospheric nitrogen (N) deposition, which are expanding problems that affect tree growth and development in forest ecosystems. Thus, a single type of N addition may not accurately reflect their ecological effects on tree seedling growth and forest ecosystem development.

We selected species of a typical subtropical area:*Cunninghamia lanceolata, Liquidambar formosana, Pinus massoniana, Phoebe zhennan,* and *Schima superba* as the research object. Seedlings were exposed to different doses of N deposition. Two-level were used, one control and the other with N supplementation 60 kg N hm^{-2} a^{-2}. Ammonium sulfate $(NH_4)_2SO_4$, ammonium nitrate (NH_4NO_3), and potassium nitrate (KNO_3) were used as N sources. The objective of this research was to investigate the possibility that these effects might be related to the difference in seedlings physiology, antioxidative defense, sensitivity and to check if these treatments could enhance seedling performance that would be useful for the protection of these species. Nutrient contents, antioxidant enzyme activity and malondialdehyde (MDA) content varied among treatments. Excessive N deposition decreased the content of MDA, and the activities of antioxidant enzymes. Height and diameter increased among all treatment under low N deposition; however it decreased under high deposition. As N deposition increased, the activity of SOD, CAT, and POD, increased, and it decreased with low level of N deposition. The MDA content decreased first and then increased as N deposition increased.

The results indicated that high N deposition would be harmful to the growth and development of seedlings because the cell in leaves would experience peroxidation that damages the structure and function of plants. Therefore, moderate deposition increased the development of seedlings. In our experiment, all species behave noticeably in response to increased deposition. In combination with the increased leaf area, the transpiration demands were increased between all species.

The outcomes here will enhance our knowledge of the physiological and antioxidant response mechanisms of the effect of N deposition with some practical implications on the protection of the forest ecosystem.

Effects of N deposition and climate on the foliar nutrition of European tree species

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Foliar nutrient concentrations and contents are important indicators of forest trees' nutritional status. Foliar nutrients depend on nutrient availability and uptake capacity of the respective tree, which at a longer time scale is influenced by soil properties and deposition, and, at shorter time scale by temperature and precipitation. Taking climate conditions into consideration is thus important when interpreting data on foliar nutrition.

To investigate the temporal climate impact on foliar chemistry, we statistically model the effect of average temperature and precipitation sum integrated over moving time-windows on foliar nutrients. The data included in these models involve foliar nutrients (N, P, K, Ca, Mg) of temperate tree species (beech, oak, spruce, and pine) from around 300 European ICP Forests monitoring plots. We further analyze whether climatic effects on foliar nutrients are impacted by deposition rates and available water capacity.

For German Level II plots, significant effects of current or lagged climate conditions occur among nutrient concentrations and contents in all investigated tree species. In general, N, P, and K are found to be less sensitive to climate variations than Mg and Ca. For the other tree species, we find significant climate effects on both nutrient ratios and nutrient concentrations. Nutrient ratios and concentrations are generally less sensitive to climate conditions than nutrient contents and foliar mass. When a climate condition influences a nutrient concentration and foliar mass in opposing directions, the effects via foliar mass tend to dominate the resulting responses of nutrient content. Our preliminary results suggest that climate conditions should be considered for the interpretation of foliar nutrition data for specific strata of tree species and climate aspects.

Effects of nitrogen deposition on tree water-use efficiency and ecosystem nitrogen dynamics: insights from a novel manipulation experiment in Italy

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: The ability of forests to continue absorbing atmospheric CO_2, and hence mitigating climate change, is constrained by global change drivers, such as increasing nitrogen (N) deposition induced by anthropogenic activities. N input from atmospheric deposition can positively affect forest productivity in N-limited forests. However, under N excess conditions (e.g., above the N critical loads), a cascade of negative effects is expected, leading to tree growth decline, increase in soil acidification and N loss pathways. Experimental simulations of increasing N deposition have been extensively used to directly determine whether atmospheric N input contributes to alleviating N limitation and to understand ecosystem responses. However, most of these experiments have considered soil N applications, often applying N doses several order magnitudes higher than ambient deposition, thus not mimicking realistic changes in N deposition. Moreover, they excluded *a priori* atmosphere-canopy exchange processes, including canopy N uptake and microbial transformations. In this context, the experiment established in a mature and eutrophic *Fagus sylvatica* L. forest in Italy represents a unique resource for advancing understanding on forest responses to global change. At this site, four treatments have been carried out since 2015: control, canopy (30 kg ha^{-1} yr^{-1}) and soil (30 and 60 kg ha^{-1} yr^{-1}) N applications. Our main questions are: do the two experimental approaches (canopy vs. soil applications) lead to different responses in terms of *i)* tree growth and intrinsic water-use efficiency and *ii)* ecosystem nitrogen processes? Moreover, can we detect symptoms of ecosystem N saturation and tree growth in the case of soil N fertilization? To answer these questions, we combined dendroecological analyses (ring widths and stable carbon isotope composition, $\delta^{13}C$) with the measure of stable N isotope composition ($\delta^{15}N$) in different forest samples, including foliar, litter, soil, main root and ectomycorrhizal root tips. On-going $\delta^{13}C$ analyses in tree rings will provide insight into physiological mechanisms underpinning growth changes in relation to different treatments. Whereas, $\delta^{15}N$ in different forest samples will help to elucidate differences in ecosystem N processes between the two approaches, i.e., N retention within the system or increasing N loss pathways and other nutrient limitations due to N saturation.

From Top to Bottom: Using Pedotransfer Functions to Predict Subsoil Organic Carbon and Nitrogen Contents

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Most monitoring systems on soil organic carbon (C) and total nitrogen (N) sequestration are restricted to the top soil, primarily caused by ressource restrictions. Accurate estimations of C and N contents at subsurface depths are challenging due to limited data availability and the high cost and time required for direct measurements.

Therefore, pedotransfer functions (PTFs) have gained prominence in soil science as a reliable tool for estimating soil properties, including the prediction of C and N concentration and stocks at various locations and depths, as a cost-effective and practical solution.

C and N concentrations and stocks play a crucial role in understanding soil health and its potential as a C and N sink. This abstract focuses on the development and application of PTFs to predict C and N concentrations and stocks in the depth range of 50 to 80 cm based on topsoil C and N analyses and soil assessments from more than 800 soil profiles in Austria.

This study employs a dataset encompassing soil samples of forests from diverse geographic regions in Austria, with measured topsoil organic C and N, and corresponding C and N content data obtained from 50 to 80 cm depths. Various soil properties from soil assessments, such as soil texture, bulk density or root density, geological and topographic indices, tree species composition and climate data are considered as potential predictors in the PTF development.

The PTFs were developed using statistical modeling techniques, including multiple linear regression, general additive models and machine learning algorithms, such as random forests or artificial neural networks. Models were assessed by cross-validation to ensure robustness and generalizability and associated quality measures such as root mean square error and coefficient of determination.

The resulting PTFs exhibit significant predictive capabilities, enabling accurate estimations of C and N concentrations and stocks at 50 to 80 cm depths based on C and N measurements at the topsoil. Therefore, they can help in identifying forest areas with high C and N stocks at 50 to 80 cm depths, estimating C and N sequestration potentials and optimizing forestry practices to enhance soil fertility, C and N storage.

Increased export of nitrate and base cations in runoff from a final cut harvested Norway spruce forest in southwest Sweden

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Deposition, soil- and groundwater as well as runoff chemistry were sampled during six years, 2014-2020, in a 7 ha Norway spruce forest catchment, “Storskogen”, in southwest Sweden. In June 2018, approximately 75% of the forest in the Storskogen catchment was clear-cut harvested. The logging was made according to normal practices, but with a large degree of environmental protection measures.

The concentration of nitrate (NO_3-N) increased considerably after the harvest at all the different sampling sites, from very low values before harvest, to high concentrations especially in the soil water and the ground water in the mineral soil and in the runoff stream water. The changes in a central wetland were smaller.

The export of total nitrogen with the run-off out from the catchment increased substantially, from approximately 2 kg N ha^{-1} yr^{-1} before harvest, to 12 kg N ha^{-1} yr^{-1} the second year after the harvest. The nitrogen export after the harvest had not culminated the second year after harvest.

Compared to before the harvest, the pH and the acid neutralizing capacity (ANC) increased in the run-off from Storskogen after the harvest. The export of base cations with the run-off almost doubled after harvest.

Long-term depositon load and forest state monitoring in the former heavy polluted area of the Ore Mts. (Czech Republic)

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Ore Mountains is one of heavy polluted areas in Europe during the second half of 20th century. Combustion plants for heat and power generation and chemical industry which used brown coal were the main sources of air pollution. Since desulfurization of main pollution sources during 1990´s, air quality improved very quickly. Soil condition, however, was affected strongly and there is no clear improvement in the soil chemistry even after thirty years. Long-term monitoring of forest health state, growth, and soil and needle chemistry could help to answer what is happening in forest ecosystem and how forest reacts on changes in air pollution and deposition load.

Research plots were installed in the young Norway spruce (*Picea abies* [L.] Karst) stands. All stands were up to 30 years old. In 1996, the monitoring system was completed. Crown condition, height increment assessment, foliage and soil sampling and analyses as well as deposition load are the main parameters evaluated within this transect.

Defoliation of tree crowns decreased from more than 40% in the 1990´s to about 20% in the last decade. We have observed slight decrease of K, Ca, P, Zn, S concentration and slight increase of N and Mg concentration in spruce needles. It results to the imbalance between N/P and N/K ratio.

Soil reaction is strongly to moderate acid, nitrogen content in humus layer and in mineral soil is sufficient, on some plot can be evaluated as increased. Main base cation (Ca and Mg) content is influenced by liming, but on the plots without this treatment it is very low, Worse situation is in case of available phosphorus - its content in both evaluated soil layers is very low even on limed plots and is still decreasing during period evaluated.

In the end of 1970´s deposition of S reached in spruce stand 100-150 $kg.ha^{-1}.year^{-1}$ and 25 $kg.ha^{-1}.year^{-1}$ in the open field, in 2022 it was only 3,1 $kg.ha^{-1}.year^{-1}$ (throughfall) and 2,6 $kg.ha^{-1}.year^{-1}$ (bulk). Nitrogen deposition decreased from about 15-25 $kg.ha^{-1}.year^{-1}$ in the 1980´s to 5-6 $kg.ha^{-1}.year^{-1}$ in 2022. pH values of precipitation are increasing during the measuring period.

Long-term effects of clear-cut harvesting on forest soil water nitrogen in Sweden

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: In Sweden's forests, almost all inorganic nitrogen is usually taken up by trees, ground vegetation and soil microorganisms, with very low leaching from the root zone soil water. However, disturbances in the forest, such as clearcutting, storm damage and bark beetle attacks, result in transiently elevated levels of nitrate in the soil water. These increased levels of nitrate contribute to soil acidification and can also be transported to groundwater and surface waters, contributing to increased nitrate levels in the groundwater and thereby impaired drinking water quality, as well as eutrophication of surface waters.

In this study, we show how nitrate concentrations in soil water are affected by disturbances, mainly in the form of clearcutting, at about 10 different forest sites in a nitrogen deposition gradient across Sweden. The results show that the nitrate levels increased shortly after clearcutting, even in low deposition areas, and that these elevated levels in the soil water continued for some years after clearcutting. Storm damage and bark beetle attacks contributed similarly to elevated levels of nitrate in soil water. This study shows that nitrogen concentrations in soil water increased also in low deposition areas. The time after the clear cut to the peak nitrogen concentration did not depend on where in the climate and deposition gradient the site was situated.

Nitrogen deposition affects forest health and stability in Switzerland

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Forests in Switzerland are subjected to high nitrogen deposition loads. There are various mechanisms of action of its effect on forest health and stability. The data presented here base on 174 plots of the Swiss Intercantonal Forest Monitoring during 40 years. Increased N deposition is both accelerating soil acidification and causing eutrophication. The progress of soil acidification as a consequence of high N input and subsequent nitrate and cation leaching can be shown in a subset of 43 monitoring plots with soil solution samplers. Nutritional element losses represent a risk for growth and vitality of forests and therefore for the sustainable forest management.

During the last 40 years the importance of climate change was getting obvious, and thus also interactions between N deposition and drought became more and more prominent. In forest ecosystems, ectomycorrhizal fungi play an essential role in the uptake of water and nutrients, and they are responding very sensitively to increased N deposition. This suggests increased risks of combination effects of drought and N deposition on forest vitality. In European beech forests, the combination of high N deposition and drought lead to low volume increment of trees and an increased risk for uprooting in storm events. In Norway spruce, the same combination resulted in a strongly increased mortality rate by bark beetle attack. Stem breakage was also increased on sites with high N deposition.

The combination of reduced growth, increased mortality and increased wind damages results in a strong reduction of carbon sequestration and counterbalances the initial growth stimulations reported in the 1980's as a result of increased N deposition.

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Nitrogen leaching from afforested soils in Denmark over 30 years

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Clean water production from planted forests on former cropland soils is crucial for aquatic biodiversity and human freshwater consumption. Concerns arise regarding the export of inorganic nitrogen, particularly nitrate (NO_3^-), due to its adverse effects on surface water quality and human health. However, there are limited long-term studies spanning decades on nitrogen and nutrient leaching from afforested soils.

In this study, we combined long-term data (1986 - 2019) of NO_3^-, ammonium (NH_4^+), chloride (Cl^-), and sulfate (SO_4^{2-}) concentrations in throughfall and soil water with water balance modeling for three ICP Forests Level II monitoring plots in Denmark. Our aim was to estimate the net leaching of these elements and investigate how atmospheric deposition, tree species, climate variability, and management actions interact to shape nitrogen leaching losses from the forest ecosystem.

Two of the forests, located in eastern Denmark on glacial till soils, consist of monoculture stands of pedunculated oak (Vestskoven – since 1998) and European beech (Stenholtsvang – since 1986). A mixed deciduous unmanaged and seminatural forest (Suserup – since 2002) on similar soil type was included to assess the potential trajectory of forest development for new forests.

We hypothesize that NO_3^--export through leaching on N rich post agricultural soils will be controlled plant N demand, with an initially decrease after afforestation to near-zero levels during the early N demanding growth stages, a gradually increase after canopy closure, reaching a constant elevated level, if atmospheric inputs are in excess of N accumulation in woody biomass.

With our findings we will demonstrate the pivotal role of climatic drivers in moderating water fluxes within the forest ecosystem, influencing the level of NO_3^-leaching and obscuring the direct impacts of management practices like thinning. Additionally, using the decadal time series of NO3 and element export, we aim to explore how nitrogen and other deposited elements, along with management, soil type, and forest age, drive trends in NO_3^--leaching over decades.

This comprehensive time series provides unique insights into the complex interplay between the atmospheric deposition, hydrology, forest management, and soil types, enabling the development of more robust estimates of ecosystem services related to water quality in future forests.

Nitrogen leaching to stream water from forest ecosystems under changing atmospheric environment in East Asia

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Excess nitrogen deposition may disturb nutrient cycles in forest ecosystems. Nitrogen leaching into stream water as NO_3^- has been considered an indicator of nitrogen saturation in ecosystems. However, it has been observed that NO_3^- concentrations in stream water did not necessarily respond to changing nitrogen deposition as expected. Atmospheric environment in East Asia has been changing largely and nitrogen deposition has gradually decreased. Responses of forest ecosystems to the changing atmospheric environment have not been enough studied, yet, in terms of recovery process. In this study, long-term changes on nitrogen deposition and NO_3^- concentration in stream water in two forest catchments in central Japan are assessed based on our previous publications and the latest datasets. In the forest catchment of Lake Ijira (IJR) on the Pacific side, the EANET regular monitoring site, NO_3^- concentration has decreased with nitrogen deposition over the past few decades, suggesting recovery from nitrogen saturation in the 1990s. On the other hand, in the forest catchment of Kajikawa (KJK) on the Sea of Japan side, the EANET research project site, NO_3^- concentration has been increasing. In the case of KJK, ecosystem nitrogen demand appered to decrease with forest maturation. However, nitrogen deposition in both sites is still enough high, ≥ 10 kg N ha^{-1} $year^{-1}$. In fact, ^{17}O excess analysis of NO_3^- suggested that biologically unprocessed atmospheric NO_3^- leached into stream water larger in KJK than in IJR. In the presentation, effects of changing climate and meterological conditions will also be discussed. Other monitoring data from forest lakes in Japan and EANET sites in neighboring countries will also be referenced for discussion.

Responses of forest ecosystems to nitrogen deposition in the United Kingdom

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Most of UK's woodland exceeds the critical nitrogen (N) loads. We reviewed current evidence from forest monitoring and experimental research on the measured impacts of N deposition on UK's forests. Forest monitoring (>20 years) suggest a significant decline in nitrate deposition in some lowland areas and in both ammonium and nitrate deposition in upland forests but no change in areas with high N deposition and near N pollution sources. Some ground flora response to decline or enrichment of N deposition has been identified, but forest age, canopy management, previous land use and edge effect need to be considered. Soil surveys suggest that UK's forest soils have accumulated N under conifers which may be released during forestry operations and pose a risk to water's quality and GHG emissions. Tree species and soil type play a vital role in the response of the forest to N inputs. Forest edge effect introduce both high spatial variability in N inputs and forest ecosystem responses to N deposition. Strong relationships between tree N uptake, litterfall, growth and insect damage have been related to N deposition. The generation of N through insect infestations of the forest canopy have been quantified and canopy N transformations demonstrated through stable isotopes studies. Dry and wet N deposition was found to be a significant predisposition factor for Acute Oak Decline. Clear thresholds of N deposition for ectomycorrhizal community's changes have been determined. Nitrogen input needs to be included in predictive modelling of biodiversity and tree health in forest ecosystems.

RISK ASSESMENT OF NITROGEN DEPOSITION IN SPAIN: TRENDS AND PERSPECTIVES USING EMPIRICAL CRITICAL LOADS.

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Human activities such as intensive agriculture and farming, fossil fuel burning and industry have significantly increased reactive nitrogen (N) emissions to the atmosphere. The subsequent deposition of this N onto natural ecosystems can alter the structure and biodiversity of ecosystems through eutrophication, acidification and disturbances of nutrient cycling. The risk assessment methodology based on critical loads (amount of atmospheric deposition of a pollutant above which negative effects on sensitive receptors of particular habitats are expected) allows the identification of the habitats threatened by a potential excess of N deposition. This methodology, developed in the framework of the Air Convention (CLRTAP/UNECE), may be used by air quality policy makers to establish emission thresholds that guarantee habitats conservation and may also be used to report the conservation status and perspective for protected habitats.
In a previous study in Spain, this methodology was applied to assess eutrophication risks by N deposition in habitats of Community interest included in the Spanish Natura 2000 network. Natural grasslands and some forests in northern mountain areas showed the highest risk, proving that biodiversity conservation in these protected areas could be endangered by N deposition.
Our objective is to expand this first risk assessment by using the recently revised empirical critical loads and atmospheric chemical transport modelling. We will use two different scenarios of pollutant emissions, in a context of climate change and taking into account the temporal evolution (between 1996 and 2055) of eutrophying nitrogen exceedances in Spain. For this purpose, a map of receptors has been constructed by combining the National Forest Inventory and the National Biodiversity Inventory cartography, and using floristic composition (dominant and diagnostic species) to codify the habitats according to the EUNIS classification as a previous step to produce a Spanish map of critical loads. Results will be presented and trends and perspectives will be discussed, with a focus on forest habitats.

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Soil microbial responses to changing climate and nitrogen availability - possible implications for carbon sequestration and nutrient availability

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: There is a new combination of environmental change over Europe during the last decade - nitrogen (N) deposition declines whilst air temperature is increasing. Soil microbes and their enzyme activities are sensitive to these environmental factors, and their responses may have implications for ecosystem C sequestration and nutrients availability.

The aim of this soil transplant experiment is to assess the responses of soil microbial functional groups and activity to i) change in climate, ii) change in N availability and iii) the combined change of both climate and N availability.

The soil transplant experiment was carried out in three Norway spruce field sites; Stråsan (central Sweden), Skogaby (SW-Sweden), and Čertovo (Czech Republic) on Podzolic soils. The mean annual temperature is 3, 8 and 5 °C and the current N deposition is 3, 15 and 15 kg N/ha.year in Stråsan, Skogaby and Čertovo respectively. In addition, there were N fertilization treatments at both Swedish sites. Intact soil cores were sampled (length 35 cm) and installed in soil at their host site in coarse mesh bags so that fine roots and fungi's mycelia could grow in. Cores were exchanged between each site and treatment (n =4) plus two internal controls and recollected after four years. Various soil microbial variables were measured: biomass C and N, enzymatic activities, and Phospholipid Fatty Acids (PLFA), including metabolic stress defined as the ratio between cyclopropyl and precursor PLFA. The microbial variables of the soil cores before and after transplantation were statistically analyzed.

We found significant differences in metabolic stress, PLFA and proportion of different microbial functional groups, especially in response to N availability. Highest metabolic stress was measured in the cores that remained in the N rich Čertovo, while it was lower in the Čertovo soil cores transplanted to warmer, but less N rich Skogaby-Control as well as in the Stråsan cores transplanted to N rich Čertovo. We will further disentangle the impact of climate, N availability and how these two drivers together affect soil microbes. We will also discuss possible implications of the microbial responses for ecosystem C sequestration and nutrient availability.

Spatial and temporal patterns of carbon stocks and nutrient availability in European forest soils under continued N inputs

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Forest soils play a key role in a range of ecosystem services, including climate control, biodiversity and water quality, and are a primary driver of forest productivity. However, insight in their response to ongoing environmental changes, such as nitrogen (N) deposition, relies on the availability of harmonised, spatially and temporally representative data.

Since the early 1990s, the ICP Forests Programme runs a harmonised forest soil monitoring survey across Europe, including large-scale monitoring on a systematic 16 x 16-km grid (Level I: approximately 5000 plots) and intensive monitoring with a time interval of roughly 10 years (Level II: 250 plots). Two surveys have been completed so far on both levels, while a third survey (2020-2025) is ongoing in most countries. A wide range of soil chemical (carbon (C), nitrogen, plant-available and semi-total elements, pH) and physical soil properties (soil texture, bulk density) have been analysed by national forest soil laboratories according to standardised protocols. All data are centralised in the database managed by the Programme Coordinating Centre of ICP Forests.

In this study, we present spatial and temporal patterns in (i) calculated stocks of soil organic C and macronutrients (N, phosphorus (P) and sulphur (S)); (ii) total and exchangeable pools of base cations (potassium, calcium, magnesium and sodium); (iii) the stoichiometry of C:N:P:S; (iv) indicators for nutrient availability; and (v) their spatial autocorrelation with N deposition levels; in both forest floors and mineral forest soils across Europe.

Observed differences between the soil surveys before and after the year 2000 are highlighted and

stratified by biogeographical region, forest and soil type. Finally, the consequences of changes in stocks and pools of plant-available nutrients are discussed against the background of the provisioning of forest ecosystem services, such as carbon sequestration in soils and aboveground biomass production.

Status and trends of nitrogen deposition in European forests

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: The input of nitrogen (N) into forests through atmospheric deposition has been determined for the main forest types within the ICP Forests Level II monitoring network since the 1990s from measured concentrations in continuously collected precipitation (bulk deposition) and throughfall (below tree canopy) samples. Over the past five years, a full deposition data set was elaborated, in which various technical issues were solved, inconsistencies were corrected, some data missing in the central database were added from national sources, and further completion was accomplished through gap-filling. Total deposition was calculated from bulk deposition and throughfall accounting for canopy exchange at annual and monthly scales. Here, we present the current status and the long-term trends (1996-2020) for throughfall and total deposition of dissolved inorganic nitrogen (DIN) compounds, including ammonium (NH_4^+-N), nitrate (NO_3^--N), and the NH_4^+-N:NO_3^--N ratio, for more than 300 Level II forest plots. Depositions of NH_4^+-N and NO_3^--N generally decreased over the studied period, and the decrease was also statistically significant on many of the plots. For NH_4^+-N, the decrease was the highest during the first decade, while its deposition has been stagnating afterwards. Furthermore, spatial patterns of trends in N depositions across biogeographic regions will be presented and discussed.

Twenty years of dry and wet deposition of nitrogen to Norway spruce forests Sweden

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: The yearly dry and wet deposition of inorganic nitrogen (inorg-N) to Norway spruce forests was estimated with a full spatial coverage over Sweden for a twenty-year period, 2001–2020, based on combined measurements with Teflon string samplers, throughfall deposition and bulk deposition to the open field. It was shown that Norway spruce forests in south Sweden receive more N from deposition than has been previously estimated, based on modelling. Clear time trends were demonstrated for decreased deposition of inorg-N to Norway spruce forests in all parts of Sweden. The decreases were somewhat larger than what could be expected from the decrease in the reported emissions of inorg-N from Europe. The results emphasize that estimates of the total deposition are necessary in order to map levels and follow the development of N deposition in forests.

Uncertainty of critical load assessment of eutrophication in the tropical forests of Southeast Asia

T1.23 Nitrogen Depositions in a changing climate: Trends and Implications on Forest Ecosystem Services

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Abstract: Spatiotemporal patterns of N deposition in Southeast Asia have changed significantly in recent years. More needs to be reported on the broad-scale effects on the ecosystems of tropical forests and the inland aquatic environment in this region. In a previous study targeting East and Southeast Asia, we assessed the risk of nutrient imbalances in the forest as elevated nitrate in surface water using a critical load of eutrophication. The exceedance map of critical load found that the risk may be higher in metropolitan areas such as Manila and Bangkok and in forested areas distributed near satellite cities and suburbs. Moreover, significant increases in nitrate were observed in the inland water aquatic environment of the EANET monitoring sites located in high-risk areas of our assessment. Meanwhile, the magnitude and flux of the nitrogen cycle in tropical forest ecosystems are significantly larger than those in subarctic and temperate forests. This indicates that applying a steady-state model, such as the critical load model, to this region has significant uncertainty derived from the temporal change of the fluxes. Moreover, the contribution of N fixation by the leguminous tree distributed in tropical regions should be considered. Many tropical forests are N-saturated originally; new criteria detecting further nitrogen leaching by N deposition should be established based on the current status of nitrate leaching. Because the denitrification process in the vadose zone is also significant, different criteria may be set for the leaching from the soil layer and to surface water. In this study, we optimized the critical load parameters for tropical areas by considering the regional parameter of plant traits and the spatial information available. We also set the plausible range of each parameter and evaluated the uncertainty of the critical load in this region. This approach could be realistic for assessing the risk of elevated nitrate concentrations in leaching, especially from suburban forests in Southeast Asia, where N deposition is increasing.

T1.24 Old-growth forest ecology and management

A Method to Assess the Level of 'Old-Growthness' in European Beech Forests : Results from a Network of World Heritage Beech Forests.

T1.24 Old-growth forest ecology and management

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Abstract: Beech (*Fagus sylvatica*) is the natural dominant tree species in large parts of temperate Europe. Also, many of the remaining primary and old-growth forests in temperate Europe comprise of pure and mixed beech forests. Although there are several successful examples of strictly protected beech old-growth forest reserves, many old-growth forests are still not identified and protected and can be legally logged before their identification . The EU Biodiversity Strategy aims to map and strictly protect all remaining old-growth forests in Europe.

When assessing and mapping the remaining old-growth in European beech forests, it is essential to apply clear criteria and thresholds in a context that is complex due to a multitude of indicators and wide variety in the levels of 'old-growthness'. In order to delineate threshold values, reference values and ranges are needed.

The UNESCO World Heritage site "Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe" is a so-called 'serial transnational site': it's a network of component parts comprising some of the best examples of primary and old-growth beech forest in Europe.

Within the LIFE-PROGNOSES project, we sampled a wide range of stand parameters that are related to characteristics of 'old-growthness' (diversity and amounts of living and dead biomass, presence of tree-related microhabitats,...) in a subset of the World Heritage site components and their buffer zones, in order to cover both the most 'natural' beech forests, but also a wide range of levels of old-growthness, as the network includes formerly managed forests that were set-aside in

recent and remote past.

Here, we will present the results of our analysis, determining a wide range of indicators and their reference values, and how to condense them to quantitative parameters (so-called Old Growth Indicators – OGI) and combine the results to produce a synthetic measure of old-growthness for European beech forests. This tool can help to organise a scientifically substantiated debate on threshold values and support the objective mapping of old-growth forests in Europe.

Aboveground Carbon Stock Mapping of a Sub-Tropical Natural Forest with Sentinel 2 Satellite Imagery: A Multi-Product Analysis Approach

T1.24 Old-growth forest ecology and management

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Abstract: Abstract

Accurate aboveground carbon (AGC) stock estimates are important for climate change policies and forest carbon management. However, such information is lacking in most Sub-Saharan African countries. Therefore, our study utilized Sentinel 2 imagery and an integrated Random Forest and Repeated K-fold Cross Validation [RKF-CV] (RF-RKF-CV) regression algorithm to predict and map the AGC of the Nkandla forest in KwaZulu-Natal province, South Africa. We compared the performance of four stand-alone RF-RKF-CV models. The models were composed of specific stand-alone Sentinel 2 spectral products which are Near Infrared based vegetation indices (NVI) only, Red-edge based vegetation indices (RVI) only, Spectral Bands (SB) and Combine Variables (CBV) derived from the first three products. The NVI model was more accurate (R^2 =0.680, RMSE = 144.52 Mg/ha), which could be attributed to the sensitivity of the NIR region to vegetation. The CBV model was the second most accurate while the RVI and SB models followed as the third and least accurate respectively. These other three lagged in accuracy as compared to the NVI model possibly due to noisy variables and a dip in the performance of the three Sentinel 2 Red-edge bands. It was also found that the number of variables used in each of the models did not have a significant influence on the accuracy. The Difference Vegetation Index, Enhanced Vegetation Index and NIR emerged as significant variables in the prediction of AGC. Since the NVI model was the most accurate, it was used to produce a map showing the distribution of the AGC across the Nkandla forest reserve. The produced AGC map will be useful for spatiotemporal analysis and validation of future AGC quantification. Our study outcomes will be of importance to forest carbon management. The study demonstrates the capabilities of the freely available fine-scale Sentinel 2 imagery products and integrated RF-RKF-CV algorithm for AGC prediction and mapping.

Best-in-Class Policy Provisions to Define and Protect Old-Growth Forests

T1.24 Old-growth forest ecology and management

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Abstract: Forests in Canada are governed largely by the provinces and territories. Thus, each sub-national jurisdiction has its own approach to the conservation of old-growth forests. The Province of Nova Scotia on Canada's east coast recently revised its policy on old-growth forests. Such forests are acknowledged to be rare relative to their abundance prior to European settlement. Because old growth delivers unique ecosystem services in terms of conservation of biodiversity, carbon, water, and soil as well as recreational, educational, and psycho-social benefits, the Government of Nova Scotia has declared old-growth forests to be of sufficient importance to warrant aggressive conservation and protection measures. An interim policy was implemented in 1999 and updated in 2012. A substantially strengthened policy was put in place in 2022. This presentation highlights the features of the 2022 policy that make it one of the most progressive policies on old-growth conservation in North America. Those features include more ecologically robust definitions of old growth, confirmed protection of old growth as well as old-growth restoration opportunity areas, strong replacement provisions should areas of public land supporting old growth be needed for provincially significant infrastructure, clarified roles for specific officials in the provincial administration, a commitment to work with privateland owners to find ways to conserve their old-growth forests, and strengthened assessment and monitoring protocols. The policy is scheduled for assessment and potential revision no later than August 2027.

Carbon accumulation, tree microhabitats, structural complexity according to naturalness and site features in old-growth beech forests in Italy

T1.24 Old-growth forest ecology and management

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Abstract: Old-growth forests provide a unique contribution to both biodiversity conservation and climate mitigation. However, stand structural dynamics and the associated ecological processes may change significantly along environmental gradients, so features associated with increased naturalness may differ even within the same forest type.

We used a network of 200+ circular sampling plots (20-m radius) established within the Italian Components of the UNESCO Site 1133 "*Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe"* to evaluate the relationships among forest carbon density, stand structural complexity, tree microhabitat concentration and tree ring-inferred community dynamics (recruitment, disturbance and growth trajectory history) along stand development and across a thermal gradient.

Within our study forests, tree communities with different management histories (early or advanced old-growth forests, mature or recently managed forests) were used to assess how naturalness increases determine changes in carbon stock, structural complexity and biodiversity. Tree-ring metrics were used to build a naturalness score that reflected parallel increases in the complexity of tree communities and the ecological processes that shaped them.

We found neat differences in forest structure and composition, and overall carbon density, between warm and cold beech forests. The established network allowed us to determine how the role of large trees and old-growth forest attributes change during stand development under different environmental conditions.

Classifying Mature Federal Forests in the United States: The Forest Inventory Growth Stage System

T1.24 Old-growth forest ecology and management
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Abstract: President Biden's executive order, 'Strengthening the Nation's Forests, Communities, and Local Economies,' (EO#14072, April 22, 2022) acknowledges the interest in mature and old-growth (MOG) forests by directing U.S. Federal agencies to define and inventory these resources on United States Forest Service (USFS) and Bureau of Land Management (BLM) lands. We propose that using an effective and enduring mature forest classification system could be adaptable to social paradigms, monitoring data streams, scientific information, and global change factors. We accommodate these design aspects by defining mature forests as a growth stage prior to the onset of old-growth attributes within a proposed Forest Inventory Growth Stage System (FIGSS). FIGSS uses the long-established USFS old-growth assessments often conducted in concert with public dialogues to identify key structural indicators of older forests. The system informs inverse modeling of the prior "mature" stage's structural thresholds enabling initial population estimates of mature forest extent using the USFS' nationally consistent Forest Inventory and Analysis (FIA) program data. With this approach, we estimate that approximately 44.8 percent of all USFS/BLM forest is mature. The FIGGS system is based on a variety of components that could be used to account for cultural values ascribed to forest conditions which could be refined across future versions such as assumptions about the relative length of growth stages, incorporating data from emerging monitoring technologies along with old-growth/mature field sampling campaigns, accommodating spectrums of site-limited and/or disturbance-driven stand development, refined variable selection processes such as machine-learning, and consideration of traditional ecological knowledge.

Dynamics of old-growth forests in Belize, Central America

T1.24 Old-growth forest ecology and management

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Abstract: To conserve old-growth forests we must understand their long-term dynamics. We studied dynamics over 24 years in four 1-hectare plots in old-growth forests (hundreds of yrs old) in Belize, Central America. The 1-hectare plots were near each other, but each was in a different forest type: hill, moist upland, riparian, and palm. In each plot we counted and identified all trees ≥10 cm DBH. Twenty-four years later we re-inventoried the plots. Among plots, the number of trees ranged from 374 to 700 ha^{-1} in the first inventory, and the number of species from 46 to 59. During the 24 years tree number declined in the hill forest but was stable in the others. Mortality (% death of trees in first inventory) among the plots ranged from 1.1-2% yr^{-1}. Recruitment (% trees newly recorded in second inventory) ranged from 0.5-2% yr^{-1}. Species totals remained stable in all plots, but a significant number of species were eliminated from and added to each plot during the 24 years. The hill forest plot was in a wind-exposed setting; the decline of tree number in it perhaps reflected the death of long-lived pioneer trees that colonized the plot after wind disturbance 40 years before the first inventory. The riparian forest plot is subject to flooding, making trees unstable and leading to many treefalls, high mortality, and high recruitment in gaps. Thus dynamics differed among the plots according to topography, and these topographically-determined forest types may be differentially susceptible to a changing climate of wind and flooding. Most important, because the dynamics of old-growth forest differed among forest types we need forest type-specific, long-term data to distinguish baseline dynamics from novel dynamics caused by climate change or human disturbance.

Exploitative or healthy coexistence: Is the practice of sacred forest system in Nigeria mutually beneficial to the ecosystem and indigenous people?

T1.24 Old-growth forest ecology and management

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Abstract: The sacred forest (SF) system, an ancient tradition, is an indigenous community-based traditional forest conservation method. It evolved through interactions between indigenous people and their environments and act as connecting link between man, nature, cultural heritage and religious beliefs. Protection is secured by indigenous people through access restriction, rules, taboos, dedication to and fear of deity(ies). Sacred forests provide ecosystem goods and services of importance to livelihoods of indigenous people. The question is whether this synergy between SFs and indigenous people is exploitative or mutually beneficial? Three prominent SFs in southwestern Nigeria were used as case study to examine the extent to which socio-economic and religio-cultural benefits derived by indigenous people from SFs contribute to biodiversity conservation. Inventory data were collected from three SFs for biodiversity assessment. Mixed-methods approach that combined semi-structured questionnaire surveys, interviews and focus group discussions were used to collect data for ecosystems services and livelihood support investigations. Results revealed that the three SFs were relatively intact with minimal anthropogenic disturbances. The high biodiversity indices (species richness: 76–106; Shannon-Wiener diversity index: 3.47–3.86; density: 1,597–2545 trees ha^{-1}) are evidence that SF is effective traditional biodiversity conservation method. This is attributed to protection by indigenous people through fear of deities, respect for taboos, access restriction/prohibition, etc. Tourism, NTFPs collection, income generation and employment were some socio-economic gains by indigenous people that drive biodiversity conservation. Important religio-cultural benefits contributing to biodiversity conservation were: use SFs for traditional festivals, places of worship and kingmaking rituals. Institutional involvement had positive effect on biodiversity conservation and ecosystem services provision from SFs. E.g., the designation of Osun-Osogbo SF as Nigerian national monument and UNESCO World Heritage site enhanced its biodiversity conservation potential, increased tourism, socio-economic gains and preserved religio-cultural values. Thus, there exist synergy between SFs and indigenous people, long-term preservation of SFs and their biodiversity depends on protection by communities while the livelihoods of indigenous people is enhanced by the socio-economic and religio-cultural benefits derived from SFs. Thus, coexistence of SFs and indigenous people is healthy and mutually beneficial.

Keywords: Biodiversity conservation, sacred forest, indigenous people, synergy, socio-economic benefits, ecosystem service

Exploring Age structure of Birch Forests in Norway: Insights from Tree Ring Data from National Forest Inventory

T1.24 Old-growth forest ecology and management

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Abstract: The age structure of forests offers valuable insights into carbon stock potential and serves as an indicator for assessing the degree of biodiversity conservation or the risk of disturbances. Additionally, age-class structure stands as a key indicator of both economic and ecological sustainability in forest management. Tree age can be affected by various factors, including disturbances, seed presence, and tree species composition. Indeed, tradeoffs between longevity and growth rates have long been noted across tree species, as they result from the complex interplay between growth dynamics and the potential costs associated with an extended lifespan. In this study, tree ring width data from the National Forest Inventory was used to analyze the age distribution of birch forests as well as growth rates across different age classes. Then, we used a generalized linear mixed-effects model to quantify the effect of different predictor variables on birch age. We found that the middle age group (50-100) dominates most regions of the country. Moreover, we observed a prevailing age cohort within most of these regions, suggesting a significant disturbance event approximately 80 years ago. We noted that the youngest forests exhibit a notable association with a high site index, particularly in the oceanic west coast areas, while as forests age, this correlation decreases. The model showed an inverse relationship between growth rate and increasing age class, i.e., fast early growth is associated with decreased longevity. Thus, fast growth in locations with high site indices would result in a shorter tree life expectancy. The findings emphasize the importance of considering biological, ecological, and historical factors for a comprehensive understanding of tree age structures in diverse forest landscapes.

New Zealand’s indigenous forests – how much of eight million hectares is Old-growth forest?

T1.24 Old-growth forest ecology and management

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Abstract: Indigenous forests cover around eight million hectares of New Zealand’s total landmass of 27 million hectares. A large part of these forests is under protection and valued for its biodiversity, recreational and non-timber related ecosystem services. While mostly undisturbed from direct human influence, indirect impacts such as pest introductions, weeds and climate-change-induced stressors (e.g. drought) are understood to be threats to the natural dynamics of these forests. Since 2002 New Zealand has been monitoring the large extend of indigenous forests via a plot-based forest inventory to understand their dynamics better, particular in regards to their carbon stocks and carbon stock changes as a whole. While the forest inventory is now only in its third measurement it provides insights in how these forests are structured and which tree species playing a mayor role as a significant carbon store. In light of the question “what defines Old Growth Forest in New Zealand” we present the methods and resulting data from our national forest inventory to develop and discuss a possible working definition based on stand structure and the relationship between live and dead biomass in New Zealands indignous forests.

Under the Paris Agreement, New Zealand forests will fall under the managed forest category. Changes in carbon stocks need to be accounted for if these are above or below the natural variation and can be attributed to human management. We will present estimates of current carbon stocks and carbon stock changes in forests that can be categorised as Old Growth forests and discuss the difficulties of disaggregating natural fluctuations and human induced changes through previous and current management.

Old-growth Araucaria-Nothofagus forests in Northwest Patagonia: fire, management, and conservation

T1.24 Old-growth forest ecology and management

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Abstract: Fire is a major disturbance process affecting the Andean Araucaria forest landscape in north-west Patagonia. Both surface and stand-replacing fires are known to shape the structure and composition of these forests. Fire history and age structures indicate that variability in fire frequency and severity are key to explaining the mosaic of forest patches across the Araucaria–*Nothofagus* landscape. Large Araucaria trees are highly resistant to fire, and this species typically survives moderate- to high-severity fires either as dispersed individuals or as small groups of multi-aged trees. Overall, stand development patterns of subalpine *Araucaria–Nothofagus* forests are largely controlled by moderate- to high-severity fires, and therefore tree regeneration dynamics is strongly dominated by a catastrophic regeneration mode. In the context of climate change, recent widespread wildfires affecting old-growth Araucaria forests appear to be novel and an early indication of a climate change driven shift in fire regimes in north-west Patagonia. Extreme wildfire events and reburns after short intervals globally have been attributed to climate trends and land-use practices. Understanding how wildfire alters the potential for subsequent wildfire and favours transition to more fire-prone landscapes through fire-driven positive feedback are key research topics for the management and conservation of old-growth Araucaria forests in northwest Patagonia.

Old-growth forests, biocultural diversity and monks in the northern Italian Apennines

T1.24 Old-growth forest ecology and management

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Abstract: The silver fir (*Abies alba*) forests of the northern Apennines (Italy) have been strongly affected by past human land-use. The conservation of the silver fir in this region was mainly related to religious orders (e.g., Camaldolese, Vallombrosian, Franciscan). The monks preserved and even planted silver fir for its greater sense of spirituality and mysticism and economic value. Inspired by spiritual principles and applying traditional ecological knowledge, monastic communities developed distinctive natural resource management models, resulting in peculiar landscapes rich in both biodiversity and bio-cultural diversity. Some of these forests represent the best-preserved silver fir forests in the northern Apennines. Their presence was the main reason of the establishment of Casentino Forests, Monte Falterona and Campigna National Park. In the last decades, the management approach in these forests has shifted from traditional use to strict conservation. The current policies don't consider the peculiar "cultural" landscape created by centuries of land use and the fact that these forest stands are currently deeply different from reference old-growth stands of the same forest type still present in the Dinaric Alps. Besides, the establishment of the National Park has provoked the exponential increment of autochthonous and introduced ungulates, making it impossible for the silver fir the natural regeneration. To prevent the loss of bio-cultural diversity and landscape and, at the same time, to leave room for natural processes like spontaneous forest regeneration, both forest and natural resources management have to be re-evaluated and regularly monitored.

Old-growthness level assessed by structural heterogeneity indices in two rare Mediterranean Quercus pubescens forests

T1.24 Old-growth forest ecology and management

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Abstract: Old-growth forests are unique ecosystems for biodiversity conservation, climate change mitigation and slope protection, as well as being a benchmark for the implementation of sustainable forest management. Although studies on old-growth forests have significantly increased in the last decades, still limited is knowledge on Mediterranean ecosystems. Particularly, no field research has been carried out hitherto in old-growth forests dominated by tree thermophilous oak species belonging to *Quercus pubescens*. To fill this knowledge gap, we characterized two *Quercus pubescens* forests (Fanuso and Gurgo) possessing old-growth traits and localized in Sicily (Mediterranean Italy). We assessed the old-growthness level by applying two structural heterogeneity indices (SHIs) specifically developed for old-growth forests, also assessing whether parameter choice can influence the SHI score. Structural attributes of living biomass and deadwood were used to calculate the indices. Both forests were found to hold some old-growth traits, while lacking other ones, with differences between sites. Fanuso proved to be closer to naturally aged forest stands, although SHI was not statistically different compared to Gurgo. Fanuso hosted a notably higher deadwood amount than Gurgo, reaching a high value (≈ 52 m^3 ha^{-1}) in the context of Mediterranean forests. Also, in this forest, the ratio dead/living wood volume exceeded the 10% threshold considered in the literature. Both forests hosted at least 100 trees ha^{-1} with a DBH > 40 cm, which accounted for about 70% of living biomass. However, both forests are characterized by a limited overall contribution of standing dead trees, as well as of large dead elements. Our study also highlights the need to standardize the parameters used to characterize the old-growthness level of Mediterranean old-growth forests in order to allow more reliable comparisons. We deem that both forests deserve primary attention also taking into account the rarity of *Quercus pubescens* forests possessing old-growth traits throughout its distribution range. Furthermore, under tailored management measures and proper silvicultural options, these stands are expected to evolve towards the old-growth stage under a medium to long-term perspective. In this regard, it is highly hoped for their inclusion in the National Network of old-growth forests as recently established in Italy.

Population Structure and Distribution of Adansonia digitata

T1.24 Old-growth forest ecology and management

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Abstract: Non-timber forest products (NTFPs) contribute to livelihood security of people especially those in the rural areas. There is however a growing concern that NTFP-providing trees are declining due to land-use change, use intensification and over-harvesting and therefore an urgent need for their sustainable use. This study was conducted in districts with the baobab resource in Malawi, namely; Mangochi, Salima, Mwanza, Neno, Chikwawa and Nsanje to understand the population dynamics of the species which would inform sustainable management of the species. The assessments were done on 1,223 trees in baobab clusters overlaid with systematic grids with a 500m spacing interval between individual plots. Baobab in Malawi is limited to a few areas where the environment is highly conducive for its growth with Neno and Mangochi as high potential sites and overall mean stocking ranging between 3 and 8 stems^{-ha}. Diameters for the resource ranged between 230 and 305 cm, translating to yield estimates between 520 and 1,084 fruits per tree for the districts. The resource was most prevalent in settlements and farmlands and least likely in grasslands. Population structures showed that the resource is unstable in replenishment with limited saplings and juveniles. Generally, the baobab population seemed less affected by disease or pest infection as no more than 3% of the assessed population was infested. Deliberate efforts should be made to promote the raising of baobab trees either through nurturing of existing few seedlings and saplings or up-scaled integration of the resource on farmlands.

Priority actions for the conservation of primary and old-growth forests in Europe

T1.24 Old-growth forest ecology and management

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Abstract: Primary and old-growth forests are extremely important for biodiversity and the provision of many other ecosystem services such as carbon storage. Yet, in Europe, most forests are currently managed and have been for centuries. As a result, primary and old-growth forests have become extremely rare. To address this, the EU Biodiversity Strategy for 2030 sets the target to strictly protect all remaining primary and old-growth forests as part of a wider ambition to strictly protect 10% of EU land-area. However, despite this target, the area of primary and old-growth forests in Europe continues to rapidly decline. In response to this, we outline four priority actions urgently needed for the conservation of primary and old-growth forests in Europe: (1) Identify and strictly protect all primary and old-growth forests; (2) Effectively protect all primary and old-growth forests; (3) Establish effective buffer areas around primary and old-growth forests; (4) Improve connectivity between primary and old-growth forests. In this study, we provide the evidence and rationale behind the need for these four priorities through a review of the literature, as well as identify key issues that should be overcome so that they can be implemented successfully.

The importance, the current state and the future of old-growth forests in Poland

T1.24 Old-growth forest ecology and management

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Abstract: Both ecology and management of old-growth forests are of great importance for Poland, because the last remnants of ancient European forests, including those featured by high degree of naturalness and still preserving primeval character, occur in the territory of this country.

The presented work has been subordinated to the two following tasks: 1. examination of the state and status of old-growth forest formations in Poland, incorporating the issue of threats for the ecosystems, 2. investigation into the definition of the old-growth forest, its changes and application. The study focuses on contemporary times, *i.e.* on the period after the World War II, however, it must have been expanded with an insight into the history of silviculture and forest protection. The research methods involved an analysis of the relevant state forest policy (from 1950s to 2020s); examination of evolution of the old-growth forest' definition, since the policy and applied definition directly impacts the management; an analysis of main directions of use of old forest ecosystems in Poland.

The research emphasizes the human-induced changes affecting old-growth forests and alterations of their definition, which as the results of the work demonstrate, continuously take place. Moreover, the work shows that old-growth forest ecosystems have been threatened by intensive use, even in the areas having high conservation status. Regrettably, the old-growth forests in Poland have become younger…

In consequence, the author reflects upon understanding of values of old-growth forests by decision making bodies and by the society.

A key part of the study is devoted to the future of an analysed forest type in Poland. A need to properly manage the old-growth forests, with protection being treated as a priority, has been highlighted. Furthermore, this is stressed that adequate policy strengthening the position of old-growth forests should be formulated and implemented. It involves not only local level, but also a state level of forest policy and management.

T1.25 Optimizing Agroforestry carbon stocks estimates

Above ground biomass variability related to stand structure heterogeneity in agroforestry systems in Portugal

T1.25 Optimizing Agroforestry carbon stocks estimates

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Abstract: Thee forest species, cork oak (*Quercus suber*), holm oak (*Quercus rotundifolia*) and umbrella pine (for *Pinus pinea*), are the most representative species of the agroforestry systems in Portugal. These forest systems are characterised by low densities, large spatial variability, and have as main productions are bark and fruit for cork oak and fruit for holm oak and umbrella pine. The stand structure is diverse with pure, mixed, even aged and uneven aged stands, which in turn is also reflected in the above ground biomass. To tackle the variability in these stands, stand structure was analysed with absolute stand density measures and structure and diversity measures and indices for the number of trees and basal and above ground biomass. The results highlighted the differences between the different stand structures. Moreover, the analysis of variance revealed significant differences between the structure and diversity indices calculated with the number of trees or basal area and aboveground biomass. This could be related to above ground biomass incorporating both diameter at breast height and total height, thus integrating the horizontal and the vertical distribution, conversely to the number of trees and basal area that evaluate only the horizontal distribution. Overall, the evaluation of stand structure with above ground biomass can give further insights the variability of stand structure, including diversity, in a three dimensional frame, which can also encompass above ground biomass partitioning per component.

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Allometric Equation for Estimating Aboveground Biomass in Fruit Trees: Implication for Climate Change Mitigation in Croplands

T1.25 Optimizing Agroforestry carbon stocks estimates

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Abstract: Estimates of carbon stock changes in croplands are an important issue for agricultural management systems and climate change mitigation. Above-ground biomass (AGB) prediction for fruit trees is an important indicator for monitoring the carbon (C) sequestration potential of orchards. According to recent studies, the Agriculture, Forestry and Other Land Use (AFOLU) sector is a major contributor to global carbon emissions and hence simultaneously holds great potential to remove atmospheric carbon, which represents negative feedback to climate change. In particular, fruit trees in orchards contribute to carbon sequestration and can play an important role in the C cycling of terrestrial ecosystems. Allometric equations are not only a basic mathematical tool for quantitatively evaluating C sequestration but also enable non-destructive testing estimation of biomass. On the other hand, a clear need to incorporate carbon flux associated with vegetation dynamics in croplands is urgent, and the importance of improving estimates of biomass and carbon storage of fruit trees has been steadily raised in several studies. For forest and plantation vegetation, destructive methods have been used to obtain vegetation dry weight and infer biomass carbon stocks (~47.4% of dry biomass). These disruptive measures are essential, but costly in terms of time and resources. Therefore, the development of relative growth equations that relate non-destructive or semi-destructive measures of vegetation structural characteristics to above-ground biomass stocks is very important. Therefore, through this review, we would like to introduce several studies related to the development of fruit tree biomass relative growth methods. (This work was carried out with the support of "Cooperative Research Program for Agriculture Science and Technology Development (Project No. RS-2023-00220456)" Rural Development Administration, Republic of Korea.)

Carbon Stocks and Economic Contributions of Smallholder Agroforestry in Northeast India: Implications for Sustainable Landscape Management

T1.25 Optimizing Agroforestry carbon stocks estimates

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Abstract: Smallholder agroforestry, a land-use system that integrates trees with agricultural crops or livestock, offers great potential for addressing climate and biodiversity goals, as well as provide economic resilience. This can prove to be significant alternative for the erstwhile indigenous shifting cultivators of Northeast India, who are undergoing an agroecological transformation. While the practice of shifting cultivation has become ecologically and nutritionally unsustainable, the tribal communities of Tripura, comprising one-third of the state's population, are now adopting agroforestry alternatives for social, economic and ecological resilience. This study aimed to estimate the aboveground biomass (AGB) and belowground biomass (BGB) carbon stocks of diverse smallholder agroforestry plots. A total of 70 plots were sampled across the two districts of Tripura, which included homegardens and plantations, for estimation of AGB and BGB using allometric equations specific to the region. The results revealed significant variations in carbon stocks among the different agroforestry systems. The average AGB carbon stock ranged from 20 to 165 Mg/ha, based on the agroforestry category. A correlation between the age of the crop stands and carbon stock was also observed. Additionally, these agroforestry plots contributed to about 23 to 78% of their annual household income. Assessing the carbon storage potential of agroforestry practices will provide valuable data for sustainable land management and policy development in this area of continuous forest landscape transformation, especially when compared with the practice of shifting cultivation. The findings of this study will contribute to the development of effective strategies and policies aimed at promoting social and economic resilience, as well as ensuring food security among indigenous communities, by utilizing forests and trees to achieve climate and biodiversity objectives.

Combining 2D and 3D methods to monitor carbon in agroforestry systems

T1.25 Optimizing Agroforestry carbon stocks estimates
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Abstract: Agroforestry, the practice of integrating trees into farming landscapes, offers substantial potential in climate change mitigation and adaptation, as well as livelihood improvement. However, these contributions are often overlooked in Measurement, Reporting, and Verification (MRV) systems, which are pivotal for countries to achieve their climate objectives under the Paris Agreement. In tropical regions, among other reasons, agroforestry accounting is constrained by uncertainties tied to data scarcity.

Here we aim to assess cost-effective methods to identify agroforestry systems and non-destructively quantify above ground biomass at the individual tree level. To accomplish this, we implemented a multi-scale approach that integrates remote sensing and deep learning with field data gathered using images (processed by photogrammetry and neural networks) and smartphone LiDAR. We linked 2D data (crown segmentations derived from satellite imagery) to 3D data (tree functional traits derived from point clouds) to monitor the biomass and carbon across a range of agroforestry systems in Peru.

This combination of technologies successfully served to monitor biomass and carbon in scattered-trees in silvopastures, hedgerows, and shaded systems. Challenges, however, arose when dealing with complex, closely-canopied systems such as multistrata and old fallows. Our findings contribute to strengthening the inclusion of agroforestry in MRV systems.

Mapping Sustainability: Agroforestry's Extent and Carbon-Sequestration Potential in Kangra District of North-western Himalayas

T1.25 Optimizing Agroforestry carbon stocks estimates

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Abstract: Implementing agroforestry can substantially contribute to attaining the United Nations' most formidable sustainable development goals (SDGs). Regrettably, a widely held fallacy persists regarding the insignificance of agroforestry, leading to its frequent neglect by decision-makers and policymakers in matters pertaining to land use and environmental issues. The lack of information regarding the regional extent of agroforestry practices and their carbon (C)-sequestration potential is the primary cause of this disregard. Several techniques are available for quantifying the C-sequestration capacity at the field level. However, the compilation of such information becomes progressively complex when evaluating it at the district level. Thus, the present investigation centres on the Kangra district in the Western Himalayas to tackle the aforementioned concern. The study employs remote sensing and Geographic Information System (GIS) methodologies to demarcate the region encompassing agroforestry and evaluate its corresponding capacity for C-sequestration. Using eleven bands of Sentinel-2 imagery (10 m resolution) and three biophysical parameters, the random forest method was used to estimate the extent of agroforestry areas, while the CO2Fix model was used to estimate the potential for C-sequestration. The results indicated that agroforestry covered about 32.43% of the district, followed by agriculture (20.78%), forest (19.41%), grassland (8.01%), water (4.7%), desolate land (3.5%), snow cover (3.4%), and built-up areas (2.75%) with an overall accuracy of 79.77% and kappa coefficient of 0.743. In addition, 28 species (61.08 tree ha^{-1}) were identified and classified into three groups: slow-growing (3 species), medium-growing (15 species), and fast-growing (10 species), having average age of 60, 18 and 5.5 years, respectively. Over a 25-year simulation period, agroforestry systems in the district would sequester 76.29 Mg C ha^{-1}, resulting in an annual C-sequestration rate of 3.05 Mg C ha^{-1} $year^{-1}$. In addition, it was anticipated that the district's agroforestry systems would have an annual CO_2 abatement capacity of 2.07 million t CO_2 equivalent. These preliminary estimates provide valuable insight into the scope of agroforestry and its C-sequestration potential, which are important indicators for the contribution of agroforestry to a country's climate change objectives or INDCs under UNFCCC.

Possibilities of Quantifying Mitigation Capacity in Agroforestry Systems

T1.25 Optimizing Agroforestry carbon stocks estimates

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Abstract: Nowadays, mitigation is playing an important role in the light of the Paris Agreement and the European Climate Regulation. In 2022, the report of the Intergovernmental Panel on Climate Change (IPCC) classified agroforestry as one of the three most important mitigation alternatives within the land use sector.

The methods used to estimate carbon sequestration are very diverse. We have large- and smaller-scale global models based on extrapolation of field measurements from sample areas, which are used in forestry for carbon sequestration estimates, and are therefore likely to result in severe under- or overestimation of the total carbon stock. A model examining agroforestry systems adapted to the Hungarian conditions has not been prepared yet.

Using cloud-based systems (e.g. Google Earth Engine or Global Forest Watch) we can create maps and graphs displaying biomass, soil carbon content, carbon absorption and greenhouse gas emissions. Their advantage is large spatial coverage, but their disadvantage is medium spatial resolution, so systems with small areas cannot be examined by them.

In case of shelterbelt systems, we can perform a more accurate carbon stock calculation based on the data of the National Forest Stock Database, which is based on field measurements and estimated data. Unfortunately, this method cannot be used in all types of systems.

In case of field measurements, we examine the amount of carbon stored in the above- and belowground biomass, as well as in the soil. In two sample areas in Hungary (alley cropping and shelterbelt systems) we use the traditional method for measuring above-ground biomass is to cut down individual trees and plants, and then measure their carbon content in laboratory. The carbon content of the soil sample is determined according to a methodology, and the root-to-shoot ratio is used to express the belowground biomass. In our research work, we want to assess the mitigation potential of Hungarian agroforestry systems, comparing the accuracy of the mentioned methods.

Soil carbon accounting in agroforestry systems – a review and standardized guideline

T1.25 Optimizing Agroforestry carbon stocks estimates

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Abstract: Agroforestry systems have great potential to sequester carbon in soil and to mitigate the impacts of climate change. Key factors herefore are predominantly the presence of perennial woody plants and the absence of soil tillage in the tree strip zone. However, obtaining reliable and comparable data from different agroforestry systems poses a challenge due to their diverse designs, management practices, and environmental conditions. This complexity makes it difficult to estimate the overall impact of agroforestry on soil carbon sequestration and other soil indicators. Many researchers have highlighted this challenge.

One promising approach to estimate carbon stocks is the use of transect sampling in alley cropping systems. By systematically sampling along transects within tree strips and adjacent arable or grassland strips, the internal heterogeneity of an alley cropping system can be addressed. However, transect sampling methodologies differ widely and may result in biases of over- or underestimation of the tree influence of the system as a whole.

We will present a review of transect sampling methodologies based on studies used in a meta-analysis on soil organic carbon sequestration in alley cropping systems and discuss six common biases with regard to sampling locations and overall system analysis. Furthermore, we propose a guideline for transect soil sampling to overcome these biases, and to contribute to improved field study design and description, comparable and robust data collection – overall improving agroforestry estimates across systems. Practical examples of the implementation of the proposed guideline will be shown from Gladbacherhof, the research farm of the Justus-Liebig-University Giessen, and practical farms involved in a citizen science agroforestry monitoring project of the University of Münster.

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

Bridging the Gap: Insights from Practitioners on Applied Forest Restoration across Europe

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: In the face of global change, the biodiversity loss and degradation in forest ecosystems have highlighted the urgent need for ecological restoration for forest conservation. In Europe, conservation has a long tradition, being particularly complex due to diverse ecological, political, social and economic conditions. Successful restoration requires a comprehensive understanding of the interactions between climate, ecosystems (including their biodiversity), and society.

The SUPERB project aims to consolidate and share the extensive knowledge on forest restoration across the various situations in the European Union, providing evidence-based practical insights. This is being achieved by: 1) collecting site-level restoration activities through European workshops with different stakeholders, 2) analysing reforestation or restoration projects and questionnaires, and 3) developing national-level restoration narratives based on national expert assessments.

This study presents a comprehensive characterization of the diverse forest restoration activities in European regions, facilitating the extraction of valuable lessons when combined with scientific information. By bridging the gap between practitioners and scientific research, this research aims to enhance the effectiveness of applied forest restoration efforts across Europe.

Carbon2Mine, a second chance for the industrial reconversion of mining areas in northern Spain. Management models and carbon cycle

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: The Carbon2Mine project is a Reverse Mining initiative funded by the European Union through the LIFE program. Focusing on the Asturian Mining Basins, an area deeply affected by the consequences of deindustrialization in Europe, the project aims to address the economic and sociodemographic imbalances resulting from this process. Furthermore, it recognizes the enduring impact of mining activities on the landscapes and ecosystems of the region.

One of the project's key objectives is to develop new forest management models that contribute to carbon sequestration and fixation while minimizing the carbon footprint associated with current management practices in the study area. These models also ensure compliance with legal conservation restrictions and regulations.

To achieve this, various models based on field data have been adjusted and extended to cover other mining areas. The project involves the characterization and interpretation of available databases, validated through aerial photography, to differentiate between degraded and natural soils in mining waste dump areas. Furthermore, a network of 150 experimental plots has been established to characterize vegetation systems.

To validate the models against real-world conditions, a grid of sampling points has been established throughout the area using a systematic statistical sampling method. At these points, data on carbon content and other soil variables have been collected, enabling the assessment of different terrain types within the project's scope.

The collected data aims to facilitate the development of sustainable forest and grassland management models for mitigating climate change. The project's specific objectives include: i) reducing the carbon footprint of forestry activities by 55%, ii) increasing vegetation presence in degraded and natural soils by 50-75%, iii) maximizing CO2 fixation in soils and vegetation through increased soil carbon sequestration, and iv) developing an assessment tool for tracking carbon capture in terrestrial ecosystems at the regional level, among other goals

Considerations of the voluntary carbon market parties to invest in prestoration actions.

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: This presentation addresses the topic posed for this prestoration session:

".. the finance sector is more than ever ready to invest into nature and green solutions, however there is large uncertainty about the quality and long–term benefits of investment opportunities, how to credit these, and how to effectively bring the large demand for investment opportunities and the widespread but dispersed need for locally-adapted prestoration (restoration combined with adaptation) actions together."

Land Life, as only private partner in SUPERB, is largely funded by the voluntary carbon market to finance its nature-based reforestation activities of degraded lands. In this presentation we will inform the audience on:

- What makes a high-quality carbon credit?
- How can benefits be shared with local communities?
- How does the voluntary carbon market support nature-based solutions?

We will address the following topics:

- Market Growth: The voluntary carbon market is projected to experience significant growth in the coming years. Increasing awareness and concern about climate change, coupled with corporate sustainability commitments, are driving the demand.
- Standardization and Transparency: Standardization and transparency are critical factors for the future success of the voluntary carbon market.
- Technology and Innovation: Advancements in technology are expected to drive innovation within the voluntary carbon market.
- Pricing and Market Mechanisms: As the demand increases, the pricing of carbon credits may become more dynamic.

The voluntary carbon market is subject to various factors and issues, including evolving global climate policies, market dynamics, and stakeholder engagement. Ongoing monitoring and adaptation to emerging trends and challenges will be key to realizing the full potential of the voluntary carbon market in addressing climate change.

Coping with tree plantation failure under extreme drought events in France: The role for insurance in the forest owner-forest company relationship

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: In France, in the case of plantation failure, the forestry company provides a replacement for dead plants if the mortality exceeds a certain percentage of the plantation. Mortality not covered by the insurance remains the forest owner's liability. However, the insurance can be waived if the mortality of the plants is unrelated to the quality of the forestry company's service, for example, in periods of excessive drought or damage caused by animals. Nevertheless, due to the lack of a clear definition of drought, this insurance clause is rarely applied, and plantation failure is more often than not the forestry company's liability, greatly increasing its costs. In this context, our study aims to address the following questions. In the case of plantation failure, is it less costly for the forest owner to replant, not replant, or restart the whole plantation? What is the impact of changing the liability scheme between the company and the forest owner in terms of replantation costs and risk sharing? What is the optimal scheme in terms of risk sharing between the stakeholders (forest owners, forest companies, insurance companies)? First, we performed a cost assessment of different itineraries of plantations as a function of different mortality rates. The breakdown of the replantation costs between the company and the forest owner was also investigated. Second, we developed a theoretical model in order to define the optimal risk distribution between the stakeholders. First results show that no replanting is the least expensive option for the forest owner, followed by replanting and then by starting the whole plantation anew. Reducing the company's liability is an interesting option to reduce its exposure to risk. Modifications of the company's liability allows for the inclusion of private insurance contracts against plantation failure.

Disinformation, idealistic visions and Santa's home: Public and political discourses surrounding the proposed EU Nature Restoration Law

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: The necessity of restoring degraded natural ecosystems, including forests, has gained strong political momentum worldwide. In the European Union, a legally binding instrument was proposed by the European Commission in June 2022 to implement Europe's domestic and international commitments under the Biodiversity Strategy for 2030 and the Convention on Biological Diversity (CBD). However, the legal proposal of the so-called Nature Restoration Law (NRL) triggered highly controversial debates among stakeholder groups and political institutions. It faced fierce opposition throughout the ordinary legislative procedure, particularly from forest and agricultural landowner associations, as well as conservative and right-wing political parties. The law only survived the political negotiations by undergoing far-reaching amendments.

This study applies Discourse Network Analysis (DNA) to i) identify supporting and opposing discourse coalitions that developed during the formulation and negotiation process of the NRL, ii) unravel the justifications and claims these discourse coalitions utilized to influence the negotiation process, and iii) analyze how different discourse coalitions influenced the negotiation process and the final outcome of the EU NRL. The analysis builds on process-tracing using qualitative content analysis of key policy outputs, starting from the legislative proposal to the final negotiated text. Perceptions and positions of public stakeholders are analyzed using data from a public consultation, while the discourses among EU parliamentary groups are derived from parliamentary debates and position papers.

In times of intensifying climate change and rapid biodiversity decline, coupled with simultaneous setbacks in environmental policy development in the European Union due to political tensions and economic crises, this study provides crucial insights into ongoing environmental political developments in the EU, where the "EU Green Deal" stands at a crossroads.

Forest recovery after fire: forest restoration in the Spanish Demo under SUPERB

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: The SUPERB project aims to develop systemic solutions for upscaling urgent ecosystem restoration for forest-related biodiversity and ecosystem services through 12 demonstration sites in Europe. One of its demos is located in Castilla y León, Spain, where the rural abandonment and the lack of forest management accentuates the processes of scrubbing of the landscape and homogenisation of the territory. This leads to an increment in forest fuel resulting in large forest fires. Moreover, large forest fires are a major impediment to the recovery of the Cantabrian brown bear (*Ursus arctos*), one of the most endangered mammals in Europe. The recovery of the Cantabrian brown bear is tightly linked to the improvement of its habitat and increasing forest resilience necessarily involves improving forest management to change the fuel model. We have therefore three main issues to resolve that are connected: tackling rural abandonment, changing the forest fuel model and to improving the habitat of the brown bear.

Within the SUPERB project we are going to carry out ecosystem restoration in the forests of El Bierzo with a socio-ecological and upscaling vision, involving stakeholders and considering restoration beyond SUPERB. We will carry out enrichment plantings with fruit broadleaves trees to improve brown bear habitat, silviculture activities to reduce forest fuel, as well as chestnut plantations near rural villages for chestnut production to help boost rural development. This will be done by involving local and regional decision-makers through stakeholder engagement workshops, which so far have already shown good involvement. We are currently implementing the whole restoration process, as the SUPERB project lasts until 2025, with some lessons learned so far.

In order to evaluate the recovery of ecosystem services of Mediterranean forests in El Bierzo after forest fires, thirty-six stands with a gradient of degradation caused by fire have been established. In these stands, samples of different indicators of ecosystem services and biodiversity are being collected. This sampling process will be carried out during three consecutive years (2022, 2023 and 2024), which will allow us to obtain preliminary results in mid-2024.

Forest reproductive material production and legal framework – how does it meet the requirements of forest regeneration and prerestoration?

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: Forest Reproductive Material (FRM) is crucial for forest restoration, artificial regeneration and nowadays much needed forest prestoration. Availability of adequate and adapted forest seedlings/cuttings are especially important after forest decline and in cases when site degradation must be prevented by fast and efficient silvicultural interventions. The complexity of FRM production grows increasingly as well as the need for adapted FRM. Thus, procurement of quality seed, as well as nursery production harmonized with needs in practical forestry could be seen as a backbone of current prestoration efforts. When production in forest nurseries is regarded, this stage in FRM procurement is even more complex and expensive then the collection of forest seeds since it lies not only on the seed production but numerous other circumstances and activities as well. But, there is a growing problem with procurement of adequate FRM in recent years, forcing forest practitioners in seedling/sapling production to face harsh challenges and production risks. This reached its peak in 2022 when pedunculate oak, one of the commercially most important tree species missed seed crop for several years in the row. The research addresses the issues of FRM production (especially nursery production), legislative framework, the needs of practical forestry in respect to FRM together with specific constraints and challenges in different countries of Central (Austria, Slovenia), Southeast (Croatia, Serbia, Bosnia and Herzegovina) and East Europe (Romania). Research includes analysis of seed stands and nursery production data with overview of legislative framework. It shows differences in approaches in European regions and countries, but underlines joint issues and challenges in facing increased challenges and meeting increased needs which arise mainly out of efforts on forest restoration/prestoration, conservation and enhancement of biodiversity and ecosystem services. Best nursery practices and the need for adequate planning are underlined so the research presents the good background for learning and improvement of FRM planning and production between countries and regions.

Keywords: Nursery production; Challenges; Constraints; Sustainable Forest Management; Tree species; nursery ownership, FRM types.

Learning from the past to face future challenges: gathering expert knowledge on the evolution of forest restoration in Europe

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: The growing recognition that healthy forests are key to tackle many of the challenges humanity faces (e.g., biodiversity, water and climatic crises) is resulting in a historical momentum encouraging forest restoration at the global, national and regional scales. This momentum is accompanied by multiple initiatives and policies that call, for example, for the restoration of at least 30% of the degraded ecosystems by 2030. However, the translation of these ambitious goals into reality is still a major challenge due to multiple limitations and uncertainties. One such challenge is that the success and failure of past restoration efforts remain poorly documented and disseminated. Thus, there is a clear need to capitalize on past experiences in forest restoration to minimize mistakes and maximize the efficient use of resources in the future. We address this challenge by collating information on the major practices and historical evolution of forest restoration in Europe. We aim to 1) examine the ecological, social, political and economic characteristics of the main forest restoration and adaptation initiatives across Europe, 2) understand how the nature of these initiatives has evolved over time and what the main drivers of change have been, and 3) synthesize the lessons learned from past and present restoration practices to facilitate success in future efforts. This is being achieved by analyzing and synthesizing the detailed information provided by 31 national experts from 20 European countries in the form of narratives and 38 indicators. As a result, the role of shifting political, ecological, social and economic conditions and decisions in shaping forest restoration in Europe over the last two centuries will be described and recommendations will be made.

Perceptions of Forest Ecosystem Benefits and Forest Restoration Across Europe: Insights from Key Informant Interviews

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: Forests provide various ecosystem benefits across geographies and landscapes. The specific benefits people in a locality perceive are influenced by their social, economic, and landscape features. In Europe, forests are managed for multiple purposes, including outdoor recreation and creating habitats for biodiversity. However, perceptions of forest ecosystem benefits have been suggested to vary across landscapes and social structures. Studies investigating people's perceptions of forests and forest restoration across various population structures and geographical locations in Europe are limited. Our study aims to explore people's perceptions of forests and forest restoration across population structures and geographical areas in Europe. Understanding the societal perceptions of forests, ecosystem benefits, and their link to forest restoration across diverse landscapes is vital for informing policies seeking to improve ecosystem functions. We employed a multi-layered approach to design the interview procedure and snowball techniques to identify 20 key informants in selected European countries, including Sweden, Germany, Scotland, Spain, and Croatia/Serbia.

Preliminary results reveal that perception of forests varied within population structures but not across study regions. We found two distinct perceptions of forests among the study respondents. On the one hand, forests are perceived as everything – -respondents with this view derived part of their livelihoods from forests but infrequently visited the forests. On the other hand, forests were perceived as unique places. People who held this view did not directly work in forests or forest-related activities; however, they recognised the roles of forests in society and nature and frequently visited the forests (many times a week). Furthermore, we found that forest restoration was perceived to be associated with improved ecosystem benefits. However, the degree of importance attached to each ecosystem benefit varied among the population and across the study regions.

Our results highlight variations in perceptions across population structures but not across the study locations. The findings are essential for survey designs, highlighting the necessity for future research on people and forests. The results suggest that future research should expand the scope of forest studies by encompassing diverse perspectives and simultaneously enhance efforts to promote forest values among various population groups.

Prestoration of Riparian Area Shaped by Human Activities and Climate Changes – Replacement of Alochthonous Poplar Plantations with Oak Forests

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: High productive poplar plantations have significant role in securing fast wood production, especially if selected non-native poplar clones are regarded. The beneficial influence of such plantations can also be seen in preparing bare land for forest communities with higher structural and composition complexity, which often provide higher biodiversity and ecosystem services. They are a part of a tradition of European forestry and the most western part of Pannonia plane is no exception. The studied area is placed in the most western part of Pannonia plain covering Northeast part of Croatia. The study represents an example of prestoration of areas covered by non-native poplar plantations through planting of oak forests, which is interesting for several reasons. Even though local society broadly respects sustainability and biodiversity through long lasting tradition of forestry, the pressure for intensive wood production, poor management due to civil war, impoverishment and depopulation of the area backed up with negative impacts of climate changes (higher severity and prolonged duration of droughts and absence of flooding) create high need for restorations. This should be tackled carefully, with high sense of environmental, societal and financial aspects. The area has significant portions covered by poplar plantations in different conditions, ages and even restoration examples, but mostly with lower productive ability and resilience capacity, low tree diversity and lower value of ecosystem services. It all leaves a significant space for increase of ecosystem services, biodiversity and adaptation capacity. The research presents activities initiated in the scope of H2020 SUPERB, which include monitoring of restoration activities conducted during the last three decades in the studied area and initiation of prestoration activities on 50 ha. Furthermore, the paper will tackle the problem of restoration with narrow-leaved ash, currently the most discussed tree species for restoration activities in lowland area of Croatia. The research clearly shows complexity of prestoration from Croatian aspect of one of the 12 adaptive restoration actions covered by SUPERB project including stressors, restoration necessary and initiated prestoration activities altogether placed in the interesting socio-economic circumstances of this poor and depopulated area of Croatia.

Restoration of forests partially affected by past human activities in the south-eastern Făgăraș Mountains within the S.U.P.E.R.B. Project.

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: In the demo study area, located in the South East of the Fagaras Mountains, Romania, the mosaic of forest landscapes includes:

Remnants of virgin and quasi-virgin forests, mostly at altitudes above 1400 m and up to the timber line, a number of forests which still have natural structures and compositions, little affected by logging;

Relatively large areas where natural beech-fir-spruce mixt forests were cut 70-90 years ago and replaced by artificial spruce plantations,
Areas where forests have been mostly ilegal felled and then abandoned;

Areas of sub-alpine secondary pastures where historically did exist scientifically important spruce-arolla pine stands and higher up dwarf pine and juniper scrubs;

Riparian alder galleries have been affected in the past by road construction, wild logging on the slopes, wood deposits and are also invaded by spruce saplings from seeds provided by existing neighbouring monocultures;

The main objectives of the reconstruction activities are:

- to achieve the ecological connectivity of the remaining quasi-virgin and natural forests still existing in the area by supporting and speeding up natural processes,

- achieving the full functionality of the upper Dâmbovița forest ecosystem (an important watershed for the Romanian Capital Bucharest) on the long term, which can evolve undisturbed by human activities as nonintervention zone in the future Făgăraș Mountains National Park.

The reconstruction activities consist mainly of:

-Initiating the return of natural forest types in spruce monocultures through careful and repeated interventions, i.e. reducing the density in spruce monocultures and saving the beech, fir trees still existing there, planting the missing species under the massif. In more difficult to access areas, the spruce trees removed are peeled and left in place;

-In areas affected by past non-compliant felling, based on analyses of historical forest planning data,

the planting composition aims at restoring forests similar to natural ones, but taking into account climate change as much as possible;

-Restoration of riparian habitats is initiated by removing spruce from the alder galleries and planting alder saplings.

-In areas above de forest line, in the continuation of the forest, attempts to recreate dwarf pines and junipers scrubs will be initiated through plantations.

Unlocking the Potential: Systemic Approaches to Scale Up Urgent Ecosystem Restoration for Forest Biodiversity and Ecosystem Services

T1.26 Prestoration – combining restoration and adaptation – of European forests for people and planet

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Abstract: The "SUPERB - Systemic solutions for upscaling of urgent ecosystem restoration for forest related biodiversity and ecosystem services" project, funded by the European Commission from 2021 to 2025 as part of the Horizon 2020 Green Deal initiative, provides robust scientific evidence in support of the proposed Nature restoration law, thereby addressing the pressing need for substantiated data in forest restoration field.

The primary objective of the SUPERB project is to create favorable conditions for large-scale restoration of forests and forest landscapes throughout Europe. This is achieved through twelve extensive demonstrations conducted in collaboration with local stakeholders. Additionally, the project focuses on generating practical knowledge based on evidence, pertaining to the sustainable management, governance, and financing of restoration efforts, by learning from previous and ongoing projects in Europe and other regions. Another important goal is to enhance societal support for restoration and its associated benefits. To accomplish this, SUPERB establishes a strong network and movement involving multiple stakeholders, promoting the development, adoption, and expansion of transformative approaches and actions for forest restoration. During this session, SUPERB work packages leaders will share key findings and results, engaging in discussions with researchers in the field. The concept of *prestoration* combining restoration and adaptation will be discussed along with approaches and benefits for biodiversity, ecosystem services and carbon storage in a European context. We will also discuss the need and options to create an enabling environment for large-scale future-oriented forest restoration and transition to integrative forest management (integrating biodiversity conservation into sustainable forest management at different scales) that receives broad-scale acceptance and support by relevant stakeholders and society at large.

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

Balancing stress and acclimation – physiological responses of boreal plants to long-term whole ecosystem warming and elevated CO2

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Global climate change is disproportionality increasing temperature in the high latitudes, including the vast, carbon rich boreal forests. Plant biochemical or hydraulic sensitivity to warmer, drier air could lead to reduced carbon uptake if species are not able to adapt or acclimate to the novel conditions. To test boreal species response to warming, a boreal black spruce bog ecosystem is being exposed to long-term temperature (0 to +9 °C) and elevated CO_2 treatments (ambient or + 500 ppm), http://mnspruce.ornl.gov. Conifer tree (*Picea mariana* and *Larix laricina*) and ericaceous shrub ecophysiology has been monitored over time revealing species-specific and seasonal differences in morphology, phenology, photosynthesis, respiration, water potential, sap flow and hydraulic stress. The warming treatments have led to a longer active season (4-5 days per °C) based on measurements of tree transpiration and phenology. Warming led to an increase in the thermal optima of photosynthesis in both tree species, but this acclimation did not keep pace with the rate of warming. In addition, since there was little evidence for acclimation of respiration, net photosynthesis declined with warming. Nighttime transpiration was evident during periods of high vapor pressure deficit in both black spruce and larch trees. Warmer plots experienced greater twig water potential stress (especially *Larix*), leading to loss of foliage and branch tip dieback. Water stress was likely due to hydraulic limitations to atmospheric water demand or, during drought, lack of root water availability due to a drop in the water table beyond the shallowly rooted plants. Late season shrub foliar losses in warmer plots were exacerbated by moth herbivory. Treatment impacts were confounded due to periodic early spring freeze events, summer heat waves and drought. Drone and ground-based measurements indicate canopy temperatures could periodically be much higher than air temperatures, even exceeding 50 °C. The dynamic and species-specific responses of vegetation to climate change treatments and extreme events highlight the complexity of modeling future responses in this ecosystem. Results are being applied to ELM-SPRUCE, a version of the E3SM land model that can be used to scale up to the landscape.

Canopy coverage in experimental plots for forest landscape restoration

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Canopy coverage plays a crucial role as bigger coverage aims to reduce the incidence of grasses, due to competition with trees for light. Canopy coverage is important for the implementation of Forest Restoration projects as grass management incurs high costs. The objective of this study was to evaluate the initial canopy coverage in different planted species. The study was conducted in an experimental trial for forest landscape restoration in the district of Hernandarias, Alto Parana department, Paraguay, which is part of the Itaipu Biosphere Reserve. Eight treatments were installed in strip patterns for utilization and conservation. Canopy coverage measurements were taken 12 months after plot installation (2021) by making two perpendicular measurements of coverage, and after that the canopy coverage area was calculated. A graphical comparison was performed, revealing that ***Mimosa bimucronata*** (DC.) Kuntze (jukeri'i) had the highest coverage with an average value of 8,33 m^2, while ***Ilex paraguayensis*** A. St.-Hil. (yerba mate) had the lowest coverage with an average value of 0,01 m^2. Among the 30 selected species, ***Mimosa bimucronata*** (DC.) Kuntze (jukeri'i) demonstrated the highest coverage. Therefore, selecting this species for future projects would be of interest, as it could have a greater impact on grass competition by reducing maintenance costs.

Canopy Nitrogen Uptake – Biogeochemically Relevant or Ecological Novelty?

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Atmospheric transport of nitrogen (N) pollution has been an important environmental issue for more than half a century. Nitrogen is a crucial nutrient for plant growth, but N has both eutrophic and phytotoxic effects at high concentrations. Hence potential nitrogen deposition effects on forest health and productivity are a balance between release from N limitations and induced phytotoxic effects under high deposition.

Interaction between changing nitrogen loading and forest health and nutrition has direct biogeochemical implications via control of the carbon cycle, and cascading implications via forest growth or decline. Traditionally it has been assumed that most nitrogen uptake by plants is through roots. Hence a logistical shortcut in many experiments which simulate nitrogen deposition in forests is applying nitrogen to the forest floor, which is reasonable if roots are the only major route of N uptake but implicitly omits canopy interactions with nitrogen deposition.

Nitrogen passing through forest canopies may be processed or taken up by epiphytic microbes and by plants themselves. How much nitrogen contributes to forest function, and the mechanisms behind this uptake, are difficult to generalize. At the plant level, canopy nitrogen uptake may contribute to plant nitrogen nutrition, and canopy interactions remove, slow, and alter nitrogen fluxes reaching the soil, affecting wider plant community properties and processes such as leaching. Canopy uptake may be a strategy for some species in particular ecological niche but not for others. However, all canopy interactions are difficult to simulate, and a large variety of different experimental methods, and study systems have been used over the past decades. This is against a background of changing deposition environment of multiple elements, as emissions controls have been implemented in some regions, while emissions have increased elsewhere.

Here I will synthesise recent evidence from experiments and observational networks for canopy uptake of nitrogen deposition as an important and biogeochemically relevant flux in the Anthropocene with a focus on why both observational and experimental studies in past conditions may have failed to detect a substantial effect of this flux, and why recent studies may do so now.

Carbon and nutrient cycling in warmer soil: Conclusions after 18 years of artificial soil warming in a temperate mountain forest

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Soil warming likely alters biogeochemical cycling processes in forest soils, but the longer-term warming effects on soil organic carbon (C) storage and nutrient pools remain elusive. In 2005 we initiated a soil warming experiment in a spruce dominated mature forest near Achenkirch, Austria which commences until today. Patches of shallow, though high organic C containing calcareous forest soil are warmed by +4°C during the snow-free seasons. Soil warming increased the soil CO_2 efflux by ~ 40% and, against all expectations, this stimulation effect remained more or less constant throughout the past 18 years of soil warming. Accordingly, soil C stocks should have significantly declined over time, but until 2019, no such significant change in topsoil C stocks could be detected (subsoil C content was lower in warmed soil). Increased C inputs from higher fine root biomass, turnover and exudation counterbalanced the respiratory C losses, although not completely. Periodic analyses of microbial community structure and physiology suggest that it took more than a decade until first sights of adaptations in microbial element cycling were realized. Nitrogen availability remained overall unaffected by warming whereas microbial phosphorous availability decreased. We will provide detailed C and nutrient budgets at the conference and discuss how meaningful such only-soil-warming studies are when considering potential warming effects on the whole forest ecosystem.

Climate change-mediated diet shifts for outbreaking forest defoliators: examining direct effects and interactions with insect disease

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: The developmental phenology of forest defoliators and their host trees is expected to advance with climate change, which can alter the phenological match between these species, and ultimately, forest defoliator diet. For example, spring egg hatch dates for forest tent caterpillar (FTC) (*Malacosoma disstria* Hübner) is expected to advance less significantly with warming than budbreak of its primary host, trembling aspen (*Populus tremuloides* Michx). This change in food resources can have direct effects on FTC but may also interact with natural enemies, including pathogens. We conducted two laboratory and one field experiment to examine interactions among FTC, climate warming-associated diet shifts, and two entomopathogens: microsporidia (*Nosema disstriae* (Microsporida: Nosematidae)) and *Bacillus thuringiensis* var *Kurstaki* (Bacillales: Bacillaceae) (Btk). FTC with known microsporidia spore loads were fed one of three diets of aspen foliage simulating either current developmental synchrony, or scenarios associated with increasing climate warming. We assessed impacts on fecundity, egg hatch, stage-specific survival, and adult traits. We also subjected FTC fed different diets to an assay where larvae were droplet-fed either a control solution or a solution with added Btk, i.e., ForayÒ 76B. We assessed mortality after 5 d and reared surviving larvae to assess larval, pupal, and total survival, as well as adult traits. Results suggest that neither microsporidia infection nor the diet alterations tested here impacted the susceptibility of 4th instar FTC larvae to Btk at a concentration of 2 IU Btk/larva. Climate-induced diet alterations did however reduce neonate survival but was associated with improved performance of surviving neonates. Results also suggest that microsporidia infection may reduce rates of successful egg hatch and the survival of older FTC larvae. This work examines the impacts of changes in host quality associated with climate change on forest insect populations, and agents that cause disease in forest pest insects. We anticipate our results can be applied to predict how climate change will impact forest pests, which is crucial for both forest and pest management planning.

Climatic gradients and Microclimatic variations of temperate forests in northern Patagonia, Argentina

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Understanding the two-dimensional mesoclimatic zonation and microclimatic variations within mountain forest ecosystems is crucial for understanding regional species turnover and effects of climate change on these systems. The temperate mountain forests in the Andean region of South America are among the largest old-growth deciduous forest areas in the world. Due to their pronounced disturbance regime and different successional stages, a climatic zonation combined with the characterisation of climatic niches is important to identify thresholds and tipping points of species occurrences.

We used micro-loggers to measure air temperature and relative humidity for one year at 40 measurement points along steep moisture gradients, as well as elevation gradients in mountain forests in northern Patagonia, Argentina. Climatic gradients from wet forests in the west to dry forests in the east and lowland forests to high-altitude forests are covered. Our results unveil mesoclimatic patterns within these forests characterised by variations in temperature and vapour pressure deficit along the altitudinal gradient in general, but also at different times of the year. Additionally, microclimatic variations were detected within the forests at the local scale, indicating the influence of disturbances, topography and forest successional stage. For example, *Austrocedrus chilensis* and *Nothofagus dombeyi* differed mainly by the temperature of the warmest days. Temperature differences between forest stands and gaps were more pronounced in the warmest month of the year and at lower elevations, with up to 2.5 K higher values in the second half of the day in gaps. Such microclimatic variations have a major influence on tree species turnover and ecological processes within these forest ecosystems.

The findings contribute to our understanding of the complex interplay between topography, climate, and vegetation in shaping the spatial patterns of species occurrences, which is essential for informed forest management and conservation strategies in this ecologically significant region.

Decline in ectomycorrhizae due to experimental drought in Sub-mediterranean Quercus pubescens stands

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Secondary *Quercus pubescens* Willd. stands in karst Sub-mediterranean of Slovenia play an important ecological role in the protection of shallow soils from erosion. The frequency and duration of droughts in this area is expected to rise in the future due to global changes and this may add to the already harsh and highly variable growth conditions there. To be able to predict the outcome for *Q. pubescens* in the increasingly drought conditions, we have set up the rain exclusion experiment in Slovenian Sub-mediterranean, which included the study of ectomycorrhizal fungi actively associated with its fine roots.

The experimental setup consisted of two plots of approx. 100 m^2 covered by translucent roof and two control plots of the same size. Sampling of ectomycorrhizal community was performed before the start of the experiment and after one year on all plots. Ectomycorrhizae were sorted based on their morphological characteristics into morphotypes and Sanger sequencing was performed for representative morphotypes. Vital and old/dead ectomycorrhizae were quantified. Diversity indices of ectomycorrhizae were calculated, and community compositions compared by “vegan” package in R.

The vitality of ectomycorrhizae significantly decreased after one year at rain exclusion plots compared to controls. Species richness and Shannon diversity index were reduced as well. Community composition of ectomycorrhizae in controls and rain-exclusion plots were significantly different after one year of experiment and the number of unique taxa decreased. The ectomycorrhizal community reduced to a subset of taxa, that were mainly present before the start of the experiment and belonged to the most frequent taxa of the site. The loss of biodiversity of active ectomycorrhizal fungi could have functional consequences for the uptake of nutrients and water in the future drought impacted *Q. pubescens* forests that need to be considered.

Deep soil organic matter response to warming

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: In an increasingly warmer world, soil will warm in near synchrony with air temperatures. Consequently, heterotrophic respiration accelerates, but is unclear how this will affect soil organic matter (SOM) stocks, the Earth's largest terrestrial stock of reactive carbon. And half of that SOM stock resides in deep soil (below 30 cm). Meta-analyses of how SOM responds to warming exist, but so far did not cover the deep SOM. Despite their large stock size, subsoils remain largely underrepresented in warming studies. But what becomes increasingly clear, is that deep SOM can respond very differently to warming than surface soils, and may show even stronger response than surface soil to changing environmental conditions.

Sources of uncertainty in predictions of how global SOM will respond to a warmer world is the lack of (1) process understanding of deep SOM dynamics, and (2) the lack of multitemporal, especially decadal, observations. (3) We still cannot synthesize and analyze data stemming from the increasing number of field experiments, because experiments were made using different methodologies, or results are reported in different units.

The aim of this presentation is to summarize the latest research insights on belowground carbon cycling, and ultimately to contribute to the answer the question: What will be the role of deep soil organic matter in terrestrial carbon cycle feedback to warming over the next century?

Diversity Patterns and the Factors: Response of Soil Microorganisms and Nematodes to Elevation Gradients in a Temperate Forest of South Korea

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Elevational gradients provide natural experimental conditions for studying the effects of climate change on forest biodiversity. Ecologists have shown that elevational gradients are associated with changes in temperature, precipitation, plant compositions, and other biotic and environmental factors, which in turn affects the communities of soil microorganisms and nematodes. Nevertheless, the diversity of soil microorganisms and nematodes and the factors along the elevation gradient are still debated. Additionally, it is unclear how their diversity simultaneously change along the elevation gradient. Here, we examined the diversity patterns of soil microorganisms and nematodes and subsequently investigated the relative importance of tree-related factors, such as tree diversity, identity and quantity, and environmental factors including climatic and edaphic factors. For this, we analyzed data from 27 plots located at different elevational bands in the temperate forest of Mt. Gariwang, South Korea. Through multimodel inference tests and variance partitioning, we identified the key factors driving each group's diversity and compared the relative contribution of tree-related and environmental effects. Our findings indicate that the bacterial and fungal diversity decreased with increasing the elevation. However, the nematode diversity did not show significant changes, which suggests that site-specific conditions have a greater influence than the elevation itself. Furthermore, the bacterial diversity was modified by factors such as soil pH and functional dispersion of leaf size, while the fungal diversity was only governed by the pH. The nematode diversity was driven by aboveground biomass, ammonium-nitrogen levels, and tree size inequality. Overall, environmental factors had a stronger impact on soil microbial diversity, whereas tree-related factors mainly regulated the nematode diversity. Our results demonstrate that the diversity patterns and the factors of soil microorganisms and nematodes vary among different organismic groups within the micro-food web. These findings provide new insights into the factors shaping soil microorganisms and nematode diversity in temperate forests and enhance the understanding of soil organismic groups' responses to the elevational gradient. Beyond ecological understanding, this knowledge can support efforts to mainstream soil biodiversity for sustainable development agenda, the post-2020 biodiversity framework, and initiatives focused on soil restoration and health management in forest ecosystems.

Effects of disrupted forest continuity on tree growth rate and environmental sensitivity

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: In light of global warming and the expected alterations to local climate, forest resilience to environmental changes is of importance for many ecosystem functions in the boreal forest. However, in the Fennoscandian boreal region, forests are subjected to intensive forestry management with little empirical knowledge on how this may affect long term productivity and sensitivity to altered growing conditions. Here, we present long term effects of disrupted forest continuity on tree growth rate and sensitivity (inter-annual growth variation) by comparing forests of long continuity (only subjected to selective logging) to those that were regrown after deforestation (clear-felling) ~60 years ago in northern Sweden. Using tree cores and dendrochronological methods, as well as measurements of microclimatic conditions and soil properties, we compare the forests' growth patterns and environmental sensitivity. In general, we found connections between early benefits to growth rates following a disruption event and increased growth sensitivity as well as dependency on precipitation. Furthermore, the growth benefits experienced by disrupted forests are exclusive to early establishing trees, whereas trees established later show growth patterns similar to those in forests with long continuity. The early establishing trees also present some indication that the rapid growth rates in early life is connected to a decreased growth potential in the long term. Thus, although continued intensive harvesting that disrupt forest continuity may initially result in highly productive forests, it may come at the expense of long-term productivity as well as increased sensitivity to environmental changes.

Effects of warming, reduced precipitation and snow changes on growth and physiology of two co-existing seedlings in a temperate secondary forest

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Seedling establishment of dominant tree species can determine the regeneration direction, and seedling stage is the most sensitive to environmental conditions (e.g., temperature and water) in the plant life cycle.

Warming and precipitation reduction in the growing season have been concurrent throughout this century in most temperate regions (e.g., Northeast China) and have increased drought risk to the growth, migration, or mortality of tree seedlings. On the other hand, there is usually a greater warming regime in the non-growing season of temperate regions, and this warming can induce the changes in snow (e.g., changes in depth of snow, leading to more frequent rain-on-snow events and freeze-thaw cycles causing snow compaction and formation of ice layers in the snowpack) and consequently influence the seedling establishment in the subsequent growing season.

Coexisting tree species with different functional traits in temperate forests may have inconsistent responses to both warming and decreased precipitation, and both warming and changes in snow, which could result in a species distribution shift and change in community dynamics. Unfortunately, little is known about the growth and physiological responses of coexisting species to the changes in these meteorological elements.

Thus, we selected seedlings of two coexisting species in a temperate secondary forest of Northeast China (water conservation forest): *Quercus mongolica* (drought-tolerant species) and *Fraxinus mandschurica* (drought-intolerant species) to analyze the growth and physiology of seedlings under three experiments: 1) constantly elevated 2 °C in the surface soil above control plots at Qingyuan Forest CERN; 2) under strictly controlled conditions simulating the predicted warming (+2 °C, +4 °C) and precipitation reduction (-30%) compared with current conditions; and 3) simulating six conditions of snow changes under warming (normal snow depth, twice snow depth, no snow cover; control, snow compaction, formation of ice layers in the snowpack).

Our results can fully understand the responses of two co-existing seedlings to warming and changes in precipitation, and predict the development direction of temperate secondary forest under the background of global changes.

Elemental Dynamics and Limitations of Quercus petraea L. Under Experimental Canopy Nitrogen Deposition

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: In the light of rising global air pollution levels, we have been engaged in better understanding the effects of increased Nitrogen (N) deposition rates on Carbon (C) sequestration in forest ecosystems.

While most experimental studies investigating N deposition have been using ground fertilization methods, those might not proveto be the most representative of the actual deposition pathway. Thus, in our research we have adopted an improved approach of above canopy N application, with a conservative rate of 20 kg N ha^{-1} yr^{-1}, which may better simulate true deposition and feasable future scenarios.

The experimental site is located in South-Tyrol, Italy, where natural mature Sessile Oak (*Quercus petraea L.*) stands have been treated since 2015 with N fertilizer applied to either above the canopy, or to the forest floor directly (for comparison), alongside unfertilized control plots.

To this day, no major shifts were detected in tree productivity, water use efficiency, leaf development, and C & N contents, nor clear treatment impact on radial tree growth.

Hence, we set an objective to explore whether potential overlooked productivity inhibitions might exist in the system. Nutrient imbalances, Phosphorus (P) in particular, may have a key role when attempting to monitor the effects of N deposition in forests. These imbalances are often induced by increased N deposition, and may shift ecosystems from N to P limitation.

We provide a deeper examination of the the state and availability of nutrients in the system, with an emphasis on P, and will report measures of total and available soil elemental fractions, foliar concentraions and ratios, and soil enzymatic activities, throughought the years of the experiment. Thus far, sub-optimal ambient P concentrations were found in the tree foliage, with a general increase in N:P ratios in the recent years, further agreveated in the N treated plots, with a slight edge towards the above canopy fertilization.

We will therefore have the opportunity to emphasize the importance of describing a wider elemental profile when undertaking forest research and management, while presenting missing regional ecosystem health data, and at the same time distinguishing between the different N application approaches.

Foliar optical signals to investigate shoot biogenic volatile organic compound emissions from Scots pine and English oak saplings under warming

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Accurate quantification of long-term emissions of biogenic volatile organic compounds (BVOCs) is essential for understanding biosphere-atmosphere feedbacks due to their key roles in atmospheric chemistry. However, proper tools for observing BVOC emissions at large scales are still missing. Remote sensing of optical signals such as photochemical reflectance index (PRI) are promising solutions to fill the spatial knowledge gap, based on the linkages of carotenoids with both BVOC biosynthesis and PRI.

We conducted the experiment in the growth chamber in summer 2022. We wanted to investigate how the relationships between foliar PRI and shoot BVOC emissions change in response to mild (35 °C) or extreme (40 °C) heat stress during the peak of growing season in Scots pine and English oak. Our research questions were: (1) do photoprotective mechanisms such as foliar carotenoid pigment contents or non-photochemical quenching dynamics mediate the relationships between PRI and BVOC emissions in response to warming? (2) do these controlling factors differ between tree species / BVOC emission types (e.g., isoprene and monoterpene emitters)? and (3) can PRI capture the changes in BVOC emissions in response to warming?

For English oak, we found a significantly increasing **isoprene** emission rate in response to mild heat stress (35 °C), but a lower **isoprene** emission rate in extreme relative to in mild heat stress in English oak. On the contrary, in Scots pine the isoprene emission rate was only slightly higher in extreme stress compared to room temperature and mild heat stress. Some main monoterpenes, including **α-pinene, camphene**, **β-pinene** and **limonene,** had clear increasing emission rates from room temperature to extreme heat stress, in both species.

In this communication, we will evaluate and examine how these BVOC dynamic patterns related to biochemical and photoprotective dynamics can be detected in terms of foliar pigment contents,

PAM fluorescence measurements and eventually, leaf spectral reflectance measurements. The expected outcomes will give new insights into leaf-level mechanistic links between PRI and BVOC emissions for plants in response to climate warming.

Genetic variation of Russula ochroleuca, a mycorrhizal generalist, along an altitudinal gradient in a German low mountain range

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Context

Climate change puts forest ecosystems under high pressure, especially in mountains, where rising temperatures force species to adapt or to migrate uphill following their moving temperature optima. Since phenotypic plasticity is limited, genetic adaptation in response to the changing climate is expected. The mycorrhizal community has to deal not only with rising temperatures, but also with changing plant communities and increased occurrence of drought events with an impact on mycelia in the topsoil. Mountain ranges and their climatic conditions changing with altitude offer the possibility to study genetic adaptation to a changing climate over short distances. We used microsatellite markers to investigate the genetic structure and potential adaptation of *Russula ochroleuca* populations along an altitudinal gradient in a German low mountain range.

Methods

Along an altitudinal gradient in the Bavarian Forest in southeast Germany, spanning a range from 300 to 1400 m a.s.l., 149 fruit bodies of *Russula ochroleuca*, a mycorrhizal generalist, were collected on 69 sample plots in managed forests and unmanaged strict forest reserves in autumn 2019. Inner tissue from the stipe was sampled and microsatellite analyses using seven markers developed in this study were performed on an ABI Prism™ 377 Sequencer.

Results

The microsatellite analyses showed a low level of inbreeding and a high genetic variation within populations along the altitudinal gradient. For three sample plots, locations of sampled fruit bodies were mapped to investigate if underground mycelia produced several contiguous fruit bodies with identical genetic profile and if it was possible to determine the area occupied by a genetic individual. However in most cases, even fruit bodies located in close proximity of a few centimeters showed different microsatellite marker profiles. A genetic structure related to altitude, management type or leading tree species was not found due to the high intra population variation.

Conclusions

The mycorrhizal generalist *Russula ochroleuca* showed an almost panmictic genetic structure along the investigated altitudinal gradient as well as across management types and forest ecotypes. With

regard to the observed high genetic variability, *R. ochroleuca* appears to be well prepared for the challenges of a changing environment due to global climate change.

Growth and phenology of Norway spruce in a future wetter climate: the FAHM study

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Global climate change alters regional precipitation patterns and causes precipitation increase in Northern Europe. More frequent rain events extend periods with high relative air humidity in forest canopies. Norway spruce (*Picea abies* [L.] H. Karst.) is a widespread, economically important conifer, which is currently facing a decline in several parts of its range due to the massive bark beetle outbreaks as well as its high susceptibility to drought, wind, and root rot damage. In spring of 2020, monospecific and mixed (50:50 with *Betula pendula*) spruce stands were planted at the Free Air Humidity Manipulation (FAHM) experimental site in hemiboreal Estonia, where 9 study plots (⌀ 14 m) include 3 controls, 3 plots with elevated air humidity (by 5-7%), and 3 plots with elevated soil moisture (by 15%). The treatments were designed following the regional climate change projections by 2100 (IPCC). Our aim was to compare basic tree growth traits, spring phenology and occurrence of lammas growth (second flush of shoots in late summer) between the treatments. After three growing seasons, the height of spruces remained 22% lower and stem diameter 15% smaller in the air humidification treatment compared to soil irrigation and control. In mixed plots, spruces growth was slower, especially in the soil irrigation treatment, than in monospecific plots. The negative effect of air humidification was, however, also smaller in mixed plots. Annual height increment of spruce was greater in trees with earlier budburst, irrespective of treatment. The lammas shoots were more frequent in soil irrigation (26%) and control plots (22%) than in air humidification (3%). Hence, spruce growth can be reduced by increasing air humidity and at wetter soil, the growth rate did not benefit from mixing with fast-growing light-demanding *B. pendula*. Higher incidence of lammas shoots on wetter soil could indicate to higher risk of frost damage but lower incidence under more humid air can counterbalance this. Although growth rate of spruce was inferior in mixed stands, smaller growth differences among treatments and lower incidence of lammas shoots still suggest that spruces may better acclimate with future more humid climate in mixed forests.

Growth and physiological acclimation patterns of Scots pine after long-term irrigation

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Scots pine (Pinus sylvestris L.) is a prevalent tree species in Europe, and understanding its acclimation potential is crucial for predicting its growth and vitality under future climatic conditions. To investigate long-term acclimation patterns to changes in soil water availability, a 17-year-long irrigation experiment was conducted in an inner-Alpine valley of Switzerland (Pfynwald). This experiment employed two treatments: i) continuous irrigation for 17 years during the vegetative season and ii) interruption of irrigation after 11 years ("stop" treatment).

Our dendrochronological investigation of the long-term effects of increased water availability revealed three stages of growth acclimation. Initially, we observed a significant increase in growth (overyielding) during the first four years. This was followed by a continuous but declining overyielding trend over the subsequent eight years. Finally, after 12 years of irrigation, the growth rates of the irrigated trees regressed to pre-irrigation levels. The "stop" treatment, which discontinued irrigation in the 12th year, showed a continued reduction in growth. However, we found that tree vitality, determined by canopy transparency, had a greater influence on growth and physiological adaptation compared to the impact of increased water availability.

In this third acclimation phase, we explored the treatments' structural and physiological differences by comparing isotope ratios recorded by stem and needle non-structural carbohydrates (NSC), xylogenesis and quantitative wood anatomical variables. Irrigated trees showed consistently longer growing periods, lower tree-ring $\delta^{13}C$ reflecting lower stomata restrictions, and higher hydraulic conductivity compared to control trees. However, the similar relationship between tree-rings $\delta^{18}O$ and $\delta^{2}H$ (O-H relationship) of irrigated and control trees indicate a similar "physiological balance" between autotrophic and heterotrophic processes. On the contrary, the stop treatment showed the lowest growth rates, highly conservative wood anatomical traits, and an ongoing "stress reactivity" and acclimation to the removal of irrigation, as indicated by the weak O-H relationship and high $\delta^{2}H$ values.

We conclude that after 17 years of treatment, i) irrigated trees have reached an acclimation balance although maintaining higher overall biomass and higher stomatal conductance and photosynthetic rates, ii) the stop trees have not yet acclimated to the non-irrigated conditions, and iii) canopy vitality strongly influences acclimation responses.

Height increment of Scots pine shows complex responses to weather conditions in the north-eastern Baltic region

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Weather growth relationships, which are crucial for the accuracy of local and regional tree growth/distribution predictions are largely acquired based on the variation deconstruction of radial increment. However, the radial increment is strongly affected by local conditions, which can have nonstationary effects, thus adding noise and uncertainty regarding the long-and medium-term weather/climate-growth relationships. In this regard, the primary, i.e., height increment, which is less affected by local and microsite, hence is a more straightforward proxy for productivity, has received considerably less attention, particularly due to laborious gathering of data. Furthermore, under accelerating environmental changes, local relationships, which are usually estimated as a linear response, are getting outdated, hence assessment of their plasticity and stationarity across the regional spatiotemporal gradient is paramount for reliability of predictions. In this study, the published long-term time series of height increment of Scots pine from the north-eastern Baltic region (Latvia, Estonia and Finland) were revisited and regional weather drivers were distilled using variance deconstruction and generalized additive modelling techniques. At the sub-regional scale, height increment was affected by a complex of meteorological conditions, which had carryover effects. Height increment was prevailingly sensitive to thermal conditions in preceding year indicating influence on the formation of growth initials rather than their elongation, with precipitation showing only marginal effect. Even though sub-regional climatic gradient was represented by the dataset, the most of the regional weather effect on height increment were linear or near-linear implying that from the perspective of local population, the analysed part of the gradient has been narrow. This also indicates high ecological plasticity of height increment of the studied population, hence ability to cope with the anticipated environmental changes.

Keywords: relative annual additional increment; Pinus sylvestris; sub-regional climatic gradient; plasticity of response; adaptability.

How canopy gaps mediate the impact of decreasing snow on tree seedlings in boreal forests?

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Forest ecosystems generally have highly heterogeneous canopies, usually recognized as canopy gap structures. While the roles of canopy gaps in the forest succession are well known, the role of gaps has not yet been fully considered in the context of climate change, especially under changing snow regimes. We therefore conducted a field manipulation experiment in a boreal forest in Hokkaido, northern Japan, to assess how gap structures mediate the impact of decreasing snow on the survival and growth of tree seedlings. Additionally, by measuring biotic and abiotic factors such as feeding damages rate, light availability, and other microclimate factors, we would elucidate the factors that possibly limit plant survival and response.

The experiment was conducted in 40 years old *Picea glehnii* forest located in the Teshio Experimental Forest. Five 10 m × 20 m canopy gap plots were created in July 2022 by cutting down all the trees in those areas. Also, five 10 m × 20 m plots were set up in the forest interior as canopy plots. Snow manipulation block and control block were then set up in each plot (5 m × 5 m each; totally 20 blocks). 20 seedlings for each 4 species (2 deciduous species and 2 coniferous species) were planted within each plot in October 2022 (totally 1,600 seedlings). Snow manipulation was conducted in the beginning and end of winter by shoveling to reduce snow cover days following RCP 4.5 scenarios (2.5 - 3°C temperature rising) from 2022 to 2024. Plant survival rate and relative growth rate were measured in late June and September along with feeding damages. Light availability and other microclimatic factors were kept measuring since October 2022. Here, we would like to provide some results from our first-year manipulation experiment.

How to predict the interacting effects of climate, water, and soil nutrient availability on forest productivity

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Contrary to earlier expectations of increased forest growth under rising temperature and atmospheric CO2 in boreal forests, growth in many Nordic forests has declined in recent years. Due to the potentially vast negative consequences for both the economy, ecology, and carbon sequestration, a better understanding of the reasons for this decline is urgently needed. Several environmental factors limit tree growth, including temperature, CO2, soil moisture, humidity of the air, and soil nutrient availability. But although the separate effects of water limitation and soil nitrogen availability are well known, it remains a challenge to predict how trees manage their combined effects under novel conditions. To address this question we introduce a new physiological model based on optimality principles which accounts for plasticity in stomatal conductance and leaf nitrogen concentration. This allows the model not only to capture gross primary productivity (GPP) and transpiration in response to weather conditions but also effects of soil moisture and nitrogen availability. We demonstrate the accuracy of the model compared to GPP estimates from eddy flux measurements and canopy transpiration in fertilized and unfertilized pine forest in northern Sweden. We also show that the response to increased soil nitrogen availability can be captured by a reduced carbon cost of N uptake and an increased leaf area per sapwood area. The results imply that the interactive effects of water and N limitation on GPP and water use in boreal pine forest can be explained by the trees striving for an optimal balance of maximizing growth while limiting hydraulic risk. This model provides a fundamental tool for analyzing the expected future growth of Nordic forests and potential management strategies.

Impact of Drought and Rewetting Cycles on Soil Greenhouse Gas Fluxes across an N Deposition Gradient in Austrian Forests

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Climate change has increased the frequency and intensity of extreme weather events such as drought periods and heavy rainfall in large areas of the world, including Central Europe. Despite decreasing nitrogen deposition rates in this region, forests are still subjected to high N deposition rates from agricultural and industrial sources. These disturbances affect fundamental biogeochemical processes and likely alter greenhouse gas fluxes in forest soils. However, the full impact of N deposition on the response of forest soils to increasing extreme weather events is still unknown.

In this project, our approach combines the use of active manipulation simulating drying-rewetting (DRW) cycles on a natural gradient over three representative Austrian broadleaf-forest sites with detailed field GHG observations, microbial laboratory analyses and process-based modelling. The DRW plots received the long-term averaged rainfall concentrated in three single extreme precipitation events and were excluded from rain the rest of the vegetation period. N-addition plots received extra N at a rate of 50 kg N ha^{-1} y^{-1}. Soil GHG fluxes were measured with automated chambers at a high temporal resolution on all plots. Soil samples were taken before and after each irrigation event to measure microbial responses to drying and rewetting and the abundance of methanotrophic bacteria. Measurements were conducted in 2021 and 2022.

Results show reduced soil CO_2 fluxes, extremely reduced N_2O fluxes, and increased CH_4 uptake under DRW treatments compared to natural environmental conditions. Natural drought conditions led to a convergence of N_2O emission levels in the DRW and control plots. N addition only had modest effects on GHG fluxes The significance of the interplay between a higher frequency and intensity of DRW cycles and N deposition rates for the soil GHG budget and the feedback between forests and climate change will be presented and discussed.

Longer-term soil respiration responses to experimental warming in subtropical and temperate forests relate to soil organic matter composition and fine root biomass

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: It is still uncertain how global warming will affect soil CO_2 fluxes and which carbon (C) cycling processes in forests soils are going to be most affected in the long-term. Here, we experimentally warmed the surface soil of a subtropical and a warm temperate forest by ~ 1.5°C from 2012 to 2022 and compared the short-term (2-3 years) with longer-term (10 years) warming effects on soil CO_2 fluxes, fine root biomass, soil organic matter (SOM) chemistry and microbial community composition. Soil warming did not affect soil CO_2 fluxes in the short term, but decreased them in the longer term (-10.3%, heterotrophic and autotrophic respiration similarly affected) in the subtropical forest. In the warm temperate forest, soil warming increased soil CO_2 fluxes by 35.3% in the short term and by 29.8% in the longer term (heterotrophic and autotrophic respiration similarly affected). Soil warming significantly increased fine root biomass in the temperate forest, whereas finer root biomass was slightly decreased in warmed soil of the subtropical forest. In the subtropical forest, soil warming significantly altered soil organic matter (SOM) properties towards increased aliphaticity and decreased O-alkyl C content. This was likely linked to the significant long-term decline in heterotrophic soil respiration at this forest site. Microbial biomass and both, bacterial and fungal diversity were not affected by long-term soil warming at either site. Albeit the distinctive soil respiration responses, soil organic carbon contents remained unaffected after 10 years of soil warming at both sites. A decrease in SOC content was only detectable in warmed-trenched plots in the warm temperate forest, suggesting that also in this forest, increased root C inputs had compensated the respiratory C losses under natural (un-trenched) conditions. Overall, our results suggests that SOM chemical composition and fine root biomass are key determinants in the long-term response of soil respiration to warming, which may vary considerably among different forest ecosystems.

Key words: soil respiration; climate change; SOM chemical composition; ^{13}C NMR spectroscopy; long-term soil warming; subtropical forest, temperate forest, fine root biomass, microbial diversity

Minerals control soil organic carbon stability predominantly via enzymes and nutrients in red soil hilly Critical Zone

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Mineral protection is a widely accepted important mechanism regulating soil organic carbon (SOC) preservation and loss. However, how minerals affect SOC dynamics, especially through the intrinsic enzyme- and nutrient-mediated processes, is not fully understood. Here, we measured specific carbon mineralization rate (C_{min}/SOC), the contents of SOC, particulate organic carbon (POC), mineral-associated organic carbon (MOC), and mineral contents (Fe/Al oxides), enzyme activities, and nutrient contents (NH_4^+-N, NO_3^--N, total N, available phosphorus) along the soil profiles of different forest types in the red soil hilly Critical Zone. We found that poorly crystalline Fe/Al oxides (Fe_o and Al_o), and complexed Fe/Al oxides (Fe_p and Al_p) were closely negatively associated with C_{min}/SOC, and positively correlated to SOC, POC, and MOC. Notably, the variations in C_{min}/SOC and SOC explained by the mineral itself were less than by its interactions with enzymes and nutrients, highlighing that minerals control SOC stability predominantly through enzyme- and nutrient-mediated processes. The key controls of minerals on POC and MOC were divergent, in which POC was indirectly influenced through the enzyme- and nutrient-mediated pathways, but MOC was directly associated with minerals and its interplay with nutrients. More importantly, minerals explained more variations in POC and MOC contents at subsoil and parent material, reflecting a depth-dependent effect. Overall, our results highlight an intrinsic enzyme- and nutrient-dependent mechanisms of mineral protection for SOC stabilization, which provides new insights into in-deep understanding of SOC dynamics.

N and P interactions in an old-growth temperate woodland subjected to long-term free CO2 enrichment

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Understanding the impacts of increasing atmospheric CO_2 concentration on nutrient availability and tree photosynthesis is essential to predict ecosystem carbon stocks. This is particularly important for temperate forests which are one of the largest CO_2 sinks in the world. Higher atmospheric CO_2 concentrations are expected to stimulate photosynthesis, but the potential for an increase in tree biomass in these forests strongly depends on nutrient availability. Increases in biomass production will require that trees take up greater amounts of nutrients from soils under elevated CO_2 (eCO_2) and/or increase nutrient-use efficiency, for instance, enhancing foliar nutrient resorption efficiency.

Very few Free Air CO_2 Enrichment (FACE) experiments have been carried out in old-growth forests. Most long-term eCO_2 studies have been conducted in younger stands that were N limited. However, P may also play a very important role in moderating productivity in temperate forests. In this study we use a whole-ecosystem FACE experiment established in an oak dominated, 175 years old temperate forest (BIFoR-FACE) to determine the stoichiometry characteristics of carbon, nitrogen and phosphorus of trees and soils in the ecosystem and reveal the carbon-nutrient interactions of the forest after 7 years of CO_2 enrichment. To do so we assess the nutrient content dynamics in green leaves, leaf litter, wood, roots and soil from 2018 to 2022.

Focused on year 2021, we show that enriching the atmosphere with 150 ppm CO_2 has stimulated nutrient resorption efficiency and net photosynthesis by 37%, while the growth of the dominant tree species (*Quercus robur*) has only slightly been increased in some of these years. Stoichiometrically, we found P-limitation as an important factor affecting productivity and higher N resorption efficiency under eCO_2. We consider the implications of the findings and explore paths of C allocation in this mature temperate oak.

Overstory-Understory relationship variation in Miombo Woodland along a rainfall and fire gradient

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Miombo woodland is a forest ecosystem that covers a large part of eastern and southern Africa including the southeast of the Democratic Republic of Congo (DRC), Angola, Malawi, Botswana, Zambia, South Africa, Namibia, Zimbabwe, Tanzania, and Mozambique. Across this wide geographic coverage, rainfall and fire have been identified among the main environmental drivers that influence the distribution, composition, and vertical structure of Miombo woodland. Like other forest ecosystems, Miombo woodland's vertical structure is composed of different strata but mainly consists of understory and overstory.

However, the forest overstory-understory relationship has been scarcely explored. Little is known about the influence of overstory conditions (diversity, canopy coverage, tree density) on understory vegetation and the mechanism involved. Most forest models in Miombo woodland have focused on the overstory woody vegetation neglecting the understory vegetation despite its importance in ecosystem functioning. Studies on the understory of Miombo have been conducted on a local scale but focused on the vegetation description, neglecting the effects that rainfall and fire can have on this relationship at different scales of impact (localized impact to regional impact).

This research uses field data collected in 12 vegetation monitoring plots of 0.5 ha to 1 ha located in Namibia and the DRC and aims: (i) to explore the variation of overstory and understory vegetation along a fire and rainfall gradient in terms of composition and structure; and (ii) to analyze the influence of overstory conditions on understory vegetation along the fire and rainfall gradient.

In the context of global change that faces Miombo woodland, a good knowledge of the relationship between environmental drivers and forest parameters will contribute to improving natural resource management and support international policy initiatives such as REDD +.

Photosynthetic thermal acclimation of clonal Norway spruce trees along a broad latitudinal gradient

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: The ability to acclimate to increasing growth temperature is a key determinant of how long-lived plants such as trees will respond to climate change. Most field-based studies on thermal acclimation to date have utilized trees from geographically separate populations that have adapted to different growing environments over generations. Here, we have excluded the potential confounding effect of local adaptation by investigating clonal Norway spruce (*Picea abies*) seedlings planted in 2013 at four sites along a latitude gradient from mid-Sweden (Uppsala) to south-western France (Bordeaux) with a 6.4 ˚C annual mean temperature range. The experimental design included 3-4 individuals of close to 300 Swedish, eastern European and mixed genotypes at each site.

The first study on photosynthetic thermal acclimation potential focused on three closely related Swedish genotypes. We found that light-saturated net photosynthesis and the maximum rate of carboxylation (V_{cmax}) at a constant reference temperature of one-year-old needles increased with increasing growth temperature, while the maximum rate of electron transport (J_{max}) did not. Both rates exhibited seasonal acclimation with lower values during the spring than during the late-summer. In addition, the J_{max} to V_{cmax} ratio at 25 ˚C was highest during the spring and decreased along the latitude gradient with increasing growth temperature driven by the increasing V_{cmax}. In a second study, the thermal acclimation of photosynthesis of selected Swedish and eastern European genotypes (two each) was compared to investigate how long-term adaptation to climatic conditions at the area of a genotypes' origin affects the ability for photosynthetic thermal acclimation. These results will be discussed regarding the potential of genotype selection to improve the photosynthetic performance of Norway spruce in a warmer climate.

Site-Specific Response of Norway Spruce to Drought Conditions in the Italian Alps

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: The Italian Alps are experiencing a rapidly shifting hydrological cycle due to climate change. With the rising occurrence and extended duration of summer droughts, significant obstacles are anticipated to emerge, impacting the resilience and productivity of forest ecosystems. In light of this, our study focuses on the Norway spruce (*Picea abies*), a species of relevant value for ecological and economic reasons within the alpine region. In 2020, we established two contrasting experimental forest sites in South Tyrol (Eastern Italian Alps) - Carezza, a humid and fresh location, and Ultimo, a comparatively warmer and drier site. At each site, twenty trees are equipped with a novel IoT device (TreeTalker), capturing hourly data on several tree physiological parameters (Flux density, Stem Water Content, Radial Growth) and environmental parameters (Temperature, Relative Humidity, Radiation). Such data are accompanied by additional stand-level parameters (soil moisture and temperature, Precipitation). The primary objective of our study was to enhance our comprehension of the ecological dynamics that drive patterns of forest resilience amidst a changing climate. Our study centered around two primary research questions. Firstly, how do spruce trees growing in contrasting microclimatic conditions respond to periods of drought? Secondly, can we discern a divergence in physiological responses that suggests site-specific adaptation of these trees? Thus, by combining physiological and environmental variables, we could characterize the physiological response of trees quantitatively. Our findings revealed a divergent response between the two sites, which can be attributed to the long-term adaptation of trees growing on drier slopes. Additionally, the insights gained from our research will be instrumental in devising adaptive forest management strategies, crucial for safeguarding the future of Norway spruce forests in the Alpine region.

Survival and growth of the same Picea abies genotypes along a transect through Europe

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Field measurements have been made on a large set of clonal Norway spruce trees planted at four sites along a latitude transect from south-west France (Bordeaux) to mid-Sweden (Uppsala). The sites were established in spring 2013. Three-year annual mean temperature has a range of 6.4 °C over the transect, which is similar to the maximum range of warming predictions for the coming century (IPCC 2013). In addition, two of the four sites are drier and two wetter allowing for studying the impact of water availability on temperature acclimation among the provenances and genotypes. The experiment is designed to have the same genetic material at all field site (~300 clones of east European and Swedish provenance, replicated 3-5 times at each site. This material gives us a unique ability to assess the relationships among tree provenance, traits, and temperature acclimation potential over a vast natural climate gradient. Results from field measurements from 2013 – 2022, covering the severe heat and drought year 2018 is included. The growth and survival responses of the genotypes were highly variable between sites indicate different sensitivities to heat and drought.

Swedish forestry in the future - the competitive effects of future tree species in mixed forestry under climate warming

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Mixed species forestry may become important for Swedish forestry in the future as a means to adapt to global change. In Sweden, average temperature is expected to increase by 3.2℃ by the end of the century. Therefore, research related to the productivity and competition of tree species in mixtures under climate warming is necessary. In addition, investigating the responses of other potential commercial tree species besides *Picea abies* and *Pinus sylvestris* to climate warming and their interactions with current commercial tree species in mixtures will be important for informing future management decisions. Several trial sites have been established in Sweden more than thirty years ago to understand the productivity of twelve tree species (i.e., both native and exotic). These sites provide useful information based on current climate and resulted in the identification of *Larix sibirica* as a potential commercial tree species in Swedish forestry. However, these ongoing research efforts will not be able to shed light on the question: how will this species respond to a warmer climate in Sweden and to what extent will this influence their interactions in species mixtures? Here, we will present results from a growth chamber experiment consisting of four commercial tree species (*Larix sibirica, Betula pendula, Pinus sylvestris and Picea abies*) in single species, two species, three species and four species mixtures under ambient and elevated temperatures (3°C). We will focus on how increased air temperature affects forest tree species productivity, their interactions with other commercial tree species in mixtures and their interactions with mycorrhizal partners. We particularly discuss shifts in the colonization of ectomycorrhizal fungi with various mixtures, as well as above- and belowground species complementarity and their responses to increased temperature.

The response of combined drought and heat stress on plant growth and carbon flow in a greenhouse study

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Anthropogenically-driven surges in abiotic stress frequency and intensity are among the major drivers of global shift in plant environment. Impaired plant growth often stems from the confluence of various stressors whose individual effects are difficult to ascertain. However, the accelerating impacts of climate change necessitate the understanding of plant growth in response to various stress factors. The purpose of this study is to investigate changes in the growth and carbon distribution patterns following the introduction of drought and heat stress in plants. To distinguish individual and combined stress impacts, treatments applied using discrete and combinative approaches. Height, root collar diameter, and biomass will be measured for plant growth, while carbon flow and distribution will be determined via stable isotope tracing. We will analyze which secondary metabolites the plants produce. We hypothesized that combined stress would produce new secondary metabolites, with more negative effects on growth and carbon distribution than individual stress. This study will contribute to the understanding of plant response mechanisms and survival strategies under stress in the future.

The SPRUCE Experiment: Cutting Edge Climate Change Research on Northern Forested Peatlands

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: The Spruce and Peatlands Responses Under Changing Environments (SPRUCE) experiment is an ambitious ecosystem-level experiment that is testing the response of high-carbon northern peatland ecosystems to increased temperatures and elevated carbon dioxide. The experiment is being conducted in a black spruce peatland in northern Minnesota at the USDA Forest Service's Marcell Experimental Forest (MEF). SPRUCE is supported by the US Department of Energy and is a collaboration between Oak Ridge National Lab, the USDA Forest Service and 100's of other scientists from across the globe. Northern peatlands are an ecosystem considered especially vulnerable to climate change and responses to warming and interactions with increased atmospheric CO_2 concentration are anticipated to have important feedbacks on global climate. SPRUCE is evaluating the response of the existing plant and soil communities to a range of warming levels from ambient to +9°C, with and without elevated CO_2, provided via large, open-top chambers. Belowground heating began in 2014, aboveground heating in 2015, and elevated CO_2 treatments commenced in June 2016. We anticipate running the experiment for 10 years. I will present an overview and some of the results of SPRUCE, including treatment effects on greenhouse gas production, soil processes, and the plant communities.

Tree drought and heat tolerance traits for climate resilient forests

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: Increasing frequency and intensity of droughts and heatwaves worldwide cause reductions in forest productivity, threatening the ecosystem services that forests provide and their carbon sequestration potential. As an example, in central and northern Europe, the summer of 2018 has exposed certain tree species to temperatures close to their thermal tolerance limits, in addition to severe drought stress. The exact individual role of drought, rising temperatures and vapor pressure deficit (VPD) in driving forest growth reductions are unknown, neither are the physiological consequences of heat and drought, but as trees need water for leaf temperature control, drought and heat tolerance might be strongly coupled. We study the interaction between drought and heat stress on trees and plants. We hypothesize that heat and drought tolerance are coupled i) on a global climatic scale as species-specific trait and ii) physiologically during acclimation to drought and heat. Two case studies will elaborate on these hypotheses. In the Mediterranean ecosystem of southern California, six plant species responded in different magnitudes to heat and drought stress. Drought tolerance increased with increasing temperatures, even in absence of soil water deficit, suggesting a physiological coupling between drought and heat tolerance. In a climate chamber experiment in southern Sweden, four important European tree species – *Pinus sylvestris, Picea abies, Betula pendula* and *Quercus robur* – were planted in pots and exposed to two different temperature and three different drought treatments. After acclimation of eight weeks, the trees were exposed to two consecutive heat waves with a two-week recovery period. Before and after acclimation and heatwaves, drought and heat tolerance indicators were measured, such as turgor loss point, photosynthetic thermal optimum and thermal tolerance. The results reveal the acclimation potential of plants and trees worldwide, and lead towards predicting acclimation potential and risks to future hot droughts. The study outlines the importance of considering the combined effects of drought, heat and accompanying VPD in assessing and predicting tree productivity, health and mortality during extreme environmental events.

VPDrought – a novel approach to disentangle atmospheric and soil drought in a natural Scots pine forest

T1.27 Response of forest ecosystems to global change: Learning from experimental manipulations and natural gradient studies

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Abstract: The intensification of droughts through rising evaporative demand (i.e., vapor pressure deficit or VPD) is a considerable concern for governments and societies because of their disastrous impacts on natural systems. For forests, ecosystem services such as wood provisioning and carbon sequestration are severely jeopardized by these changes, leading to significant uncertainties regarding climate regulation. Climate-vegetation models are not only in need of data on atmospheric and soil drought sensing mechanisms but are also critically challenged by insufficient understanding of the processes driving forest vulnerability to climate change. Only by deciphering the single vs. combined VPD and soil moisture effects will we be able to improve global predictions.

We apply a scale spanning approach to disentangle the processes affected by atmospheric (i.e., VPD) and soil droughts from the tissue to the tree and the ecosystem level. We set up the first atmospheric humidity and soil moisture manipulative experiment in a mature natural forest. We combine air humidity (and thus VPD) manipulation using a humidification system in the canopy of adult trees exposed naturally to high summer VPD and a below canopy through-fall exclusion system. The system is installed at the long-term Pfynwald irrigation experiment, which is since 2003 a pivotal WSL monitoring and experimental site anticipated to be near its tipping point with respect to climate change.

This experiment helps us understand how the soil moisture responses of trees, shrubs, and microbial communities are altered by atmospheric dryness from the tissue- to the ecosystem-level. This novel manipulative VPD and soil moisture experiment provides a critical empirical test platform to address the most critical questions in the context of climate impacts in temperate forests. The data will ultimately allow the development of novel predictive methods to assess climate change impacts on

forests. Preliminary data will show the effects of altered atmospheric and soil drought on adult Sots pine trees.

T1.28 Restoring degraded riparian ecosystems: Context matters

Assessing Tropical Riparian Zones Conditions By Blue Target Protocol

T1.28 Restoring degraded riparian ecosystems: Context matters

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Abstract: Environmental assessment protocols have demonstrated a good ability to assist in the management of actions aimed at preserving, conserving and recovering ecosystems. However, most existing protocols focus either on the terrestrial structure or on the aquatic landscape, not directly addressing the riparian zones, important areas for the stability of processes related to the hydrological cycle, contributing to the availability and quality of water from streams. The Blue Targeting Tool (BTT) - designed by Water Management in Baltic Forests (WAMBAF) project in Swedish forest areas - is a document with a binary structure and simple language that seeks to enable and promote the participation of many stakeholders of society in assessing the integrity of riparian areas through 4 evaluative sections: Conservation, Impact, Sensitivity and Additional Values. Given the success of this protocol in Swedish forest management areas, this project was structured with the aim of designing a tropical version with a focus on high gradient regions in the Atlantic Forest biome. The adapted version was applied in the state of São Paulo (Brazil), in 15 reaches of headwater streams belonging to the Corumbataí river basin. In addition to the protocols, 3 environmental parameters were collected to provide data on stream water, riparian forest and landscape conditions. With the objective of evaluating the consistency of the assessments, the participants in the application of the protocol were classified as specialists (ESP) and non-specialists (NES), totaling 254 evaluations (ESP=60 and NES=164). The scores obtained by applying the protocol showed consistent results between groups; where most topics showed similar choice percentages between ESP and NES (response difference ≤ 25%). The protocol showed a good ability to indirectly measure the structure of the riparian forest present based on calculated basal area values, grouping the study areas into classes with significant difference (p(median) < 5%) between them. The results obtained demonstrate the potential of this protocol in promoting integration between different stakeholders for the joint construction of a database for monitoring riparian areas. However, it is still necessary to engage more stakeholders and validate the protocol with scientific data.

Evaluation of ecological restoration efforts on riparian ecosystems in neotropical region: effects on water quality

T1.28 Restoring degraded riparian ecosystems: Context matters

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Abstract: The riparian forest is considered an important component for maintaining the dynamics and functionality of streams. Restoration of tropical riparian forests can have an equally significant effect on tropical streams and, consequently, is a promising tool for the restoration of tropical aquatic ecosystems and the maintenance of their ecosystem services. In neotropical regions, restoration of streams is carried out indirectly through forest restoration of riparian vegetation, without direct intervention in the channel. Likewise, knowledge about the impacts of stream restoration measures implemented at the channel scale is little known in these regions. This study aims to evaluate the effects of ecological restoration efforts on water quality riparian ecosystems in 15 catchments along a gradient of restored forests of different ages in southeastern Brazil. The basal area of the riparian forest was measured, using transect plots (25m x 10m) installed across the stream in each of the 15 catchments. In-situ measurements of water temperature and electrical conductivity were performed using the YSI ProODO optical dissolved oxygen and the YSI 85 conductivity. Laboratory analysis was conducted on water samples collected during the dry and wet seasons of 2022 to determine the concentrations of total dissolved carbon, dissolved organic carbon, dissolved inorganic carbon, total nitrogen, and orthophosphate (P). The results demonstrate that basal area was higher in older restored riparian areas compared to younger riparian areas. The older areas showed lower electrical conductivity values, with a median of 18.8 µS/cm, it also showed the lowest values of total dissolved carbon and dissolved inorganic carbon, both in the dry season and in the rainy season, with values of 4.14 mg/L and 6.39 mg/L, and 1.60 mg/L and 1.97 mg/L, respectively. For the dissolved organic carbon and orthophosphate (P) there was no statistical difference between the values of among the ages of the forests. We concluded that age of restored riparian forest was strongly linked to the riparian forest structure demonstrating that older restored areas was responsible to improve the water quality, showing the importance of restoration of degraded riparian ecosystems for the water quality in neotropical streams.

Improving forested riparian zones with green and blue infrastructure measures along small watercourse in Latvia

T1.28 Restoring degraded riparian ecosystems: Context matters

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Abstract: Forested riparian zones along small watercourses are vital for ecosystem health. These zones act as buffers, protecting and filtering water, stabilizing banks and reducing erosion. They support habitats for diverse species and facilitate species movement. Riparian zones regulate the hydrological cycle, controlling water flow and preventing floods, and contribute to groundwater recharge. They also provide recreational opportunities and enhance the aesthetic appeal of landscapes. Preserving these areas is essential for ecosystem sustainability and the well-being of communities.

The study area focuses on a 1.4 km section of the Tora River that runs through forest land in the north-central part of Latvia. The average width of the river in the study area is 2-4 meters, with a 50-meter wide riparian protection zone. The forest along the river has previously been managed without considering water quality, resulting in even-aged and over-dense spruce stands in close proximity to the water. However, the riparian zone also includes valuable habitats and structures that are important for biodiversity, such as standing and fallen deadwood and old oak trees from previous generations, which harbor several rare species.

To improve water quality in the stream, safeguard existing natural values, enhance environmental accessibility, and educate the public, green and blue infrastructure measures will be implemented in the area during the summer and autumn months of 2023. These measures will involve diversifying the riparian zone, thinning dense spruce stands, promoting the growth of broadleaved tree species, constructing a peak flow control structure in the ditch before it discharges into the Tora River, and creating a nature trail with informative exhibits about the processes occurring in the riparian zone.

Environmental monitoring has been conducted in the study area for the past two years in preparation for the planned green and blue infrastructure measures, and it will continue for several more years. This monitoring includes tracking various parameters across the entire territory, such as physical and chemical indicators of ground, precipitation, and river water. It also involves monitoring groundwater levels and air temperature on the riverbank (to assess shading) and analyzing the volume and composition of litter.

Restoring degraded riparian areas in Ghana: Key lessons for up scaling

T1.28 Restoring degraded riparian ecosystems: Context matters

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Abstract: Riparian ecosystems are critical for the provision of ecosystem services such as clean water, and are integral to the hydrological cycle. However, riparian areas in most developing countries including Ghana have been degraded by human-activities such as excessive water abstraction, unsustainable farming practices, excessive tree cutting, and uncontrolled sand mining. There have been efforts to restore degraded riparian ecosystems in Ghana, and there is the need to evaluate their progress to identify factors that contribute to their success or otherwise. The objective of this study was to provide new insights into field implementation of riparian restoration projects by compiling information and data from secondary sources in a database from 2010 to 2022 to identify key interventions, constraints and important lessons that could inform up scaling in the country and across the sub-region. In the last decade, riparian restoration projects have focused on both micro-watersheds and corridors that cover large geographic areas. Key interventions that have been implemented include natural regeneration, assisted natural regeneration, planting of indigenous tree species and agroforestry practices. It is noteworthy that most initiatives adopted participatory approaches involving non-governmental organisations, local communities and public sector agencies. Overall, the projects have contributed to improving the integrity of riparian areas, but constraints such as inadequate funding, inadequate knowledge on the choice of suitable species, destruction from animal browsing and seasonal bushfires, inadequate effective monitoring and evaluation, and the exclusion of groups including pastoralists remain. Some of the important lessons include the need for a strong collaboration and continuous engagement among key stakeholders, especially the traditional authorities and land users. Furthermore, local people should be empowered through training and capacity building activities, and incorporate local indigenous knowledge to guarantee local ownership. Promoting community water infrastructure and technologies to increase access to safe water, designing inclusive monitoring and evaluation frameworks, and dealing with threats from bushfires and animal browsing and applying decision-support tools for restoration are important lessons to implement riparian restoration projects on the ground.

Restoring Degraded Riparian Ecosystems in Sub-Saharan Africa: A Multi-Disciplinary Approach and Methodological Framework

T1.28 Restoring degraded riparian ecosystems: Context matters

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Abstract: Riparian habitats, usually found where land and water meet, are essential for the provision of water and for maintaining other ecosystem services including biodiversity. However, these ecosystems have been severely degraded by human activities including urbanization, deforestation, mining, and agriculture, particularly in sub-Saharan Africa. Using case studies from Ghana, where mining is a common activity in riparian forest areas, this paper analyzes the present level of knowledge regarding restoration techniques for damaged riparian ecosystems. The paper argues that successful riparian ecosystem restoration requires a multi-disciplinary approach, involving close collaboration between ecologists, hydrologists, social scientists, and other stakeholders.

The methodology for restoring degraded riparian ecosystems involves a multi-phase approach that includes initial assessment, planning, implementation, and monitoring. The assessment phase involves gathering baseline data on the extent and nature of the degradation, as well as identifying key ecological, social, and economic values associated with the ecosystem. The planning phase involves developing a restoration strategy tailored to the specific needs and goals of the ecosystem. The restoration strategy may include various techniques such as erosion control, riparian re-vegetation, and invasive species removal. The implementation phase involves carrying out the restoration actions identified in the planning phase, which can range from interventions such as habitat restoration, streambank stabilization, water flow management, and community engagement initiatives to larger and more complex projects. This phase requires close collaboration between various stakeholders, including landowners, government agencies, and community groups. The last phase involves monitoring to evaluate the success of the restoration activities, and using adaptive management principles to improve or revise activities where necessary. Monitoring may involve the use of various indicators, such as ecological health, flood control, and water quality. To conclude, restoring degraded riparian ecosystems is a complex process, and it should be implemented using collaborative and adaptive approaches that recognize the complexity of riparian ecosystems and the socio-ecological systems in which they are embedded.

Restoring Degraded Riparian Ecosystems: Case study Ondiri Wetland in Kenya

T1.28 Restoring degraded riparian ecosystems: Context matters

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Abstract: Ondiri wetland which forms the headwaters of River Nairobi; is a quaking bog undergoing degradation mostly due to anthropogenic activities thus reducing its ecological functions such as providing habitat for flora and fauna. The main objective of the study was to assess the levels and causes of degradation and undertake rehabilitation activities to restore its functions. The study was undertaken from 2018 to 2022. The specific objectives of the study were: to determine the impacts of land-use activities on the ecological and socio-economic functions of the wetland; to assess the pollution and degradation of water quality in the wetland; and to undertake rehabilitation activities using ecologically appropriate tree species and grasses. The survey purposively targeted the households bordering the wetland while for quantitative data, water samples were collected to monitor concentration of heavy metals and Total Dissolved Solids (TDS). Rehabilitation of the degraded sections of the wetland was undertaken using bamboo and indigenous tree species which were planted in three layers within the riparian zone. Planting layout along the riparian zone was as follows: layer 1: bamboo species adjacent to the water body and sedges, layer 2: assorted indigenous trees next to farmlands, layer 3: fruit trees adjacent to farmlands. Approximately 2.0 km of riparian land has been rehabilitated. The results of this study show that negative land-use systems such as intensive agricultural activities, unsustainable abstraction of water and poor sewage systems have affected water quality, quantity and reduced biodiversity. Results of three years' annual trend of cadmium, lead and chromium after rehabilitation technology intervention in the wetland revealed that cadmium level in year 1 was 11.12mg/l, year 2, 8.96mg/l and year 3, 2.9.mg/l. Lead levels decreased from 2.74mg/l to 2.68mg/l and 2.20mg/l, respectively whereas chromium levels remained constant at 1mg/l. All these levels of heavy metals are beyond allowable limits by World Health Organization (WHO). TDS remained at 900mg/l for the 3 years which is above WHO limits. The study recommends complete rehabilitation of the 3.3km perimeter using suitable grass and tree species. Urgent gazettement and protection of the wetland using multi-agency approach is also recommended.

Small waterways are neglected in production forestry operations across northern, high-latitude forests

T1.28 Restoring degraded riparian ecosystems: Context matters

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Abstract: High-latitude forests are home to vast freshwater resources and are among Earth's most intensively managed forests. An implication of this intensive management is the widespread yet undetected loss of intact headwater stream length and ecological function. Headwaters can represent 70-80% of the total stream length in forested watersheds and are essential for downstream water quality, water security, and biodiversity. Riparian buffers are the primary prescribed tool used in forestry as protection. Here we evaluated the loss of intact headwater riparian zones using national and regional-scale LiDAR scans of three of the top five wood-producing regions, along with records of every harvest in the five years before the scan. Our findings indicate that New Brunswick, Canada, and the country of Finland had more intact riparian zones following harvesting than the country of Sweden, with an average reduction in the tree cover of 9%, 24%, and 40%, respectively, when comparing unharvested and harvested riparian zones. This suggests that forestry operations in Finland and Sweden could better prioritise protecting small waterways. However, it is important to note that stream density in New Brunswick is 1.3 km/km^2 compared to 0.2 km/km^2 in Finland and 1 km/km^2 in Sweden, partly due to differences in climate, but also political decisions about what is worth protecting. There are differences in how each country defines and includes waterways on maps, with Finland classifying waterways like straightened streams or ditches differently in their stream database. This could explain why Finland appears to have fewer waterways than Sweden, when climate and topography are similar. If we assume that Finland has a comparable number of waterways as Sweden, there is the potential that they are not protecting riparian forests along 80% of their waterways. Similarly, the lower results seen in Sweden could be due to many waterways being assumed to be ditches, where no buffer would be required - even if upstream and downstream would be considered more 'natural'. In addition to implementing clearer riparian buffer policies in Sweden, identifying and defining the extent of the headwater stream network is crucial in protecting these fragile ecosystems and their downstream users.

The Rwanda Riparian Restoration Project

T1.28 Restoring degraded riparian ecosystems: Context matters

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Abstract: The small, landlocked nation of Rwanda is one of mountainous terrain, combined with intensive land use and production by the country's multitude of smallholder farmers. Steep slopes are intensively farmed, resulting in soil erosion representing a major threat to food security. Such erosion results in the siltation of rivers that interlace these mountains. Landslides, collapse of river banks and loss of adjacent farmlands is cited as a major concern for farming communities. Downstream, these rivers feed into dams which supply a significant portion of the country's energy needs through hydropower. Siltation represents cost and production issues for such hydropower production. Localized problems are also of concern in this agrarian country, with

Riparian buffer zones, representing the land adjacent to the rivers, varying in width of between 1 and 20 meters depending upon the size of the river, are classified as government lands, under the jurisdiction of the Rwanda Water Resources Board. Farming is prohibited within such lands, which are set aside for conservation and protection purposes. The cultural and socio-economic context of Rwanda results in a scenario where such delineations are respected by the surrounding farming communities.

Between 2019-2022 the Government of Rwanda, in partnership with implementing entity EcoPlanet Bamboo, undertook a pilot restoration project targeting the planting of 150km of such riparian buffer zones utilizing select species of non-invasive, densely clumping sympodial bamboo. Based on the success of this initial project and support of surrounding communities, the project is now being scaled up utilizing carbon finance across key upland watersheds, in partnership with district authorities and surrounding communities.

This presentation will discuss the approach, the multiple actors involved from government to implementation, to carbon financing, the context of this unique project and its replicability elsewhere, as well as the lessons learned to date.

T1.29 Risk-based surveillance for quarantine forest pests

A new approach for identifying future biotic threats using current pest distributions

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: Quantitative evidence plays a valuable role in helping to inform and build consensus in complex decision-making, such as the problem of ranking future biotic threats to a region. It does this by providing lines of evidence that are transparent, easily shared and repeatable. Examples of this type of quantitative evidence are the analysis of global trade pathways that may transport a pest from one region to another, or grouping regions by their communities of pests.

Here we present a new probabilistic method that uses data from the European and Mediterranean Plant Protection Organisation's global database to rank the future pest threats for a host tree species in a particular region. The method is based upon the analysis of similarities between pairs of pest distributions. The approach allows for uncertainties to be placed upon the pest threat rankings and measures of performance to be calculated using current pest distributions. The method is explained using examples of specific tree species in Europe.

Analysis of Quarantine Forest Pest Monitoring Techniques and Results in Croatia: A Five-Year Synopsis

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: Preservation of forest health and reduction of harmful impacts from native and invasive alien species on ecosystems are of critical importance in Croatian forest stands. Some of the non-native insect and fungal species have been recognized as potentially dangerous forest pests that could have devastating effects of natural forest ecosystems in Croatia.

We present a five-year synopsis of quarantine forest pest monitoring in Croatia, concentrating on the employed methodologies and monitored pests. The analysis incorporates traditional approaches, such as visual inspections, trapping, morphological and molecular analyses, conforming to the European Food Safety Authority (EFSA) guidelines. New methods and technologies are also used: small aerial vehicles or drones equipped with multispectral sensors provide a better insight into forest health and damage, and pests can be monitored over larger areas.

In the last five years we have monitored a range of quarantine insect and fungal pests in various forest ecosystems and on wide diversity of host plants. The results of our study provide valuable insights into the national surveillance scheme for invasive pests and pathogens, species of surveyed pests and their potential impact on forest health. The study highlights successful application of various methods, including visual inspections, trapping used as early warning system, use of UAV, morphological and molecular analyses, in detecting and identifying alien insects and fungal pests. The results from this overview serve as a foundation for the development of targeted strategies and informed decision-making for future survey programs, enabling the prevention of introduction and spread of forest pests and continued protection of forest ecosystems in Croatia.

Bio-economic optimization of surveillance for detection of priority quarantine forest pests in Switzerland

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: When designing surveillance schemes for several forest pests simultaneously, one must address several questions: (i) What is the optimal total yearly investment? (ii) Which of the surveyed organisms should receive more resources? And (iii), at which locations should these resources be invested? To answer these questions for a monitoring program for six priority quarantine and two quarantine forest pests in Switzerland, we used a bio-economic model. The model determines optimal type, number, and location of survey locations, accounting for differences in introduction likelihood, detectability, and spread rates across different locales. It relies on fine-scale trade data, information on host tree availability in urban and forest environments, human population density, eradication costs, and specific biological information for the respective pests.

The model gave an estimate for yearly investment in monitoring, and survey recommendations varied per species and locale. For two of the eight species, *Anoplophora glabripennis* and *Anoplophora chinensis,* the model deemed surveys by means of trapping as economically unjustified. For these species, the estimated probability of background detection by the public in case of an establishment was very high and spread rates comparably low, reducing the benefits from formal surveys. Instead, relying more on citizen “scientists” would be more cost-effective.

The model suggests where in Switzerland sampling would yield the highest economic benefit – with greater effort in areas with higher introduction risk and for species with low likelihoods of detection by the public and fast spread rates. We discuss how the model suggestions differ from simpler approaches and highlight the strengths and weaknesses of our bio-economic approach for risk-based surveillance monitoring.

Characterisation of foliar fungal endophytes and pathogens in Irish forest trees

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: In the last few decades, because of changing climate and increased international and intercontinental travel, the rate of detection of novel invasive plant pests and pathogens has been steadily increasing (Ramsfield et al. 2016). This is particularly true for tree pests and pathogens on the island of Ireland, where in the last two decades many new disease-causing insects and microorganisms have made their appearance and caused damage(O'Hanlon et al., 2020). To address this issue, AdaptForRes project was established. One of the aims of this multi-stakeholder project, which includes partners in academia, governmental institutions and industry, is creating a surveillance network capable of detecting the arrival of novel pests and diseases, following the example of past projects that have shown the efficacy of said method (Bulman, 2008).

For the first time island-wide several sites will be surveyed, both in person and through the assistance of forest inspectors. These sites were chosen according to their proximity to shipping ports, cities and/or sawmills, locations that increase the chance of novel pathogens to be introduced and spread. In order to validate the surveillance network, we are evaluating the community of foliar endophytic fungi of sessile oak (*Quercus petraea*), Scots pine (*Pinus sylvestris*) and Sitka spruce (*Picea Sitchensis*), three of the most important forest tree species in the island of Ireland. Twigs and leaves will be randomly sampled in each site, then they will be plated to isolate endophytic fungi which will then be morphotyped and identified through barcoding. From the first sampling round, more than 100 morphotypes were isolated and analysed, showing the potential presence of pathogens. Moreover, foliar samples will also be stored for metabarcoding, in order to reveal the presence of slow-growing or cryptic species. The data obtained through these surveys will be analysed in combination with other datasets to generate an optimised surveillance network. This work will also generate a collection of fungal isolates, pathogenic or not, that will be used for further research on a national and international level. We might also show the presence and distribution of pathogens that have already been reported or of novel ones.

Clues for inferring invasion routes of invasive wood-boring insects

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: Inferring the introduction routes of non-native species is useful not only for controlling their spread but also for preventing further invasions of other species with similar ecological characteristics. Most recent studies for estimating invasion pathways of alien species have used genetic analysis, as molecular ecology has progressed. But, much other information is available to estimate invasion routes. In this talk, we will introduce clues for inferring invasion routes and discuss their effective combinations.

In Japan, three wood-boring insect pests have recently invaded; the red-necked long-horned beetle (*Aromia bungii*), the Asian longhorned beetle (*Anoplophora grabripennis*), and the rusty-spotted long-horned beetle (*Apriona swainsoni*). These species have severely damaged and killed many broadleaf trees. Their original distributions are in continental East Asia. Although larvae of these species bore living host trees, they can become adults even if host trees die during their development. Therefore, these pests are able to be transported across the sea via wood packaging materials as well as living trees.

We used the following clues to infer the invasion routes of these three species; morphological variation, spatio-temporal change of damaged trees, the surrounding environment around the invaded area, import records of living trees in the invaded area, and genetic population structure. Morphological variations can suggest the origin of the organisms before developing molecular markers. Genetic population structure suggests the size of introduced populations and the diversity of sources. Spatio-temporal change of damaged trees allows estimating of initially established sites. The environment around the initially invaded area and import records of living trees are useful for inferring whether the species were introduced through live trees or wood-packing materials. For example, in *A. bungii*, the genetic population structure suggested multiple introductions into six non-continual invaded regions. In addition, the initially established sites were estimated to be near or in industrial parks based on spatio-temporal change of damaged trees in most of the invaded regions. From these clues, we inferred the invasion route of *A. bungii* as follows; wood packing materials infested by their larvae were imported from its original country and they were transported into various industrial parks in Japan.

Crop-based surveillance methodology: a new multi-pest survey approach.

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: The EU is continually exposed to the introduction of new pests and pathogens, increasing the need for greater phytosanitary effectiveness. EU Regulation 2016/2031 requires Member States to carry out surveys of quarantine pests in the EU and pests not yet listed. In this context, one of the main current challenges is to better organise surveillance campaigns, moving from pest-based surveillance to a crop-based surveillance strategy, i.e. monitoring several pests and pathogens at the same time, in order to reduce the survey effort while maintaining, or even increasing, the overall effectiveness of the surveillance programme. The European Commission asked EFSA to provide scientific and technical assistance in the field of plant health, including the transition to this new approach. One of the tasks of the ongoing EFSA-funded "Innovative Approaches to Survey broadleaved tree Pests and Pathogens" (IASPP) project is to support this approach by developing multiple surveys on broadleaved tree pests, identifying the best strategies that can be used across several organisms active at the same time. Based on the latest available literature, including the *ad hoc* prepared EFSA's pest survey cards (PSCs), key information on the host-parasite system was collected and pests and pathogens were grouped according to their phenological and physiological similarities.

Don’t be a Know-It-All: A Retrospective Analysis of Phylogenetic Host Range of Invasive Pathogens

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: Risk uncertainty limits the effectiveness of proactive biosecurity to avoid negative impacts on all types of forest ecosystems and people who depend on them. Although most invasive forest pathogens were already described species, the risk they posed could not be assessed before they became established, and their biogeographic origins, taxonomy, and genetics continued to remain uncertain even during and after the epiphytotics they caused. To mitigate the uncertainty, “sentinel” trees are monitored outside of their native range where they might be exposed to a new pool of pathogens, leading to pre-invasion host records. North American trees have been planted abroad for forestry for over 500 years, resulting in thousands of pathogen records. In order to assess the power of the sentinel approach, a retrospective analysis of pre- and post-invasion knowledge of phylogenetic host range was conducted for the much smaller number of pathogens that are known to be invasive in North America. Biogeography and host records were reviewed for an updated, comprehensive list of established invasive forest pathogens in North America, and a chronology was built for hundreds of thousands of records of North American hosts on other continents. A phylogenetic tree of woody plants was then used to a) standardize a chronology of pre- and post-invasion changes in documented host ranges and b) predict richness of invasive pathogens based on floristic similarity of invaded to original ranges.

Forest Biosecurity in Canada – an Integrated Approach

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: Canada's forest biosecurity policy and regulatory frameworks are governed under a number of international agreements, and federal and provincial legislation. Given the breadth and diversity as well as the ecological and economic importance of Canada's forests, forest biosecurity in Canada is constantly evolving and improving. Historical and recent examples of the impacts of non-native pest introductions and approaches to addressing incursions and introductions, illustrate both the challenges and successes of past, current and potential future collaborations between different jurisdictions. As most non-native species in forest ecosystems have been introduced accidentally, invasive species management programs in Canada focus on prevention. Prevention efforts in Canada emphasize pathways and commodities with historically high propagule pressure. Our knowledge of the pathways involved in the invasion of forest ecosystems in Canada is primarily based on border interception records, risk assessments for pests and pathways, surveillance programs, and participation in international research networks (e.g., the International Forest Quarantine Research Group). This presentation will summarize forest biosecurity in Canada and present some summaries of pest interception databases that are ongoing as part of a collaboration between the CFIA and CFS.

New invasive forest pests threatening the European and Mediterranean forests: an EPPO perspective

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract:
European and Mediterranean Plant Protection Organization (EPPO) is an intergovernmental organization created in 1951 by 15 countries, which now (2023) has 52 member countries. It works for and with National Plant Protection Organizations and widely engage experts from the EPPO region and beyond in its work.

One of the EPPO's missions is a cooperation between member governments to pursue and develop protection of plants and plant products against pests and the prevention of their international spread, especially their introduction into the EPPO region.

This mission is achieved by creating and managing an early warning system (EPPO Alert List), evaluation of the risks presented by emerging pests (Pest Risk Analysis), preparation of recommendations on pests which should be regulated in the EPPO region, and preparation of associated Standards (e.g., on diagnostics, phytosanitary measures).

In the presentation, an update will be made on the EPPO Global Database (preparation of dynamic datasheets on 300+ priority pests), recent additions of forestry pests to the EPPO Alert List, A1 and A 2 Lists, Pest Risk Analyses recently performed or reviewed by EPPO, and recent development of the EPPO Network of specialists working on surveillance, monitoring, and control of the Emerald ash borer, *Agrilus planipennis* in Europe.

Plant health surveillance in Switzerland: from legislation to implementation

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: Risk based plant health surveillance is critical for early detection of dangerous insect pests and pathogens and thus, for their successful eradication. While in agricultural systems, surveillance designs are mostly based on the well-known distribution of target crops, planning a sound protocol for forest ecosystems is more challenging. Switzerland shares a common phytosanitary area with the European Union (EU) and as such, introduced a legal obligation for plant health surveillance of so called "priority quarantine pests" which are shared with the EU. While guidelines and their integration within the legal phytosanitary framework are crucial, developing a plant health surveillance system that is scientifically sound, risk-based, optimized for costs as well as accepted by those responsible for its implementation, is vital for success. In order to achieve this, we developed a tailored approach for the specific needs of Swiss forests. The Swiss Federal Institute for Forest, Snow and Landscape Research WSL adapted a model for risk-based and cost-efficient plant health surveillance in Swiss forests, based on a model developed for the United States Department for Agriculture (USDA). Concurrently, we involved regional forest health officers in a three-year pilot programme in which we jointly developed, tested and optimized methods in the field for country-wide application.

Specifics of forest ecosystems aren't always considered in broad plant health aspects and it is thus even more important that international exchange and support in these matters is further strengthened.

The Forest Trapping Network: a new surveillance method for invasive forest pest species in the United Kingdom

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: The Forest Trapping Network (FTN) is a rolling programme designed by Forest Research to survey forests across Great Britain for a broad range of invertebrate pests over a five-year cycle. The FTN aims to: efficiently trap for Coleopteran pest species identified in the new EU Exit Regulations 2020, and any further pest threats identified in the future; ease logistical issues by consolidating current trapping programmes for individual pest species into a single network; and improve current trapping methods for quarantine pests. The FTN began with a series of pilot studies between 2020-2022 and was fully launched in 2023.

In each year of the five-year cycle, we will select 25 forests across GB. At each forest, we will install a cross-vane trap baited with a broad-spectrum attractant appropriate to the tree species in five forest blocks of different species (spruce, fir, pine, oak, and other mixed broadleaf). Individuals caught from target groups (including Cerambycidae, Scolytinae and Molytinae) which contain the target pest species will be identified to species level.

Pilot data from 2021/2022 suggested that none of the pests identified in the EU Exit Regulations 2020 had become established at any forest surveyed by the FTN. However, we detected the quarantine species *Ips typographus* in one forest. 11,373 individuals from target groups were sampled in total: the majority (98%) were members of Scolytinae (34 species). The remaining 14 species belonged to a range of target groups including four species of Cerambycidae, two of Molytinae and three species of Siricidae. We found one new county record (*Xeris pallicoxae*, a nationally rare woodwasp).

The broad-spectrum trapping employed by the FTN will aid early detection of invasive forest pests across GB, which are likely to become a greater threat as climate change facilitates range expansions. There is also potential for the FTN to be adapted to cater for additional regional requirements - for example, traps for *Ips cembrae* and *Ips sexdentatus* within the existing Pest Free Area in Scotland. Finally, the FTN is likely to expand our knowledge of the life-histories and native ranges of forest-dwelling insects in Great Britain.

Trade networks and alien species: global trends of introduction risk

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: In the last decades, globalization has dramatically increased the volume of transported goods and the number of commercial partners. As a result of this higher connectivity, many insect species have been unintentionally and repeatedly introduced outside their native ranges. Many of those alien species can become forest pests leading to huge economic impacts on non-native forest ecosystems worldwide. Depending on their traits, species can be moved through specific or generic pathways. While specialized insects feeding on single host plant species are often strongly associated with the flow of living plants, others are weakly associated with specific commodities, mainly depending on the total volume of trade.

International trade can be effectively represented by unipartite and bipartite networks. Networks can describe complex relationships and are constituted by nodes (i.e. countries) and links (trade routes). The complexity of international trade networks can be thus simplified using indexes, such as node-level metrics (e.g. degree centrality), network-level metrics (e.g. connectance and modularity). First, we want to investigate the role of network metrics in explaining patterns of global first findings of insects. Second, comparing imports and exports, and including temporal dimension we described current trends in trade data of high-risk pathways.

Our findings showed that, besides the total income, network metrics are a useful tool in explaining alien species introductions for single countries. Moreover, networks can describe global dynamics in international trade, such as globalization process or perturbations related to exceptional events such as wars or pandemics. The increasing connectivity of commercial route network and the opening of new markets, especially for those high-risk pathways, will lead to increase the risk of alien species introductions in the future. Given the current trends in the international trade network, more efforts will be needed to cope with alien insects in the coming years.

Using host groupings to rank future biotic threats before arrival

T1.29 Risk-based surveillance for quarantine forest pests

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Abstract: Invasive species are seen to be a major threat to both biodiversity and ecosystem services. Pest-risk analysis can be a key step to identify potentially invasive species for a given region, and prioritise preventative action for high risk species. Some common methodologies rely on mutual consensus among a large group of experts on a given topic, which can be logistically intensive and time consuming. Species distribution modelling is a tool that could inform the pest risk analysis process by quantifying the habitat suitability of a species in a region, and a resulting ranking of establishment likelihood of potential future biotic threats prior to arrival in a region. However, this quantitative approach is often infeasible due to the low availability of georeferenced occurrence data.

This study looks at overcoming this data availability issue by using host occurrence data to estimate the likelihood of establishment of forestry pest species. Occurrence data of a species' hosts were used with species distribution models to develop a ranked list of forestry pests that were most likely to establish in a region based on the environmental conditions where hosts are recorded. This approach is based on the hypothesis that for a pest and host to exist in unison, they must both be able to survive in similar environments.

Ireland was used as a test region for this new approach. For each pest a habitat suitability map of the pest's host group was estimated for Ireland using the SDMs. The distribution modelling was validated by using spatial cross validation, and AUC metrics were used to assess overall model performance. The produced maps were then compared to rank the risk of establishment by the relative habitat suitability between each pest's host group. Similarities to this research were found in the literature, namely used for quantifying disease risk by measuring the habitat suitability of disease vectors like mosquitoes. We discuss how quantifying the risk of establishment is important in whittling down potential biotic threat candidates for consideration when prioritising biosecurity strategies, and acknowledge how more recent advancements in computing power improve the accessibility and practicality of this comparison methodology.

T1.30 Securing multiple ecosystem services from mountain forests

Altitudinal distribution of Swiss stone pine (Pinus cembra) in the Styrian Alps as facilitator of silvicultural stability and resilience strategies

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Alpine forest ecosystems dominated by Norway spruce (*Picea abies*) in the Austrian Alps are facing increasing threats through bark beetle (*Ips typographus*) infestations. The situation calls for immediate diversification of the tree species spectrum in order to create stable and resilient forest stands for providing multiple ecosystem services for the presence. The project Dynamic Forest Type Classification in the Austrian province of Styria created an empirical database resulting from 1800 forest site investigation plots. Analyzed data show that in the Western Styrian Alps Swiss stone pine (*Pinus cembra*) may be dominant or sub-dominant in many forest stands across six forest vegetation zones (FVZ), currently from the moderate cool mixed forest zone up to the very cold conifer forest zone. This corresponds to an altitudinal gradient of more than 1000 m, ranging from about 1300 m up to 2300 m ASL.

The actual presence of Swiss stone pine (SP) in the analyzed forest plots could at least partly have been facilitated through the occurrence of *Rhododendron* species, which co-host *Chrysomyxa rhododendri*, a fungus which infects *Picea abies* and decreases its vitality in the alpine forest ecosystems. Together with forest management this might be one of the reasons for the presence of SP in such a wide altitudinal range.

In the current situation SP turns out to be a suitable alternative for the diversification of the tree species spectrum in Styrian and Austrian alpine forest ecosystems, as it can successfully grow on most of the given forest sites within the relevant FVZ. From acidic siliceous to loamy carbonate bedrocks SP is able to establish on forest sites as dominant or subdominant tree species. Additionally, tree species suitability of SP is high in the FVZ, with increasing growth in the lower FVZ. Both the high presence and suitability on various forest sites define SP as prominent tree species in alpine forest ecosystems for increasing their stability and resilience. For a successful establishment of SP, its competition with *Picea abies, Larix decidua* and *Abies alba* has to be silviculturally regulated in order to maintain its share.

Are landscape changes due to past disturbances making mountain forests less vulnerable to future threats?

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Mountain forests have been highly impacted by global changes. Natural disturbances, such as windstorm and bark beetle outbreaks are expected to increase, jeopardizing ecosystem services provided by forest ecosystems. In the Eastern Italian Alps, the 2018 windstorm Vaia has caused significant damages in mountain forests, creating a heterogeneous landscape of disturbed and intact forest stands. Subsequently, it triggered bark beetles disturbances that were further exacerbated by high summer temperatures and drought events. There is a growing interest in understanding how these newly formed forest landscapes will develop in the future, and how forest management influences these dynamics. We studied the future susceptibility of forest stands towards natural disturbances and climate changes in a landscape located in the Eastern Italian Alps highly affected by the Vaia storm. Our aim was to understand whether the impact of the windstorm on current forest structure will lead to an amplification or a reduction of bark beetle-mediated disturbances and future windthrows.

Using a process-based forest landscape model (iLand), we initialized a forest landscape using pre- and a post-windstorm forest conditions. We simulated forest successional dynamics under combinations of climate change and management scenarios (Business-as-Usual vs forest diversification) for the next 200 years, investigating forest's recovery and comparing of the susceptibility to future windstorm and bark beetle disturbances for the two landscape scenarios.

Results showed an overall increase of bark beetle disturbances and windthrows events for both landscape scenarios under climate changes. Nevertheless, simulated disturbance damages were higher for the pre-storm scenario due to high structural and compositional homogeneity. Differently, in the post-windstorm landscape scenario the spatial and compositional heterogeneity caused by the storm led to a reduction of future windstorm severity and bark beetles disturbances, especially when forest diversity was further promoted by alternative management. Our findings show that forest stands after a significant disturbance impact are more likely to resemble a more stable and resistant system, especially when applying forest interventions that improve both composition and structural heterogeneity. In the absence of significant disturbance events, present stands are highly vulnerable and current management practices are not capable to ensure resistant ecosystems.

Assessing recreational value of mountain forest: the case of Tržič municipality, Slovenia

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Recreation is an important forest ecosystem service in mountain areas contributing to the well-being of individuals and communities. Assessing the recreational value of forests in terms of recreational use includes the assessment of the various factors such as accessibility, amenities, visitor preferences, as well as the impact of the visit on forest and their long-term vital condition. This paper presents a comprehensive approach for assessing the recreational value of forests carried out as part of the project ForestEcoValue (Interreg Alpine Space). In order to conduct the assessment in an area predominantly comprising mountain forests, we use the municipality of Tržič (155 km^2 landcover: over 74% forest) as a study area and set the objectives of the assessment. We considered different user groups and conducted surveys to understand their preferences and expectations. Visitor numbers were quantified using visitor logs and monitoring methods to determine the demand for recreational activities. Accessibility and facilities, including trails and visitor facilities, were assessed for quality and capacity. In addition, the natural features and overall condition of the forest ecosystem were assessed as they enhance the recreational experience. The data analysis revealed trends and patterns that provide valuable insights into the recreational value of forests. The results show the importance for considering recreation in forest management, policy decisions and conservation efforts. Communicating the assessment outputs to stakeholders can raise awareness, support sustainable practises and facilitate decision-making processes. Overall, this summary highlights the importance of a multidimensional assessment approach for understanding and optimizing the recreational value of forests in a way that provides win-win solutions with the primary functions of the mountain forest in the area, namely timber production at lower elevations and protection against natural hazards at higher elevations.

Changes in Carbon Sequestration by Forest Biomass in Secondary Forests System based on 10 years Observation in Liaodong Mountains, China

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: The aboveground biomass (AGB) in forests plays an important role in the carbon cycle and climate change, has been widely recognized as evaluating carbon sequestration and carbon balance capacity of forest ecosystems. Accurate estimation of forest AGB is particularly important for studying the carbon cycle of the terrestrial ecosystem.

To estimate the accurate AGB in the forests, we established long-term fixed plots in three forest types, including secondary forest, Korean pine plantation and larch plantation. The plots area was set as 50 m×50 m. DBH, height and the death of each tree in the plots were recorded from 2012 to 2022. And then the total AGB was calculated by the allometry models, and the carbon sequestration from forest biomass was calculated at last.

The storage of AGB in secondary forest was the highest among three forest types, which increased from 45.25 Mg/ha in 2012 to 52.24 Mg/ha in 2022. But the increasement of AGB in larch plantation was the highest from 2012 to 2022. Furthermore, the loss AGB from death of trees has 2.27% of the percentage.

These results indicated that the highest carbon sequestration from biomass was found in the larch plantation in the secondary forest systems in Liaodong Mountains, China. And the dynamics of tree mortality should also be considered in carbon cycle of the terrestrial ecosystem.

Communities' Perception of Ecosystem Services on the Forest Rehabilitation of Abandoned Mine Areas in Korea

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Rehabilitation of mining areas can reduce various damages to ecosystems. However, the rehabilitation effects on the ecosystem services (ES) and contribution to local communities are not well known. It is important to clearly identify the ES beneficiaries affected by mining activities, to find out how the beneficiaries make a profit from surrounding areas in cooperation with local stakeholders, and to manage the rehabilitation areas for the ES that the beneficiaries want. This study chose 18 ES (4 provisioning, 7 regulating, 5 cultural, and 2 habitat services) based on TEEB (The Economics of Ecosystems and Biodiversity). Then 11-points Likert scale (0: unknowability, 1~5: negative benefit, 6~10: positive benefit), semi-structured surveys were conducted for 87 community residents (62 from Taebaek-si and 25 from Jeongseon-gun) to investigate social awareness and identify key services. The results from two local communities showed high awareness and demands mainly on cultural (mental & physical health, aesthetic appreciation, and recreation) and regulating services (local climate & air quality, and moderation of extreme events). These services were related to daily lives in local communities, provided positive benefits to them, and potentially improved future livelihoods of the residents. However, the average scores were limited to 6~7 points, indicating that the benefits to local communities were meager. The awareness of provisioning services was negative even if it provides goods and profit opportunities. This indicated a disconnection between local communities and provisioning services due to forest rehabilitation without considering local communities that traditionally relied on specific provisioning services before mining activities. Future forest rehabilitation in abandoned mine areas needs considering welfare of local communities for sustainable use of rehabilitated forest and enhancing ES. This study conducted only qualitative evaluation based on frequency analyses. Quantification and valuation of key ES are warranted in the future to promote ecosystem services from forest rehabilitation of abandoned mine areas. The perception of forestry and mining experts using Delphi method is also presented and discussed.

Ecological aspects of forest regeneration of large clear-cut areas in the mountains

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Changes in climate increases frequency of disturbances and severity of insect attacks also to the forests in the mountains of the Central Europe. Disintegration of the forest stands and rise in number and especially size of clear-felled areas in commercial forests in mountains bring difficulties in forest regeneration regarding harsh climate. To recover fulfilment of ecosystem services, the forests has to be renewed. Natural regeneration is often slow and in favour to limited number of species with pioneer strategy, more successively coping with the conditions. Frequently, regeneration of more diverse forests cannot be done without an artificial regeneration. To establish forest stand of more sensitive target species, two-phase forest regeneration using pioneer species as nursing (preparatory) trees is recommended. The paper will aim to highlight most important ecological aspects of (micro-) climate of forest regeneration in mountains and to formulate arising recommendations for forest praxis. Emphasis will be laid especially on temperatures (air and soil), air humidity and soil moisture. The parameters were monitored in young stands of different species (spruce, birch, dwarf pine), diverse conditions (age, plantation/forest density), positions (depth, height above ground, distance to tree, aspects). There were found differences in temperature regime, soil moisture and air humidity. For two-phase reforestation, the results e.g. show more favourable conditions for planting of target species in N, NW or W side of the crown of conifer nursing plants. The positions are less affected by temperature extremes, proximity to the plant increases air humidity. Because of the air temperature layering, injury by late frost can be reduced by planting of advanced (higher) seedlings. The synthesis of published personal data and results of new data analyses will bring more specific outcomes, which can help to secure multiple ecosystem services of renewed mountain forests successfully.

Effects of adaptive plantations on ecosystem service provision in Swiss forests

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Climate change affects forests, and the effects are expected to increase in the coming decades. Therefore, adaptive management strategies are essential to mitigate these effects. We used MASSIMO, an empirical individual-tree management scenario simulation model, to investigate the ability of Swiss forests to adapt their tree species compositions to changing climatic conditions. Specifically, we implemented an *adaptive plantation* module that enables, in addition to natural regeneration, the planting of tree species adapted to the expected future climate conditions. The plantation module is based on observed tree species mixtures from the Swiss National Forest inventory and on expert recommendations for current and potential well-adapted future plant communities. Thereby, future plant communities have been simulated based on current plant communities, soil information and climate scenarios. These plant communities depict the idealized tree species composition (including recruitment) in natural forests in balance with the dominant current or future environmental conditions. For planting, we considered both native and non-native species, including *Pseudotsuga menziesii*, *Cedrus atlantica* and *Quercus cerris*. Forest development simulations with MASSIMO, reflecting recent management practices indicated that changes in species composition were considerably slower than required to match future climate conditions. This was observed with both natural regeneration and adaptive planting. Therefore, to effectively address future climate challenges while ensuring sustainable timber production, protective function and other ecosystem services, Swiss forests may require additional support, such as shortening of rotation periods to faster regenerate or plant climate adapted tree species.

Forest management for ecosystem services and its financial compensation: the Swiss National Forest Inventory survey among foresters

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Most central European forests simultaneously provide multiple ecosystem services. These include wood production, protection from avalanches, rockfall and landslides, carbon sequestration, recreation and the provision of drinking water and habitat for a broad range of species. Forest management is necessary to provide and sustain many of those ecosystem services. Often, the management costs are at least partly covered by the revenue of the harvested wood or through subsidies, for example in protective forests against avalanches and rockfall. However, in many cases, management for ecosystem services is not compensated for. Prominent examples are interventions to maintain the safety for recreation in (peri-) urban forest, carbon sequestration or to promote forest biodiversity. Hence, new compensation schemes such as carbon and biodiversity certificates have been developed. The extent to which management interventions are conducted for the provision of ecosystem services other than wood production, and to what degree and by whom they are financially covered is only partly known at the Swiss national scale. We included a series of questions in the forester's survey of the Swiss National Forest Inventory (NFI) covering approximately 3700 sample plots to reveal the 1) forest area, on which management interventions for ecosystem services other than wood production has been conducted, 2) the funding body and 3) to which degree management costs are covered. Ecosystem services considered are protection of drinking water supply, protection of biodiversity, recreation, education, protection against gravitational natural hazards and carbon sequestration. First results point to an almost full coverage of protective forest management through cantonal and federal contributions. Management for drinking water supply, recreation and biodiversity promotion is more prevalent in public forests and is mostly covered by the (public) forest owner. The forest area, on which certificates support management is relatively small and the largest area is for carbon sequestration. We discuss challenges related to delimitating management interventions for different ecosystem services and the potential and risks of new funding schemes. As the sample covers a systematically distributed half of the Swiss NFI, covering diverse forest types and management situations, this survey is valuable for forest policy making in Switzerland and beyond.

Identifying climate change forest refugia in the central European mountains

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Ongoing climate change is altering the geographic distributions of plant species world-wide. In a warming world, terrestrial taxa are predominantly shifting toward colder locations, corresponding to higher latitudes and higher elevations, to track their climate niches. Consequently, during the last decades, a progressive decline of cold mountain habitats and their biota has been observed. The vulnerability of mountainous ecosystems urges to adapt current management plans to climate change in order to conserve and protect areas with strong biodiversity potential. In this context, refugia of forest tree species may play a fundamental role to sustain long-term population viability, enabling vegetation communities' persistence, minimizing the potential for deleterious species interactions and avoiding regional species extinctions. Therefore, we are aiming at predicting the location of forest refugia and characterize environmental factors leading to forest refugia occurrence under future climate change in central European mountains. To achieve this, we used fine-scale spatial datasets combined with an advanced individual-based forest model, iLand, allowing us to simulate future vegetation dynamics. Our results show the relative importance of key biotic and abiotic predictors (i.e. climate conditions, current vegetation composition, topography and soil attributes) for future forest refugia occurrence in the Central European mountainous ecosystems. These research outputs will provide a ground to quantify the vulnerability of forest refugia to altered disturbances (bark beetles outbreaks and windstorms) on forest refugia and critical information for improving habitats conservation efforts in central European mountains.

Managing European Alpine forests with close-to-nature forestry under climate change: Impacts on carbon sequestration and other ecosystem services.

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Close-to-nature forestry (CNF) has a long tradition in managing European Alpine forests and contributes to the continuous provision of key forest ecosystem services, such as protection against natural hazards. Climate change poses, however, new challenges and raises questions about the future applicability of CNF in the Alpine region: Is CNF a promising approach to adapt forests to the consequences of climate change? And can the current management practices meet the increasing societal demands towards alpine forests, including the potentials for climate change mitigation?

To answer these questions, we used the climate-sensitive forest-growth simulator ForClim to simulate forest development over 90 years for more than 11.000 ha across two case study sites representing a large biogeographic gradient (Karavanke mountains, Slovenia; inner-alpine Val Müstair, Switzerland). Simulations considered different climate scenarios and management strategies: current CNF management, CNF with increased or reduced management intensity, a strategy considering the planting of climate-adapted tree species, and two reference strategies with extremely intensive (clearcut) and no management. Impacts of management on the provision of forest ecosystem services and biodiversity were assessed by an indicator framework that also covers carbon sequestration in- and outside the forest ecosystem boundary.

Our results showed that CNF performs well in ensuring multiple forest ecosystem services and biodiversity in the long term. However, none of the strategies provides all objectives equally well; e.g., while biodiversity was increased by no management, protection and timber production jointly benefited from the adaptation strategy. The effects of climate change differed both, between and within the case study sites along environmental gradients. In the inner-alpine Val Müstair, ecosystem services were more sensitive to climate change than in the Karavanke mountains. Under the extreme climate change scenario, carbon sequestration potentials decreased at lower elevations in Val Müstair. This negative effect could be compensated to a certain degree by the strategy which fostered climate-adapted species.

To conclude, sustaining multiple ecosystem services and carbon sequestration potentials against uncertainties of climate change requires an adaptation of CNF by fostering climate-adapted tree species. Furthermore, a diversified management including protected areas is central for the conservation and enhancement of biodiversity in alpine forests.

Monitoring a forest landscape and their ecosystem functions after large fires in sub-Antarctic ecosystems

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Western Patagonia is recognized as one of most isolated regions, with large proportion of intact temperate old-growth forests, but is also recognized for having suffered largest fires in modern human history (1930-60), where over 3 million hectares were burned. Although more than half a century has passed since these large-scale fires, there is still no empirical evaluation of the land cover dynamics to establish the rate of forest loss and recovery, and its effect on the structure and function of the landscape post fires. We aimed to assess forest recovery processes post-fires and ecosystem functions at the landscape level over the 1984-2018 period in western Patagonia. A landscape ecology approach was applied through analysis of land cover dynamics focused on temperate forest. A set of ecosystem functions of regulation, support and provision was mapped through quantitative data and spatial proxies. The results showed that despite past fires the Coyhaique province landscape has maintained an area of ~ 79% unchanged during the last 34 years. The old-growth forest loss ~32,600 ha, and the secondary forest has increased by over ~69,000 ha during the 1984-2018 period. An improvement in the landscape function to regulate climate was observed through the potential carbon stock proxy, which showed an increase of 3.6% as a result of secondary forest recovery. Water supply function showed greater capacity in old-growth forests of mountains, while lowest capacity in more anthropized areas. In Conclusion, the balance of loss and gains highlights the recovery of native forests, being one of few temperate forest ecosystems from the southern hemisphere showing this process. Despite this forest recovery process, ecosystem functions do not recover at the same rate, highlighting that the greatest functional capacity of the landscape is generated in forests far from anthropized areas. The implications of the results obtained stimulate a socio-ecological and technical-political discussion to harmonize a sustainable use of an ecosystem poorly studied in western Patagonia.

Role of forest cover in supporting sediment retention ecosystem service using modelling and valuation in the Himalayan watershed

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Soil erosion is one of the most implicit risks that influence the ecology as well as economy of the Himalayan watershed. Soil and water quality in a watershed are adversely affected by soil erosion due to sedimentation deposition and export. Soil erosion is accelerated due to the diverse land use and fragile ecosystems in the watershed. However, forests and its density based on canopy cover plays a major role in controlling soil erosion and supporting sediment retention services in the ecosystem. The study attempted to comprehend the role of forest density and to evaluate the cost of the service in monetary terms for the sediment retention ecosystem services. Global dataset was used to assess the contribution of forest cover density class in sediment retention ecosystem service. The sediment retention service was estimated using InVEST Sediment Delivery Ratio (SDR) model. The basin was assessed for SDR for three forest cover types *i.e.,* Very Dense, Moderately Dense and Open Forest under two scenarios *i.e.,* with (F_1) and without (F_0) forest cover. The replacement cost method was used to estimate costs of soil loss. Furthermore, to understand role of forest density, the costs of sediment retention service were valuated for all three forest cover types (very dense, moderately dense and open forest) in two scenarios *i.e,* 'F_1' & 'F_0' The results indicated that very dense forest provides more sediment retention service as compared to the moderately dense and open forest. Also, it was found that the cost of sediment retention service was higher under F_1 scenario when compared to F_0 scenario. The results indicated that the potential contribution of the forest vegetation in avoiding soil erosion in the watershed was found to be 1.4×10^8 tons. The study concluded that the forests play a key role in supporting sediment retention service in Himalayan watersheds. Results indicates that sub watersheds with greater and denser forest cover are least prone to erosion. Furthermore, valuation methods integrated with advanced system analysis are useful for sustainable management, decision making and restoration practices in the Himalayan watershed.

The impact of alternative land use scenarios in the sustainabiility of protected mountain forests

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Native Forests in mountain regions are important elements for the tourism sector. Considering the ecosystem services provided, conservation in these forests is increasing popularity in the agenda of the governmental actors at different scales. In addition, combined housing crisis and tourism development impact in the real-estate market causing additional land-pressure into forestlands. In Argentina, the region of Patagonia is considered as one of the most attractive and visited tourism destinations in the country. Protected areas in this region are territories where conservation, tourism and traditional productive activities converge, increasing the pressure over the territory. In this context, our aim was to analyse the impact of different land-use future scenarios in a particular mountainous protected area in Patagonia as a case study. In order to do so, actors interests and power as well as sustainability indicators based on a pressure-state-response methodology using the SDGs targets as baselines, were used to develop a set of future scenarios based on the main land-use pressures affecting the territory: development of formal tourism, development of informal tourism, conservation intensification, forest sector growth and livestock expansion. Following a multivariate analysis we selected the main influencing indicators acting as tipping points to evaluate the level of sustainability of the hypothetic scenarios by developing land-use models. Results showed that the development of tourism can have different winners and losers depending on the formality of the activity and that the conservation scenario may not be the most sustainable if the cultural dimension of the study area is considered. Additionally, the optimal scenario for a high sustainable value may be a combination of characteristics of the different contrasting activities. Further, it is important to analyse the informal interests of actors since they may play a crucial role.

The Role of Deforestation and Forestry Interventions in Landslide Prone Areas : A Case Study of the Rift Valley Region, Kenya.

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Landslides pose a significant threat to Kenya's livelihoods and cause extensive social, economic, and environmental damage. The Rift Valley region has experienced numerous landslide incidents, largely attributed to deforestation. The steep terrain, vulnerable soils, heavy rainfall, and seismic activity in the Rift Valley make it highly susceptible to landslides. There is currently a lack of clear understanding regarding the role of forests in mitigating natural disasters and managing watersheds. To address this knowledge gap and develop effective interventions, a study was conducted in the landslide-prone areas of the Cherangany Escarpment in Elgeyo Marakwet County, Rift Valley. The study employed an exploratory survey design to gain familiarity and a deeper understanding of the problem. Data were collected through various methods, including Key Informant Interviews, Focus Group Discussions, rapid bio-physical assessment, and observations. Socio-economic data, both qualitative and quantitative, were obtained from the Focus Group Discussions and informal Key Informant Interviews. The collected data encompassed historical landslide occurrences, perceptions of landslides, land use and land use change, impacts of landslides, and existing and potential landslide remediation measures/policies. The results revealed an increase in landslide frequency in the Cherangany Escarpment over the past two decades, mainly attributed to intense rainfall. Although earthquakes can trigger landslides, local knowledge could not establish a direct link between earthquakes and landslide occurrences in the region. The study also found that the natural forests in the area were previously intact and biodiverse, with selective clearing and shifting cultivation practices by the local population. However, population growth led to increased encroachment on steep slopes for agricultural purposes, resulting in the loss of stabilizing trees and exacerbating landslide incidents. Fragile geology, combined with high rainfall and steep slopes, were additional factors contributing to the escalating landslide rates. To restore, rehabilitate, and conserve the ecosystem, protect human livelihoods, and preserve wildlife habitats, it is crucial to adopt and implement appropriate mitigation measures. These measures should include the restoration of the landscape with suitable tree species. By addressing deforestation, stabilizing slopes, and managing land use, the region can reduce the risk of landslides and protect the delicate balance of its natural environment.

Use of pioneer broadleaves for restoration and diversification of forests in the mountains of the former air-polluted region in Central Europe

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: The mountain forests in the border area among the Czech Republic, Germany and Poland were in the 1970s and 1980s heavily damaged by air pollutants (SO_2, NO_x, dust etc.). Although the pollution was later substantially reduced, restoration of diversified forests, able to secure multiple services, proved to be extremely difficult at the high elevations. The contribution summarizes the knowledge and experience with the use of pioneer broadleaves for forest restoration or diversification of coniferous stands. Attention is given to birch (*Betula pubescens* and *Betula pendula*), rowan (*Sorbus aucuparia*) and grey alder (*Alnus incana*). The effect of fertilizers applied to the planted trees was also assessed to provide the young stands with the initial nutritional support on acidified sites. The information provided is based on findings from plantation experiments established on degraded sites and on the experience of forest practitioners from the region. To evaluate the pioneer broadleaves, the survival rate of plantations, their height increment, radial increment and nutritional status were assessed. Soil chemistry was monitored as well. The main results are as follows: Birch seems a universal and resistant pioneer tree. However, to reforest mountain sites, it is highly important to distinguish between the tetraploid and diploid taxa. The tetraploid birches, belonging to *Betula pubescens* complex, should be preferred to the diploid *Betula pendula* to replant the harsh mountain sites in Central Europe. Rowan is more shade tolerant tree. Therefore, this species is suitable for mixtures with the target (climax) species or other pioneers. Grey alder should be used on climatically less exposed sites. On the other hand, grey alder responds well to fertilization and is beneficial on sites where the topsoil was degraded or removed by improper management or erosion. On the whole, the stands of pioneer broadleaves can provide the necessary ecological cover to stabilize the degraded habitats as well as to form an admixture to coniferous forests on exposed or degraded sites. More sensitive climax tree species can be introduced under the shelter of these nurse pioneer broadleaves. Protection of the broadleaves from the hoofed game is essential to ensure the success of the plantations.

Vegetation Density and Altitude Determine the Supply of dry Afromontane Forest Ecosystem Services: evidence from Ethiopia

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Mapping forest ecosystem services (ES) and identifying both natural and anthropogenic factors influencing their supply and distribution is a key step for developing a sustainable and climate-smart forest management plan. This is particularly important for the management of dry and mountain forests which are among the most threatened and neglected ecosystems globally. These forests are facing increasing demands for different land uses and ES with rising conflicts with each other.

This study identified, quantified, and mapped the spatial distribution of one supporting, three regulating, and four provisioning forest ES. Furthermore, a set of potential natural and anthropogenic factors influencing ES distribution in Desa'a forest, a dry Afromontane Forest in Tigray, Ethiopia, was assessed. The supply of some of the assessed ES depended on vegetation density, while the supply of others depended on woody species diversity, which resulted in a clustering of ES in two different geographical areas. Both natural and anthropogenic factors were important for explaining variations in the spatial distribution of ES. However, the most influential factors were vegetation density and altitude.

Our findings can contribute to the development of sustainable forest management strategies for dry and mountain forests by providing knowledge on the spatial supply of ES. The ES maps can be used as a basis for developing dedicated zoning plans for the study area which could improve forest management.

Vulnerability to climate change may affect ecosystem services in mountain ranges of Valdivian Temperate Rainforest in South-Central Chile

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Mountain forests are considered particularly vulnerable to the effects of climate change but deliver important ecosystem services. A previous study situated in Panguipulli, in the Valdivian Temperate Rainforest Ecoregion, in Chile, revealed that a high proportion of the population depends on forest ecosystem services to sustain their livelihoods. Specifically, wood, NTFPs, protection and scenic beauty are valued.

With the objective of evaluating the vulnerability of mountain forests in this territory, in 2013 22 plots have been established in an altitudinal gradient from 600 to 1250 masl. At the beginning of the study, a socio-environmental vulnerability index was generated on expert´s opinion. With the aim of validating this appreciation and being able to offer adaptation strategies, these plots have been monitored in dasometric and floristic terms, now reaching a period of 10 years.

Data has shown that the gradient covers 4 forest types, each associated with different ecosystem services and levels of vulnerability. Based on the data time series, each of them growth, mortality of trees, regeneration and indicator species of herbaceous plants were analized with the following main results:

Tree growth is highly dependent on site and exposure conditions, especially in higher altitudes. In the *Laureliopsis philippiana - Nothofagus alpina – Nothofagus dombeyi* forest type a high mortality was observed. Monitoring of herbaceous indicator species shows a slight increase of *Chusquea culeou* in all forest types, a native invasive bamboo species that is considered an indicator for forest degradation. On the other hand, an increase of *Pseudopanax valdiviensis* is observed in the two lower forest types, a climbing species typical of more mature forests in a state of growth and conservation.

Contrary to what was assumed in the initial study, the high mortality in the *Laureliopsis philippiana - Nothofagus alpina – Nothofagus dombeyi* forest type in combination with the bioclimatic stress, observed in recent years, might indicate a high vulnerability to climate change. As it is predominant in this mountain area, the consequences for the supply of ecosistem services might be important. For adaptation measurements it is necessary to understand the triggered dynamic, and continue monitoring if species move through natural regeneration.

Wild and semi-wild edible plants as coping strategies to conflict and climate-change-induced food shortages: Evidence from Tigray, Ethiopia

T1.30 Securing multiple ecosystem services from mountain forests

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Abstract: Introduction/Background: Global food insecurity is on the rise due to increasing conflicts combined with climate change-induced problems. Dry forests, on which millions of poor people rely, are well known for their provisioning ecosystem services like food. Hence, wild and semi-wild edible plants provide cheap, easily accessible, and readily usable food/nutrition alternatives in the fight against increasing food shortages and at times of conflict.

Objectives: The objective of the study was to identify and document wild and semi-wild edible plants that are used as coping mechanisms to conflict and climate-change-induced food shortages in Tigray, Ethiopia.

Methodology: An ethnobotanical study of wild and semi-wild edible plantswas conducted in Dess'a dry Afromontane Forest, part of the Eastern Afromontane Hotspote. Thirty key informants and 222 general informants were included in the study. Semi-structured interviews, group discussions and field observation were used to collect data. The obtained data were quantified using informant consensus, preference ranking and direct matrix ranking.

Result: A total of 68 wild and semi-wild edible plant species belonging to 55 genera and 38 families out of which forty (58.8%) wild species and 28 (41.2%) semi-wild species were collected. Fruits of *Opuntiaficus-indica* and leaves of *Amaranthusdubius* and *Capsella bursa-pastoris* were the most preferred edible plants. Age, gender, educational level, marital status, and key informant vs. general respondents were found to have significant differences in knowledge about these edible plants. Immediate consumption in the field, household consumption and supplementary food were the main uses of these plants. When other foods are ample these plants are used as snacks and as main foods during times of food shortage, famine and conflict. Drought, fuel wood collection, lack of good management, overgrazing, agricultural expansion and urbanization were the major threats to the sustainability of these plants.

Implication/conclusion: Wild edible plants are safeguards for poor communities during difficult times. The role of these plants in ensuring food and nutrition security is high, and thus better management of these valuable plants is essential. Further development of the species and these foods is also important.

Keywords: wild and semi-wild edible plants, forest management, sustainability, ethnobotany

T1.31 Silviculture of boreal forests in the face of climate change

19 Years After Experimental Silvicultural Treatments in Boreal Forest: Driving Factors of Natural Regeneration and Rhizosphere Microbiome

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: In Canada, clearcutting has been the dominant forest management practices, causing biodiversity loss, vulnerability of regeneration to natural disturbances and depletion of forest sources. Partial harvest is considered as a promising alternative to clearcutting system to integrate ecological, economical, and social objectives into silvicultural planning. However, partial harvest has not been widely adapted to the Canadian boreal forest yet and needs further evaluation for multidisciplinary research to adopt it to achieve sustainable management goals. The aim of this study is to evaluate the effects of partial harvests (50-75% of basal area removal) on conifer regeneration and soil microbiome in natural even-aged black spruce (Picea mariana (Mill.) B.S.P.) stands 18 years after silvicultural intervention. An experimental design with six sites (younger stands: 2,316 trees/ha, 79 years old; older stands: 1,272 trees/ha, 156 years old) and six silvicultural treatments (clearcut: 100% of basal area removal; seed-tree: 75%; close-selection, distant-selection, mini-strip: 50%; unmanaged as a control) was established by Canadian Forest Service in Monts-Valin and North Shore regions of Quebec. First, we counted and categorized all seedlings by species and height class in each micro-plot and assessed a dominant seedling for the growth features (age, height, diameter, reproduction type) and micro-environment (solar radiation, rooting substrate, soil properties). Second, we evaluated water use efficiency of two conifer seedlings (P. mariana, Abies balsamea) by analyzing stable carbon isotope ratio ($\delta^{13}C$) in one-year-old 5 cm branch cuttings. Third, the effects of the silvicultural treatments on soil microbiome (fungi and bacteria in bulk and rhizosphere soil) were studied by applying state of the DNA metabarcoding techniques and soil physiochemical analyses. This knowledge will be useful to better understand the dynamics and driving factors of regeneration of Canadian boreal forests after partial harvest to build decision making tools in order to adapt partial harvest to the sustainable forest management goals.

A Fennoscandian regional study of forest growth to answer the new climate and silvicultural challenges

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: In Fennoscandia there are several forest growth models (FGMs) used as support to research and practical management. They have been fitted mostly on stands managed with the dominant Rotation Forestry (RF) system and growing under the past & current climate.

There are two main changes in the forestry sector. First, the ongoing climate change is predicted to strongly affect Fennoscandia by increasing temperatures and changing precipitation patterns. Second, there is an increased interest in continuous cover forestry (CCF), which avoids the use of large clear-felling leading to uneven-aged stands. However, CCF data are still limited in Fennoscandia.

This will result in applying FGMs fitted on past conditions in drastically different ones, either in terms of climate or forest structures. Furthermore, models for RF usually rely on predictors that are meaningless or unknown in CCF stands, such as stand age or site index (SI, stand height at a certain age).

Our aim is to fit new FGMs that can be applied in the future climatic conditions and in all kinds of forest structures, for all Fennoscandia, by merging data from Finland, Norway, and Sweden. We will use the three National Forest Inventories (NFIs) for fitting, making the model more robust by employing a very wide range of data. We will use a hybrid modelling approach (combining empirical and process-based methods) for better climate-sensitivity. We will independently validate them on Long-Term Experiments (LTEs), collecting all the sparse data about CCF and other alternative structures together with the already abundant RF data.

We will investigate forest growth at a larger scale than it has ever been done for the region.

We will focus here on the preliminary analyses of growth dynamics in the NFI data. We will show: issues on merging data collected with the different systems; sources of additional interregional data; harmonization of the indices of forest productivity, to overcome the problems of SI for uneven-aged stands; and comparison of general forest growth dynamics across the countries and bioclimatic regions. These results alone will be extremely useful in understanding forest dynamics at the regional scale and providing a basis for future silvicultural recommendations.

Boreal silviculture in the face of climate change: A North American perspective

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Climate change is expected to have a disproportionately large impact on boreal forests both directly, such as through weather influences on tree growth, and indirectly through increases in disturbances including fire, insects and drought. In addition, the worldwide demand for wood products in increasing meaning that silviculturists and silviculture researchers will have to balance ever more demands on our forests. In the boreal forests of western North America, a variety of new operational silviculture practices and research projects have recently been initiated related to climate change adaptation. Operationally, climate based seed zones, tree breeding for both growth and climate resilience, nursery production techniques to promote strong root systems, and partial harvesting of mixed-species stands are all being done to meet combinations of climate adaptation and productivity goals. Silviculture research ranging in scale from individual tree to stand to forest landscapes is also underway. For example, thinning and competition control has been demonstrated to increase water availability and drought resiliency at the individual tree scale in lodgepole pine and mixed conifer forests. At the stand scale, new techniques for actively growing mixed-species stands with a range of tolerances are being developed from studies such as the Judy Creek trembling aspen – white spruce trial. While at the landscape scale, timber supply modelling is being used to evaluate the impacts of different silvicultural regimes, in particular differences in management intensity, stand density, and species composition, on wood supply and future disturbance risk. However, in many ways the science and implementation of climate smart silviculture is moving faster than forest policy which will need to change if climate adaptation silviculture is to be fully operationalized.

Can resilience to climate impacts be increased by promoting historic forest composition and structure?

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Climate informed adaptive silviculture strategies will often need to consider the ecological and management legacies that have shaped our current forests. In the sub-boreal forests of western Canada the composition and structure of many stands reflects historic diameter-limit cutting entries that targeted specific species but were not designed to achieve long-term objectives. These historic entries have produced complex multi-species stands; however, the composition of the stands have been considerably altered from their historic conditions. These management legacies provide both opportunities and constraints when trying to plan for future climates. Using the JPRF Adaptive Silviculture for Climate Change (ASCC) instillation as a case study we: 1) evaluate how diameter limit-cutting influence the composition and structure of the forest stands compared to historical conditions, 2) assess the vulnerability of the forests to climate change, and 3) appraise whether management designed to restore historic forest structure decreases sensitivity to climate change. The JPRF ASCC installation is large scale (200 ha), consisting of five silviculture treatments that provide a gradient from no-intervention (no-harvest control) to clear-cut, with three intermediate harvesting treatments (resistance, resilience and transition) that represent different degrees of forest retention. The forests are representative of Sub-boreal Spruce forests that are the dry and warm type of this ecotype. Climate change is projected to make the region warmer, but there is less certainty about whether the area will become warmer and wetter, or warmer and drier. The legacy of past management is that the forest is projected to be more susceptible to future drought and wildfire risk in the near-term, with the longer-term implications for climate sensitivity dependent on the realized climate trajectory. Restoration of historic stand structures is projected to temporarily mitigate some climate impacts, but with trade-offs between some forest services.

Climate Change Impacts on Canada's Boreal Forest: Advancing Silviculture through the Silva21 Research Program

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: The circumboreal forest, the world's largest land biome, is crucial for habitat, biodiversity, and renewable resources. Climate change introduces uncertainty for future forest dynamics and productivity. Canada, with 28% of the world's boreal zone, holds 270 million hectares of boreal forests vital for the forestry economy. The Silva21 research project aims to advance silviculture practices, particularly in the changing climate of various forest types, including the boreal forest. Projections generated for Canada's boreal ecozones reveal extreme changes. The boreal cordillera in the northwest will experience an 83% gain in mean annual precipitation, while parts of the boreal plains and boreal shield west will face significant drying and warming trends with a ten-fold increase in mean annual temperature and climate moisture index falling below zero, respectively. The boreal shield east will experience warmer and wetter winters despite increased annual precipitation due to 26% less snowfall. These changes pose risks of disturbances such as drought, forest fires, and pest outbreaks, leading to a decline in aboveground biomass and a shift to younger stands dominated by early successional species. Boreal species may seek refuge in northeast Canada in regions of greater moisture availability, potentially causing the deborealization of dominant species and increased mixedwood stands. Proactive forest management and silviculture planning are crucial to anticipate these changes in climate and forest structure and maintain stand production and carbon sequestration. Employing a no-regret approach to silviculture, multiple treatments should be applied at different stages of a forest's life cycle based on regional requirements. In addition to treatments this includes 1) observing stand attributes and climatic drivers of tree growth, as well as stand development and disturbances using remote sensing, satellite imagery and continuous forest inventory framework, 2) adapt region-specific silviculture that considers local cost-benefit analyses and operational realities, and 3) adapt strategies to future forest reality to promote long-term forest resilience or transition to future climate. Lessons learned from Silva21, including long-term legacy trials, will benefit other countries with similar anticipated projects and shifts in boreal regions worldwide.

Developing models of site index and stand characteristics for silver birch plantations

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Along with growing interest in biodiversity and forest health, research on the silviculture of boreal broadleaved tree species has recently taken on greater significance. The most important broadleaved tree species in Finnish forestry is silver birch (*Betula pendula* Roth). Although there are growth and yield models for naturally regenerated silver birch, models focusing on planted silver birch stands are still needed. The objectives of this research for planted silver birch were to examine the dominant height growth for site productivity and to develop the models of site index and stand characteristics in Finland. The Swedish field experiments were also examined to compare the growth and to validate the models fitted using the Finnish data. The data used for modeling included the long-term thinning experiments of silver birch plantations that were measured repeatedly over a 30-year period in most cases. Additionally, to increase regional coverage and sample size, we included field trials comprising both birch breeding materials and unimproved birches. The 43 experimental sites (354 plots in total) were located across southern and central Finland and included both former agricultural land and forest sites. The age range in the observations was 7–69 years, and the measurements were taken 1–9 times with a 5-year interval. The plots were thinned 0–4 times depending on experimental designs. The data for modeling were restricted to the stands thinned from below. The data for the Swedish thinning trial data were collected from 36 sites in southern and central Sweden. Because the dominant height differed between unimproved and improved birches, the breeding effect was included in a site index model using the Chapman-Richards function. In stand models for unimproved birches, the selected response variables were basal area-weighted mean height, basal area-weighted mean dbh, and stand basal area. The estimated site index, age, the number of trees, and thinning dummy variables were the most significant predictors when fitted using seemingly unrelated regression with mixed effects. These growth models will be implemented in simulation software, and they will provide more reliable estimates for the future development of planted silver birch stands.

Disturbance effects of alternative forest management strategies – landscape simulation modeling as a decision support tool

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Forest disturbances are a source of considerable uncertainty and economic loss for forest managers. Climate change is expected to intensify disturbance regimes and interactions between different disturbances, e.g. wind and bark beetle in boreal forests. A wide variety of measures to adapt to these uncertainties has been proposed, such as adapting species composition and rotation lengths or shifting to continuous-cover forestry. To understand the potential effects of these options and to guide forest managers, innovative tools are needed which consider the interactive effects of climate change and disturbances.

We used a landscape simulation approach (iLand model) to explore a wide array of alternative management scenarios for a landscape in Southern Finland. iLand is a process-based model, which includes dynamic disturbance modules and an agent-based forest management engine allowing for the implementation of detailed forest management strategies. We simulated adaptations of even-aged management (increased broadleaf shares, changed rotations lengths) as well as different spatial intermixtures of even- and uneven-aged management. We focused on the effects of wind and bark beetle disturbances, particularly the amount of wood affected by disturbance, comparing both historic climate and multiple climate change scenarios.

The simulations suggested notable differences between management scenarios, with disturbance impacts being particularly sensitive to rotation lengths and broadleaf shares. Bark beetle disturbances increased considerably under climate change. While reducing spruce shares and rotation lengths reduced these particular disturbance risks, it also reduced wood production. When intermixing even- and uneven-aged management, the spatial arrangement had an effect, with disturbance risks of a stand being affected also by the management in surrounding stands. Our results highlight the potential of using simulation modelling to explore a wide portfolio of management options and their effects on future forest disturbance risks and ecosystem services, particularly when it is necessary to consider trade-offs between multiple management objectives.

Establishing mixed conifer forests - a study testing different spatial planting designs and scarification methods

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Sweden has a rich history of forest cultivation and management. Traditionally, forestry has been focused on even-aged monocultures of either Norway spruce (*Picea abies*) or Scots pine (*Pinus sylvestris*) usually planted in a spacing of about 2 by 2 meters. However, alternative management methods are needed to increase diversity and decrease risks from abiotic and biotic threats and to improve forest growth while maintaining ecological functions. Establishment of mixed forest in boreal forest often rely on spontaneous ingrowth that complement planted seedlings but there is an increasing demand for knowledge on establishment of mixed species stands where several tree-species are planted. New research shows that seedling density, not the spatial planting design, is important for stem quality and production. In this study, we evaluate the early results from a regeneration experiment with focus on establishment of mixed forest with different spatial planting designs. Tree species treatment plots with either mixture (M) or monoculture of Norway spruce (S) and Scots pine (P) were planted in the spring of 2020 on three sites. For each M, S and P treatment, three levels of spatial design were further established, resulting in a total of nine treatments replicated on three blocks. The spatial design was created by three types of soil scarification with an excavator: Single seedlings (S1) planted in small mounds with bare mineral soil (0.5 m^2), groups with three seedlings (S3) in small inverse scarification patches (1 m^2) and groups with five seedlings (S5) in large inverse scarification patches (2.25 m^2). The hypothesis tested was inverse scarification would (i) make a smaller impact on the forest floor compared to mounding, (ii) increased seedling vitality and survival and (iii) improve seedling growth. Seedlings in the experiment were measured one-three years after planting, including height growth and eventual damages and vitality. In addition to hypothesis testing, results will be discussed in relation to eventual practical implications.

Forest management trends under climate change in Fennoscandia: potential effects on disturbance agents.

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: This literature review explores the relationship between natural disturbances and the impact of management practices on the susceptibility to damage. Natural disturbances, such as wildfires, insect outbreaks, and storms, play a vital role in shaping ecosystems. However, human activities and forest management decisions can either exacerbate or mitigate the effects of these disturbances. Understanding the interplay between natural disturbances and management strategies is crucial for sustainable land management and conservation efforts. Natural disturbances are becoming increasingly severe and frequent due to factors like climate change and land use patterns. Therefore, comprehending how management practices can influence susceptibility to damage is essential for developing effective mitigation strategies. Additionally, with growing human populations and increased utilization of natural resources, it is crucial to strike a balance between resource extraction and ecosystem resilience. This literature review aims to shed light on how management choices can impact the susceptibility of ecosystems to natural disturbances. We looked at different management strategies, such as prescribed burning, few or no thinnings, mixed forest stands, shorter rotations and selective logging among others, and how they can affect forest's susceptibility to damage. Proper implementation of these practices can reduce fuel loads, enhance biodiversity, and promote forest resilience. However, inadequate or inappropriate management approaches may increase susceptibility to disturbances. The outcomes of this research could have broad implications for land managers, policymakers, and conservation practitioners. Firstly, it can inform the development of adaptive management strategies that consider the potential impacts of natural disturbances and climate change. By identifying the most effective management practices, policymakers can implement policies that promote ecosystem resilience. Secondly, this review can contribute to the development of adaptive management approaches, landscape-scale adaptation plans, and informed decision-making processes, ultimately promoting the sustainable use and conservation of natural resources.

Future challenges for the boreal forest in context of climate change

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: The boreal coniferous forest belt is a forest ecosystem (Taigan) that stretches across the globe from northern Europe, along northern Russia (Siberia) across the Bering Strait to Canada and Alaska. The boreal forest covers approximately 15% of the Earth's land mass and constitutes the world's largest land-based carbon reservoir. The boreal forests plays also a very important role for climate mitigation and the possibilities to replace fossil-based materials or other materials that are not sustainable for the environment.

Growth in most boreal forest ecosystems is limited by plant nutrients and primarily nitrogen, but of course also by the harsh winter climate. Climate change will have a very large impact on the boreal forest both regarding forest growth and increased risk of various forest damages.

An earlier start of the photosynthetically active period in the spring will most likely mean that more sunlight can be used for photosynthesis production, which can lead to increased growth. There are also other factors that can affect forest growth, such as increased concentration of CO_2, soil nutrient availability, bud-burst/leaf unfolding and changes in precipitation pattern. Native tree species can use further north and new tree species can be introduced if necessary.

The other side of the coin is the forest damage because a warmer climate can favor pests but also some harmful pathogens. In addition, new pests and pathogens can be introduced and established as the harsh boreal climate becomes milder. Other concerns are increased frequency of extremely dry summers, winter storms and other extreme weather events.

In order to create a more sustainable and resilient forestry, we should consider the way we manage the forest. An adaptation of existing forestry methods and new ways of managing the forest will be needed in the future, without jeopardize the role of the boreal forest to mitigate climate change.

How Increased Understanding of Disturbance Dynamics Can Influence Silvicultural Systems in the Southern Boreal Forest

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: The boreal forest reaches its southern extent in the Great Lakes Region of the United States (Wisconsin, Minnesota, and Michigan). A major forest ecosystem within the southern boreal forest is lowland conifer or peatland forests, which are dominated by black spruce (*Picea mariana*) and eastern larch (*Larix laricina*) in the overstory. Conventionally these systems have been managed as even-age systems using a clearcut regeneration harvest, relying on a combination of natural regeneration and artificial regeneration through aerial seeding. The regeneration harvest occurs as the stands reach the stem exclusion stage of stand development. There is increasing interest in exploring alternative or disturbance-based silviculture to increase tree species diversity and structural complexity to meet goals that increase wildlife habitat and climate resilience. Our lab established hundreds of plots across black spruce and eastern larch forest communities to explore stand development and the influence of two of the major disturbance agents: eastern spruce dwarf mistletoe (*Arceuthobium pusillum*) and eastern larch beetle (*Dendroctonus simplex*). Both disturbance agents highlighted the potential for two-aged and uneven-aged management to increase diversity and complexity in these systems. For example, we found that black spruce forests have the potential to be managed using the triad approach with some areas managed using more intensive clearcut regeneration harvest, some managed more extensively using irregular shelterwood with reserve regeneration harvests, and some using active or passive reserves. Increasing the diversity of management within these systems can help adapt these forests to a changing climate and increase ecological and economic resilience.

Knowledge brokering and the historical legitimization of mechanized forestry

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: This presentation addresses knowledge as a policy instrument in relations to engage small-scale forest owners in contributing to profound societal transitions, such as the transition to a carbon neutral society. Learning from past transitions, the presentation is based on a historical case: the transition to mechanized forestry in the boreal regions of Sweden during the 1950s and 1960s. This transition aimed to enforce Swedish forest industry and was mainly expected to be implemented through a forestry act. As such, it was supported by state authorities and joint stock companies. However, it met resistance from small-scale forest owners, a group owning about half of the Swedish forest land. Instead of industrial silviculturalists, many of them identified themselves as farmers and were less keen to invest into chainsaws and tractors. In this context, we focus on how local forest owner associations used local knowledge campaigns to engage small-scale forest owners in adapting to mechanized forestry. We employ the concept of "knowledge brokering," describing a process of "translating" knowledges and interests to "enroll" non-expert actors to a certain cause. The analysis was based on readings of historical texts. We found various effects of knowledge brokering on the Swedish small-scale forest owners. First, knowledge brokering helped building a multimedia knowledge society around forest owners, including, for instance, film screenings, forestry dictionaries, forestry journals, and machine demonstrations. Second, it provided forest owners with technical know-how through recurrent technological trials. Third, it helped building an educational structure for forest owners, most noteworthy through the means of locally arranged study circle courses. Forth, it shaped the identity of "the forest owner" as something different from "the farmer." Fifth, and finally, it contributed with critical perspectives and cautious attitudes towards new technologies. We argue that knowledge brokering, ultimately, helped legitimizing the process of mechanization and, thus, contributed to the achieving of a profound societal transition in Sweden. We also argue that the climate transition can learn from historical cases, such as the mechanization of forestry, in combining the "hard" top-down policy instruments with "soft" bottoms-up instrument of knowledge brokering.

Mean wood cell age in trees and wood assortments

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: In Sweden and in many other countries felled trees are mainly used for timber and pulpwood. The top of the tree and the branches may be used for bioenergy, but this fraction are by some seen as unsustainable because it takes a rotation (80-120 years) to produce. Generally, the age of a tree means the years since it started to grow, but we know cells grow every year, and take up carbon. Thus a living tree has cells with age down to 0.

The topic of this study is to estimate the mean and max wood cell age per tree and per wood assortment. This question is relevant as forests are important for carbon sequestration and storage as well are as a source for bioenergy.

Growth functions in the Swedish planning system Heureka result in diameter at 1.3 m, height and tree volume. These data and taper functions are used for calculation of stem area each annual ring in at every decimeter of an average tree. Taper functions are also used for bucking in timber, pulpwood and energy wood. Then mean and max wood cell age per assortment are calculated. Also branches may be included (but are not in the following example).

Spruce (Pices abies) stand on a productive site in South of Sweden (SI Spruce 34 m at 100 years) may be clear felled at 50 years age. The volume mean tree with height 21.4 m and dbh 23.5 cm are bucked to timber to diameter 14 cm under bark at 11.0 m height, pulpwood from 11.0 to 17.3 m to diameter 5 cm ub, and then 4.1 m of energy wood. Mean age of wood cells - as well as carbon uptake - are for timber 14 years, for pulpwood 8 years and for energy wood 4 years. Corresponding max age for wood cells are 50, 25 and 11 years. Mean wood cell age for a tree are 13 years.

This results show it is important we include mean and max wood cell age as variables when describing trees and stands, specially in relation to carbon sequestration.

Mitigation and adaptation of carbon sequestration in multi objective forest management through co-creation with stakeholders (HIILIPOLKU)

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Forest management can affect how much carbon is stored in forest biomass and forest soils. Understanding of how forest management practices can be optimized for either carbon sequestration, water protection, or biodiversity has become more accurate. However, reaching the carbon neutrality goals, requires practice-validated strategies for the implementation of best-suited carbon sequestration methods in multi objective forest management.

The main objective of the HIILIPOLKU (https://www.luke.fi/en/projects/hiilipolku) is to create co-creation practices in partnership with local forestry actors (e.g. landowners, forest service entrepreneurs, NGOs) that nudge carbon sequestration in forests with simultaneous support for water and biodiversity protection. Practices will be based on research information and strive for socially just and rewarding implementation. The local, voluntary-based model of carbon sequestration by individual forest owners produced in the study is conceptualized and its applicability nationally in forest counseling will be evaluated.

The HIILIPOLKU study will be carried out in the Puruvesi catchment area, South-East Finland, boreal forest. The development of carbon stock in trees and soils under different forest treatment options are calculated and their change is estimated with Motti- and SUSI-model simulations in current and future climate conditions. The preliminary simulations results have, for example, shown that there will be more carbon sequestration when longer rotation period is chosen and respectively biodiversity increase when share of broadleaves trees increase in forest. The results of the carbon balance, wood production as well as impacts on the water quality and biodiversity will be applied stand level to the forest of individual forest owners and further utilized in co-creation process. The best feasible solutions and compensation strategies for socially and economically acceptable carbon sequestration in forests will be developed, while taking water protection and biodiversity into account.

Modelling Wind Damage in Swedish Forests: Resistant Edge Management

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Windstorms are predicted to increase in frequency and severity in Northern Europe as climate change develops. Critical wind conditions and their consequential damage threaten multiple services provided by forests (including monetary and biodiversity value) as well as impact human health and security (both directly and indirectly). High wind speeds can cause damage to forest stands through uprooting and snapping. The increase in damage experienced due to severe storm events over time may be due to changes in wind speed and direction, but is also likely influenced by changes in forest management. To better manage forest land to prevent losses from wind storms, we must understand what conditions make a stand susceptible to wind felling. In this paper, data from the Swedish National Forest Inventory was used to model the effects of site, stand and, more specifically, edge characteristics on wind mortality. We hypothesized that an edge's presence and edge's orientation will significantly influence the probability of wind-induced mortality within a stand. We further hypothesized that orientation toward the westerly to the southwesterly directions would lead to increased mortality. In order to test these hypotheses and analyze the influential factors on presence and quantity of wind damage in Swedish forests, generalized linear Mixed-Effects Models were created using R. A binomial model provided insights on factors that increased the probability of wind damage occurring in managed forest, with particular focus on the timing and spatial orientation of adjacent clearcuts. Additionally, a Gaussian model relating volume lost in windstorm events to spatial and temporal variables along with management activity was the basis for more in-depth investigation into the risks and expected losses under extreme wind conditions and currently common management regimes. From these results, a deeper understanding of current and future risks for mortality due to wind damage in Swedish production forests was achieved, allowing for more comprehensive management decisions for sustainable forestry practices.

Open Forest and Nature data in evaluation of the success of regeneration of pine, spruce and birch, and their mixtures

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: This study evaluates factors affecting the success of regeneration of Scots pine, Norway spruce and silver birch using open forest and nature data. Such knowledge would be used in silvicultural planning to diversify tree species usage, moving away from an overreliance on spruce, and to promote the establishment of mixed forests.

Regeneration treatments included monocultures of planted pine, spruce and silver birch and seeded pine, and their 50/50-mixtures created by planting. In addition, pine mixture was created by direct seeding and birch mixture by natural regeneration. Soil inversion was used for soil preparation in planting, whereas patch scarification was used for direct seeding. Field data was measured after the first growing season from the experiments established during 2020–2022, comprising of 284 sample plots (1000 m^2) in 18 mineral soil stands in Finland.

Several variables from open forest and nature datasets were used to predict the regeneration success at the seedling and plot level. Different terrain indices, e.g. topographic wetness (TWI), were computed from digital elevation models. Site and stand characteristics at final felling were obtained from Finnish Forest Centre datasets. Climatic and geological variables were downloaded from the datasets of the Finnish Meteorological Institute and the Geological Survey of Finland. Erosion risk and forest trafficability indices from open datasets were also incorporated.

Several variables were found to affect the regeneration success. TWI showed a positive correlation with the survival and height increment of planted spruce and silver birch. Stand volume at clearcut correlated negatively with the survival of planted pines and the number of pine seedlings in direct seeding. High potential evaporation in July decreased the number of pine seedlings regenerated in direct seeding.

Open forest and nature data could be used more efficiently at the regeneration phase. Information on site and growing stock and their variation within regeneration area would help support the selection of regeneration method and tree species at a micro-stand level by dividing a stand to smaller units based on e.g., soil properties and microtopography. These ongoing experiments will provide additional data in the future.

Red wood ant (Formica rufa group) survival in clearcuts can be increased by concentrating retention trees to an area surrounding the ant mounds

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Red wood ants (RWA) of the *Formica rufa* group are keystone species in boreal forest, where they act as ecosystem engineers, building large mounds of conifer needles and other litter materials. These mounds function as hotspots for carbon and nitrogen mineralisation, as well as for many different arthropod species that utilize them for protection and resources. It is known that RWA colonies can be negatively affected by logging, and these effects are thought to be amplified by climate-change. Recently there has also been an international call for developing forest management plans that take RWA protection into consideration.

Here we look at a concrete and easily practiced measure that could be quickly implemented through policy change. In Swedish law, forest owners are obligated to save a number of retention trees at a clearcut. The trees chosen could be the ones that stand next to RWA mounds, but would such measures be sufficient to have a positive effect? To answer this, we experimentally measure the effect of saving the trees next to a RWA mound during the final harvest.

In cooperation with Swedish state owned company Sveaskog, we mapped RWA mounds in forest stands that are going to be harvested by clearcutting. When found, all trees within a 10 meter radius from the mound were measured, as well as the mounds themselves. Every second plot was used as a treatment where the trees were marked to be retention trees, while the other plots served as controls. After the stands were clearcut, and a RWA foraging season had past, we measured the effect on RWA, both as mound abandonment, and as the conditions of the mounds and of worker health. Stands that were not cut at all served as a baseline measure.

Our results so far show lower mound abandonment and higher health at treated sites where trees were kept in the 10 meter radius plot around the mound. In conclusion, our results point to recommending forest owners and managers to concentrate retention trees to the vicinity of RWA mounds to protect RWA and their mounds.

Short-term effects of thinning on above-ground biomass in Scots pine stands

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Forests play an essential part in the mitigation of climate change consequences, since trees uptake CO_2 from the atmosphere through photosynthesis and store carbon throughout their life. Allometric functions derived from destructive sampling can be used to predict the variation in carbon storage. In addition to edaphoclimatic conditions, forest management practices, such as thinning, also have an impact on growth and biomass allocation patterns. Scots pine (*Pinus sylvestris*) is one of the most relevant tree species in Sweden and the world. Within this context, this study aimed to evaluate the short-term effects of thinning on above-ground biomass compartments (stem, needles and branches) and total biomass on Scots pine stands in Sweden. The study was conducted in Siljansfors and Jädraås, located in central Sweden. The experiment has four treatments: control (unthinned), thinning from below (25% of basal area removal), thinning from above (25% of basal area removal) and heavy thinning from below (63% of basal area removal), randomized within blocks. In total we have four blocks, two on each site. Destructive biomass sampling was performed before thinning and three growing seasons after thinning. Allometric equations were created to estimate total biomass, as well as biomass in the different above-ground compartments. Additionally, we will also showcase the seasonal variation and development of leaf area index (LAI) for the different treatments. We hypothesized that 1) individual trees in the same diameter classes in the heavy thinning treatment will have increased biomass growth, whereas 2) total stand biomass will be higher in the control treatment in comparison to the thinned ones, and 3) the reduction in LAI after thinning will still be lower in the heavy thinning compared to control after three years, but 4) in lighter thinnings LAI is again at the same level as the control.

Within-stand variation and its influence on thinning practices

T1.31 Silviculture of boreal forests in the face of climate change

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Abstract: Within-stand variation and its influence on thinning practices

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Abstract

The state of within-stand variation in boreal, coniferous production forests, and how it is dealt with in thinning operations, is a scarcely researched subject area. In fall 2018, we surveyed a series of Norway spruce or Scots pine dominated production stands scheduled for first commercial thinning. Here, we evaluated how within-stand variation was handled in the thinning operations and finally how the stands and subsequent thinning practice conformed with the thinning guidelines.

Within-stand variation in the yield attributes was evaluated in various ways and it was expressed using the Q_n scale estimator. Initially, yield attributes before and after thinning were compared using paired t-tests. At last, the thinning practice was evaluated before and after thinning by modelling the agreement with the basal area target as a function of stem density and dominant height.

Thinning reduced the within-stand variation in basal area, standing volume, and stem density, however, dominant height, quadratic mean diameter and basal area weighted mean height remained unaffected. Thinning had a short-term effect on within-stand variation as it returned to the pre-thinning state 10 years after thinning. Sample plots conformed more with the basal area target in the thinning guidelines with increasing dominant height and stem density, both before and after thinning. Only stands with high stem density and at high dominant heights (>16 m) agreed with the thinning guidelines.

The reduction of within-stand variation may increase the homogeneity in tree size but the reduction itself may produce future stands which contain little biodiversity. The consequence of the poor agreement with the thinning guidelines may be postponed executions of thinning, which in turn

increase the stands' susceptibility to wind-throw. Adapted silvicultural guidelines may be needed to promote early thinning operations.

T1.32 The biosecurity risks of international movement of tree seeds

Cydia inquinatana as a seed pest in an Acer platanoides seed orchard

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: To increase the resilience of boreal forests facing the changing climate the species selection used in artificial forest regeneration needs to be diversified. Norway maple (*Acer platanoides* L.) is one potential species for this in the Nordic countries. In Finland the species' natural distribution is limited to southernmost part of the country, but particularly in the warmer climate it can be planted further north.

The northernmost seed orchard (sv458, Turvala) of *A. platanoides* in Finland is situated in Punkaharju (61° 47' N; 29° 21' E), which is outside of the natural range of the species. In a seed harvest in 2020 X-ray radiography of intact seeds showed that some of the seeds were infested with an unidentified insect larva. The species was identified as scarce maple piercer (*Cydia inquinatana* (Hübner, 1799)) by a DNA analysis.

In September 2021 seeds were collected from 20 individual trees from the seed orchard to assess the prevalence of the insect. All seeds from three branches from each tree were collected and X-rayed to assess seed quality. Additionally fresh seeds fallen prematurely on the ground were collected from 4 circular $1m^2$ plots around each of the 20 trees and similarly assessed. The DNA of 68 insect larvae found in the seeds (half collected from the crowns and half from the ground) was extracted and sequenced.

The DNA analysis confirmed the insect species to be *C. inquinatana.* Larvae were found in 2% of the seeds collected from the crowns and an additional 9% were destroyed by them. In the seeds collected from the ground, the percentages were 11% and 30%, respectively. 74% of the seeds collected from the crowns were healthy and viable according to the radiography, whereas 39% were such on the ground. According to statistical analysis there were no differences in the proportion of larvae infested or damaged seeds among the trees.

The results show that seed specialist *C. inquinatana* – whose only known host species in Finland is *A. platanoides* – is able to cause seed damage in a seed orchard located outside of the tree species' natural distribution range.

Detecting fungal pathogens in forest nurseries: seedborne fungal communities and foliar fungal communities of nursery-grown Pinus sylvestris seedlings

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: Fungal infections can have high economic impact in the production of forest tree seedlings, especially in case of intensive management practises (e.g. extensive monocultures, dense cultivation systems, shortage of beneficial organisms). Fungal pathogens are often controlled with different management methods, including cultural methods and fungicidal applications. Better knowledge about local fungal communities, especially common pathogens, would improve preventative and directed control methods and ultimately reduce the use of chemical treatments. In this study, we investigated (1) fungal communities associated with seed material of *Pinus sylvestris*, *Picea abies* and *Larix sibirica* from different origins used in Swedish forest nurseries and (2) the seasonal dynamics of foliar fungal communities associated with nursery-grown *P. sylvestris*-seedlings. Additionally, four microbial treatments were tested to investigate possible effects on seedling growth and disease control. Treatments and sampling of healthy needles were done every third week during one growing season. DNA was extracted from (1) seeds and (2) needles, followed by amplification with fungal-specific primers and high-throughput sequencing of the ITS2 region. Results showed a clear separation of fungal community composition on seeds of different tree species and a gradual geographical separation of different seed origins. The fungal pathogens *Sydowia polyspora* and *Cladosporium* sp. were found on all seed samples, while *Ophiostoma* sp., *Phoma herbarum*, and *Sirococcus conigenium* were among the most abundant species. On *P. sylvestris* seedlings, the results showed large changes in foliar fungal community composition over time. *Phoma herbarum*, *Cladosporium sp*., and *S. polyspora* were among the most abundant species on seedling needles. A low number of disease incidents were reported (overall infection rate < 0.6%). However, infection of *Diplodia sapinea* were found during the study period. Microbial treatments were not found to have either a positive or negative impact on seedling growth or survival. In this study, we found the same fungal pathogens to be highly abundant on seed material as well as *P. sylvestris* seedlings. Provided information on fungal communities, especially occurrence of fungal pathogens, from both seed material and nursery-grown *P. sylvestris* seedlings is relevant to improve preventative and directed control strategies of fungal diseases in forest nurseries.

Environmentally friendly seed treatments to reduce pathogenic fungi in conifer seeds

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: The absence of pathogenic fungi in seeds is critical for forest regeneration to produce healthy plants for future forests. Our previous work has shown that tree seeds contain a wide variety of fungi, including plant pathogens. One of these fungi found in Swedish seed orchards was *Diplodia sapinea* - a serious fungal pathogen of pines that causes shoot blight and crown dieback. This fungus has a very plastic lifestyle; it can exist for many months to years as an endophyte or latent pathogen, and becomes active following stress (e.g., drought) or other conditions that affect tree vigor. There is a need to better control infestations of collected and stored seed to minimize the introduction of *D. sapinea* and other pathogens during plant propagation in reforestation operations. Treatments such as heat or UV-C light are options that can be applied to seed that may reduce the incidence of *D. sapinea* and other fungi in seed, but they have not been widely tested on forest tree seed, and the effects of such treatments on tree seed fungi (including *D. sapinea*) and seed germination are unknown. In this project, we assessed germination and fungi associated with *Pinus contorta*, *Pinus sylvestris* and *Pseudotsuga menziesii* seeds, with a specific focus on *D. sapinea*, before and after the UV-C light treatments (one and three times using CleanLight machine) and heat treatment (55°C for 8 hours). Fungal populations were assessed using an RNA metabarcoding approach to identify and quantify viable fungi in seeds, as targeting only viable fungi is important to accurately assess the efficacy of treatments. Additionally, the amount of viable *D. sapinea* present in the seeds was specifically tracked in the different treatments using RT-qPCR. Ultimately, this project provides management options and allows to mitigate the risk of introduction and spread of *D. sapinea* and other fungal pathogens with seeds used in reforestation nurseries.

EUPHRESCO project COSEPATH, are seeds a potential pathway for pests and pathogens and a risk for future forestry?

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: The introduction and spread of harmful organisms have important economic and ecological consequences. Traditionally, tree seed material has been considered a relatively low risk pathway for the movement of exotic pests and pathogens, although there is a growing awareness that the risks are only poorly understood. Spread through the movement of infected seed may be one of the drivers for the emergence of diseases such as pitch canker caused by *Fusarium circinatum* on pine and Douglas-fir, Neonectria canker caused by *Neonectria neomacrospora* on fir or Sirococcus blight caused by *Sirococcus* species on a wide range of conifers. The objectives of the EUPHRESCO project COSEPATH were (i) to gather current knowledge on seed borne pathogens of conifers; (ii) to generate data on the movement of conifer seed, focusing on the most traded conifer genera and/or species; (iii) to compare and run 'in parallel' testing of seed lots using the traditional and molecular methodologies by different laboratories with the aim of harmonising methodologies for the detection of pathogens. Information generated from this project provided sound scientific evidence of seed borne fungi that could be useful to professionals (nurseries, producers, foresters, importers), policy (government), scientific community (researchers) and for any interested party. At the same time, the project highlighted the gaps in knowledge that will need to be addressed in future studies to minimise risks of introducing pests and diseases through seed movement and trade.

From eco-evolutionary perspectives to pest risk assessment in seed-borne insects: a literature review

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: Plant-insect interactions have provided for decades many ways to understand how some species affect the distribution, the abundance, and the evolution of others. Because they affect the number of viable seeds available for plant recruitment, seed predators have received considerable attention from ecologists for the influence they may have on plant demography, spatial distribution, diversity and evolution. Considered as the most important seed predators during the pre-dispersal phase of seed development, the success of insects in the exploitation of the pre-dispersal niche primarily rely on their flexibility in synchronizing their life-cycles with the ephemeral availability of seeds on their host plant, and on evolved strategies for coping with the highly variable and unpredictable seed resource in both space and time. Besides their ecological interest, cone- and seed-feeding insects caught the attention since the first half of the 1900s as serious pests of seed crops for afforestation after tree harvesting. Their economic impact even increased when seed orchards were established in 1950-1960, and they have remained so far a serious threat for the ever-growing need of wood for a variety of products as a cause of seed deficit in the newest seed orchards. Here, we will review the ecological and risk assessment implications of insect pre-dispersal seed predation in forested ecosystems. We will discuss how tree-insect seed predator interactions illustrate key mechanisms of animal-plant relationships and their potential consequences on invasion risk. We will also discuss seed deficiency issues for reforestation and possible management aspects for seed orchards.

Fungal pathogens in Norway spruce seed production: incidences and causation.

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: Swedish forestry is sustained by planting about 200 million Norway spruce (*Picea* abies) seedlings every year. Most of these seedlings come from seeds originating from seed orchards, which have been established to transfer the genetic gain in growth and yield achieved through plant breeding since the 1940s. However, today there is a deficit of seeds coming from Swedish seed orchards because of irregular flowering and cone set, but also due to pest and pathogen infections. Norway spruce buds and seeds are colonized with a wide range of fungal species. We have used high-throughput sequencing to investigate the species composition in buds and seeds from Norway spruce seed orchards. A genetic locus in Norway spruce associated with presence/absence of *Thekopsora areolata* — the causal agent of cherry spruce rust, a major pathogen of cones was identified with genome-wide association mapping. Furthermore, to investigate the reproduction mode and population structure of this pathogen, newly developed microsatellite markers and a hierarchical sampling strategy were used. From one location in Norway, one location in Finland and five locations in Sweden, one aecium per infected cone was analysed. In addition, multiple aecia per scale and cone were sampled at two locations in Sweden. The results show an overall high genotypic diversity, and at country and location levels no genetic structure was found which indicates high gene flow and random mating in *T. areolata*. However, at the cone/scale level multiple identical genotypes were found. These results suggest that *T. areolata* has long distance spore dispersal in Fennoscandia with common recombination events and clonal or vegetative spread in cones and scales. Furthermore, the genome of *T. areolata* was sequenced and assembled. Analyses of the gene expression of two spore types, urediospores and aeciospores, were performed.

Mycobiome research for safer international tree seed trade

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: Tree seeds are generally regarded as a pathway with a low risk of introducing plant pathogenic fungi. Consequently, seed movement is generally not regulated from a phytosanitary perspective, despite evidence of certain harmful fungi, such as *Diplodia sapinea* or *Fusarium circinatum*, having been introduced to new areas through the importation of seeds. Additionally, recent studies have revealed significant levels of infection and diversity among fungi, including pathogens, associated with seeds and indicated that tree seeds are a pathway of introduction for potentially pathogenic fungi. Here we present the outcomes of extensive research conducted to analyze all fungi, including viable ones, associated with traded tree seeds and seeds obtained from botanic gardens. Through traditional plating as well as RNA-based and DNA-based high-throughput amplicon sequencing, we characterize the diversity of these fungi, identify the main factors influencing their species composition, and investigate the vertical transmission of tree seed-associated fungi. Our findings confirm that tree seeds harbor a wide range of fungi, some of which have the potential to harm plants. Furthermore, the composition of fungal species appears to be primarily influenced by the species of the host tree, likely due to the prevalence of vertical transmission. These results indicate a significant risk of introducing and establishing seed-borne fungi in new environments, emphasizing the importance of further studies of the spread and impact of these fungi. Moreover, enhanced risk assessment and management strategies are necessary to mitigate the phytosanitary risk of tree seed trade effectively.

Seed pathway of tree pest dissemination: gathering knowledge to improve forest health management

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: The Earth is not only a blue planet, but also a green one, with forests covering around 38% of habitable land surface. However, like any other crops, forest health is threatened by pests whose impact varies greatly depending on the tree species, management practices, and regions of the world. In a context of global trade, the transport of infested plant materials is a major factor in the spread of organisms to new territories, which can be the source of emerging diseases. It is critical to deploy strategies to limit this from happening. All around the world, regional plant protection organizations play key roles to promote phytosanitary measures or regulation. Identifying pests and their vectors is a first step towards risk analysis, and international initiatives are bringing together research results on the role of seeds as vectors of pests. The International Seed Testing Association (ISTA) has a long history in promoting uniformity in seed quality evaluation, as illustrated by the activities of its technical committees on forest tree and shrub seed (FTS), and seed health (SHC). Among these, ISTA contributes to increase our knowledge of the diversity of seed pests and to develop suitable detection methods. One of such a tool, the ISTA Reference Pest List (ISTA-RPL) is a repertoire of seed-borne pathogenic organisms in about 70 plant species, including a dozen of forest trees. It aims to inventory, based on scientific results, if these pests can (or cannot) be transmitted vertically or transferred in the environment under natural conditions, making seeds a vector of dissemination. This literature resource may be a valuable source for risk assessors and policymakers in their goal to evaluate the need to regulate pests or not. It also opens avenues of R&D work by seed companies, academic laboratories, or industry to develop diagnostics, detection methods, or treatments.

Seed-Borne Diseases as Potential Biosecurity Risks in Agroforestry Systems: The Case of Grevillea robusta and Moringa oleifera in Kenya

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: Tree seed is the most commonly used forestry propagation material globally. Most seed-borne pathogens that include fungi, bacteria and viruses are found on the seed coat, inside the seed or in debris and are undetectable through visual observation. Seed exchange also transfers seed-borne pathogens and pests and poses serious biosecurity risks since they are broad spectrum and infect many plant species, animals and sometimes humans. Seed-borne diseases and pests further cause food insecurity in developing countries by causing severe postharvest losses and seedling mortality in the nurseries and on farms. *Grevillea robusta* and *Moringa oleifera* are popular agroforestry species with multiple benefits whose seed is moved widely across the East and Central African region. This study determined important seed-borne pathogens and insect pests affecting the two tree species and developed protocols for their germplasm health testing. Standard International Seed Testing Association (ISTA) seed health testing methods were used to test seed lots of five provenances of each tree species. Three replicates of four hundred seeds from each provenance were tested using standard blotter test and agar plate methods to detect seed-borne pathogens while insect pests were detected visually and through microscopy. The most prevalent pathogenic fungi isolated were *Fusarium sp*. At 13.5% on *G. robusta* and 11.25% on *M. oleifera*. The average occurrence of other fungal genera isolated from both tree species were *Aspergillus sp*. (11.5%), *Penicillium sp.* (10.5%), *Botryosphaeria sp*. (7.5%), *Phoma sp.* (7.0%) and *Alternaria* sp. (2.5%). These pathogens are known to cause postharvest seed rots and also field losses worldwide through seedling rots, blights and deaths. *Pestalotia sp.* was only isolated from *G. robusta* seeds. Isolations from untreated seeds used as control in the laboratory analysis included two more species; *Rhizopus sp.* (4.5%) and *Cladosporium sp.* (3.75%). This study led to the development of seed pathogen detection protocols for the two trees species in Kenya. The protocols together with sensitization of stakeholders on the potential risks posed by seed-borne pathogens will be part of biosecurity and phytosanitary measures to facilitate exchange of quality and disease free tree seed for forestry and agroforestry systems to reduce associated losses.

Seed-borne fungi detected on conifer seed and the potential biosecurity risk for future forestry

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: Seed-borne pathogens of forestry species have not been well studied, despite increasing concern about global trade and biosecurity. To investigate the presence of potential pathogens on conifer seeds, unprocessed seeds of fir (*Abies fraseri, A. procera*) and spruce (*Picea sitchensis*) were sourced from UK forestry sites, and processed seeds of spruce (*P. abies, P. sitchensis*), fir (*A. alba, A. fraseri*) and cedar (*Cedrus atlantica*) were sourced from international seed suppliers. Each batch was quality assessed using ISTA protocols and seed X-rays, moisture content measurements, germination and viability tests were performed. To investigate the presence of fungi, seeds were subjected to three different surface sterilisation and culture media combinations. Pure cultures were obtained, their DNA was extracted and the ITS region of the different morphotypes was sequenced using the primers ITS1F-ITS4. The NCBI BLAST database was used to confirm the identity of the cultures. A total of 74 unique fungal species were identified from cultures across all seed batches and media types. On no single media/treatment combination all 74 fungi were detected. Seeds disinfected with sodium hypochlorite and plated on potato dextrose agar (PDA) plus streptomycin sulphate (PDA+S) media yielded both the highest total diversity of fungi, and the highest number of unique identifications. The next highest diversity was detected on seeds disinfected with H2O2 and plated on PDA+S media, but a greater number of unique identifications was found following the ISTA protocol using water agar (WA) media with H2O2 seed sterilisation. Several important plant pathogens were detected. The detection of *Sirococcus piceicola* on *P. sitchensis* seed collected from a UK forest site was the first record of this fungus in the UK. The findings of this study suggest that the global movement of tree seed could presents significant risks in terms of the introduction and spread of forest pathogens.

Sowing the safe and healthy seeds of our future forests

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: Tree planting and reforestation efforts require an extensive production system of seed and seedlings with improved gains, including adaptation to future climates. Along this operational system, seedlings are attacked by seed-borne pests and pathogens which cause substantial economic losses and threaten the large investment into selecting seeds of higher performance. Filamentous fungi are the primary cause of diseases related to seed-borne pathogens. They can be pathogenic or can become pathogenic depending on environmental conditions. The presence of dormant fungi inside the seed also raises some concerns about the risk of introduction of exotic invasive pathogens via seed trade. The current knowledge on the diversity and function of conifer seed-borne fungi remains limited, and the exact cause and the risk associated with many pre-emergent seedling diseases is still poorly understood. To fill this gap, we are presently exploring the diversity of fungal communities (i.e. the "mycobiome") of seeds from four conifer species of high ecological value and significant importance for reforestation in North-America. We have identified 150 fungal species from 60 seed-lots using culture-based methods, fungal DNA-barcoding, and third-generation sequencing with a portable sequencing device (Oxford Nanopore MinION™ technology). The most frequent fungal species (about 15% of our collection) identified on the seed coat and inside the seed are presently screened for pathogenicity in an in vitro assay. We expect to rapidly leverage these resources to create innovative solutions that will improve the present capacity for identifying, detecting, and mitigating fungal diseases in early stages of the reforestation system, reduce the risk of introduction of exotic pathogen via seed trade and help to secure the renewal of tomorrow's forests.

THE EFFECT OF DIFFERENT NUTRIENT MEDIA ON THE DIVERSITY OF CULTURABLE SEED ENDOPHYTES IN EUROPEAN BEECH (FAGUS SYLVATICA L.)

T1.32 The biosecurity risks of international movement of tree seeds

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Abstract: The knowledge about associations between plants and fungal endophytes is limited, especially within tree seeds. Recent molecular studies show that high diversity of fungal communities inhabits tree seeds. Potential plant pathogens which may be introduced to new regions by seeds trade are part of them. However, traditional culturing, one of the most common assessing methods of fungal diversity in plant material, allows to capture only a small fraction of them. On the other hand, this method enables the detection of viable fungi and provides pure isolates for future studies. Different nutrient media have been used within this method, and more studies are needed to test the effect of nutrient media type on the captured diversity of fungi. Therefore, the impact of media and seed origins on endophyte diversity was tested. Seeds of European beech (Fagus sylvatica L.) from six locations within Europe were plated on three commonly used media types that differ in carbon sources (Malt Extract Agar, Potato Dextrose Agar and Water Agar). Moreover, the study assessed the overall diversity of endophytes within tested seeds. Almost all tested seeds of European beech yielded fungi. A high diversity of fungal endophytes was detected, including plant pathogens. Diversity and community composition captured in this study were not influenced by medium type. Obtained fungal communities among the three used media did not differ significantly, indicating similar ability in utilisation of both simple and complex carbohydrates by them, which allows for the comparison of fungal diversity assessed by those media. However, the seed origin seems to be a key driver of fungal diversity and community composition differences. It indicates the possibility of the movement of potential fungal pathogens within the seeds trade for tree regeneration purposes. The use of local seeds sources in forest regeneration could reduce this danger.

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

A comprehensive analysis of the molecular defence response of maritime pine to the pinewood nematode

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: Pine wilt disease (PWD), caused by the pinewood nematode (PWN) *Bursaphelenchus xylophilus* has been severely affecting maritime pine (*Pinus pinaster* Ait.) forests in the Iberian Peninsula. Although *P. pinaster* is highly susceptible to PWD, heritable resistance has been reported. Additionally, recent transcriptomic and biochemical analyses of *P. pinaster* trees exposed to PWN highlighted the importance of the jasmonic acid (JA) defence pathway, secondary metabolism pathways like terpene and lignin biosynthesis, oxidative stress response genes, and resistance genes in achieving resistance. In contrast, activation of the salicylic acid (SA) defence pathway has been linked with susceptibility to PWN. In this work, the main objectives were to further characterize the molecular interaction of *P. pinaster*-PWN at the post-transcriptional regulation level by microRNAs, and to identify *P. pinaster* SNPs associated to PWD resistance taking advantage of available data and resources. Small non-coding RNA sequencing of PWN artificially inoculated and control plant samples allowed to identify a set of differentially expressed (DE) microRNAs (miRNAs). The predicted target genes of miRNAs DE in inoculated *versus* control plants are involved in JA defence pathway, response to oxidative stress, and terpenoid biosynthesis, whilst miRNAs DE in resistant *versus* susceptible plants were predicted to target*RLKs* and a *GDP-L-fucose synthase*. Further studies using RT-qPCR have highlighted other possible miRNA roles in the regulation of immunity pathways, cell wall reinforcement, and oxidoreductase activity in resistant genotypes. As a complementary approach, available RNA-seq data from PWN-inoculated susceptible and resistant plants were used for SNP discovery and a customised SNP array (4TREE Axiom array) was used to genotype over 500 plants from another PWN inoculation assay. The analyses, including a multi-locus GWAS to associate 6348 genotyped SNPs with the phenotypic variability in PWN response,

identified 9 SNPs associated with the phenotypic response after PWN inoculation. Some of the identified SNPs were related to the abscisic acid pathway, linoleic acid synthesis, and signalling responses downstream of pathogen perception. Overall, the results from the molecular analyses here presented contribute to clarify the underlying mechanisms involved in PWD resistance and provides SNPs that may be useful for selection/breeding purposes.

Characterisation of cuticular compounds of alternative vectors of pinewood nematode (Bursaphelenchus xylophilus) and the threat posed to UK forestry

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: Pine wilt disease (PWD) is recognised as one of the most serious threats to conifer forestry worldwide. The disease is caused by the pinewood nematode (PWN), *Bursaphelenchus xylophilus*, which has formed novel phoretic associations with different species of cerambycid beetles, in the genus *Monochamus,* in each new country it has become established in (Japan, China, Korea, Taiwan, Portugal, Spain, and its native North America). PWD continues to spread despite extensive border surveillance and containment efforts in the affected countries, whilst climate change and global movements exacerbate the risk of spread. PWN has been intercepted on infested material coming through UK ports and processors, and is expected to arrive in the UK in the coming years. In contrast to continental Europe, the UK has no indigenous *Monochamus* species. But does the absence of *Monochamus* preclude the establishment of PWN? We will examine the potential of alternative vector species that may facilitate the spread of PWN in the UK. The UK has genera of beetles (including but not limited to: *Tomicus, Hylobius* and *Pissodes*) which like *Monochamus,* carry out maturation feeding on healthy plant tissues, and could enable infection via primary transmission of the nematode, in the absence of *Monochamus*. These genera and other cerambycids are already known to carry related *Bursaphelenchus* spp. (although not *B. xylophilus*), and, therefore may have previously been overlooked as potential transmitters of PWN, both in the UK and Europe. PWN aggregates toward their *Monochamus* vectors in the pupal stage using chemical cues (volatile organic cuticular compounds, VOCCs) from the cuticles of the beetles. This research builds on existing work characterising and comparing the specific cuticular profiles of *Monochamus galloprovincialis* to candidate vector species native to the UK and Portugal. Comparing cuticular profiles could provide insight into why *Monochamus* is favoured and may also highlight candidate species for further investigation. We will discuss the implication of our findings on the projected security of UK pine forests in the absence of PWN's preferred vector.

Comparison of tree injection effects of abamectin and emamectin benzoate single and mixed formulation products against pinewood nematode

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: Tree injection is the most commonly used method to prevent pine wilt disease caused by Pine Wood Nematode (PWN). In Korea, abamectin and emamectin benzoate single agents are the most commonly used agents to prevent PWN infections. These nematicide and nematicide-insecticide mixed formulations are used to inhibit the proliferation of PWN and control insect vectors. This study examined the effect of each formulation and (or) product of these pesticides by injecting the recommended doses of the formulations in live pine trees two months prior to inoculation of PWN. The effect of preventing proliferation of PWN lasted for 2 years, but the efficacy was different depending on the formulation or product. Generally, the effect of emamectin benzoate products was significantly higher than that of abamectin. Among the abamectin formulations, the effect of micro-emulsion was significantly higher than that of the emulsifiable concentrate; and in emamectin benzoate formulations, the lowest effect was recorded in treatments with micro-emulsion. In mixed formulations, all treatments showed 100% prevention in the first year, but in the second year, the effect of abamectin mixture was lower than that of emamectin benzoate mixture. Emamectin benzoate products were superior to abamectin products as tree injection nematicides for the prevention of the PWN. However, since the effect varies depending on the product, it is thought that sufficient consideration is required when selecting the formulation.

Effectiveness of a DNA detection kit based on LAMP method for rapid detection of Bursaphelenchus xylophilus in Pinus pinaster

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: The conventional *Bursaphelenchus xylophilus* diagnostic methods involves the nematode isolation by the Baermann funnel technique and subsequent identification via morphological identification or molecular-based techniques using PCR or real-time PCR. These are time-consuming methods and requires specialized expertise. Nevertheless, a DNA detection kit based on loop-mediated isothermal amplification (LAMP) was recently developed to be used under field conditions and without the need of specialized techniques for a rapid detection. This methodology was developed using *Pinus densiflora* and *Pinus thunbergii* as *B. xylophilus* host and a Japanese isolate of this nematode. The aim of this study is to examine if this method is able to detect *B. xylophilus* isolates from different origins using *Pinus pinaster* as the nematode host and the efficacy of this detection kit.

We conducted two experiments, in the Experiment 1, *P. pinaster* wood chips were artificially inoculated with seven *B. xylophilus* isolates of different origins and after 30 days of incubation at 25 °C, the LAMP kit was used to detect the nematode. In Experiment 2, three-year-old *P. pinaster* seedlings were artificially inoculated with a Spanish isolate of the nematode and then sampled at 3 different dates after inoculation to determine the presence of the *B. xylophilus* using the LAMP kit.

The DNA detection kit evaluated was able to detect *B. xylophilus* isolates from all of the assessed origins and we observed the sensitivity of the detection increases when the nematode densities do.

Emerging Threats to Spanish Pine Forests: Exploring the Impact of Pine Wilt Disease on the Forestry Sector in Galicia

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: One of the current concerns for Spanish and European pine forests lies in the pinewood nematode Bursaphelenchus xylophilus (PWN), responsible for causing pine wilt disease. This nematode has emerged as one of the most dreadful threats in those countries where it is not native, leading to substantial environmental and economic damages in stands of various pine species. Portugal, where the nematode was first detected in Europe, has been designated as a demarcated area due to the infestation severity. In Spain, bordering regions with Portugal (Extremadura, Galicia, and Castilla y León) have experienced some disease outbreaks since 2008. Anticipated models indicate a natural expansion of the disease in these areas over the next decade.

Galicia, in NW Spain, is likely the Spanish region most vulnerable to this disease and where the economic impact can be particularly unfavourable. This is due to the vast area of stands of pine species susceptible to this disease (P. pinaster, P. radiata and P. sylvestris) and the significant economic and social importance of the softwood value chain. Furthermore, there are factors that contribute to the difficulties in controlling a potential outbreak and exacerbate the impacts, not only of an actual infection but also of the perceived risk that it is possible. With 98% of the region's forests under private ownership and extensive fragmentation, the value of standing timber becomes highly vulnerable when mandatory measures are imposed. The threat of PWN intensifies the incentive to switch to Eucalyptus or even consider abandoning forestry activities altogether. Additionally, the southern parts of Galicia are recurrently plagued by forest fires, which pose a risk due to the presence of burnt wood.

Present work aims to comprehensively examine and explore the potential ramifications of the expanding pine wilt disease on the forestry sector, specifically within the pine wood value chain and associated processing industry in the northwest of the Iberian Peninsula. The analysis considers the imminent risk of disease spread and its impact. Alongside the direct mortality induced in forests, the study also delves into the effects of containment and control policies, shedding light on their efficacy and implications.

Examination of the effect of nematicide injection on pine trees in the natural occurrence of pine wilt disease

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: The effect of nematicide tree injection on Pine Wood Nematode (PWN) is normally tested by artificially inoculating PWN after tree injection with nematicides. However, in the current study, the efficacy of nematicides in preventing proliferation of the PWN and eventual tree death was examined on black pine, *Pinus thunbergii* on an island that is naturally infested by PWN. The number of dead pine trees and the number of pine trees infected with PWN were investigated for 1 to 3 years after tree injection with abamectin, emamectin benzoate, and acetamiprid and emamectin benzoate mixed formulations. The number of dead trees decreased by more than 90% in treated pine tree stands in both the 1st and 2nd year when compared to the initial tree-death rate before treatment. Among the dead pine trees, the number of trees in which PWNs were detected decreased by more than 85% in the first year, and by more than 93.8% in the second year when compared with the initial detection rate in dead tree stands sampled before treatment. On the other hand, in untreated tree stands, pine tree death increased by 46.2% and 75% after 1 and 3 years, respectively; and the number of dead trees in which PWNs were detected increased by 68% in the first year and by 4% in the second year. Our results therefore showed that when PWN outbreaks were left untreated, the occurrence of dying trees markedly increased every year. And in nematicide tree-injected treatments, the number of dead trees in the second year was lower compared to the first year, proving that the tree injection had a significant effect on suppressing the pine wilt disease.

Identification of new parasitism-related target genes in the migratory endoparasitic nematode Bursaphelenchus xylophilus.

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: The migratory plant-parasitic nematode (PPN) *Bursaphelenchus xylophilus* (pinewood nematode, PWN) is a European quarantine organism listed as a top pathogen that causes economic and ecological damage to the coniferous forestry industry. To find new solutions in sustainable agriculture and forestry systems, is essential to understand the mechanisms of parasitism. The interactions between the nematode and the host are mediated by proteins which are critical molecules during infection. Most of these proteins are (potentially) produced in the pharyngeal gland cells, considered a specialized tissue and are delivered into the host to promote the disease. Supported by genomic and transcriptomic data previously established for the PWN, a promoter DNA motif (STATAWAARS) was identified and associated in the promotor region of different secreted pharyngeal gland cells coding parasitism-related genes, allowing the identification of a large set of genes potentially involved in the infection. The analysis of the top most abundant genes revealed a repertoire of sequences that have no known annotation or similarity to other identified sequences - novel or *pioneer* genes. These genes are enriched in these tissues and are species-specific and/or genus specific. By *in situ* hybridization we validated that some of these specific proteins are expressed in the pharyngeal gland cells. Oxidative stress assays revealed that some gland cells-expressed *pioneer*genes have an up-regulation when exposed to an oxidative agent, suggesting that these proteins might have an important biochemically function in the ROS scavenging. Considering the extensive damage caused by PWN, the finding of new parasitism-related proteins represents new targets for the development of new biotechnological solutions for nematode control.

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Impact of breeding for resistance to the pinewood nematode on the Galician Pinus pinaster breeding program

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: Traditional forest-tree breeding programs provide society with improved tree growth and stem straightness. Recently, the most advanced forest breeding programs also try to meet the needs of the forestry industry by improving their breeding populations for wood quality. In addition, globalization and climate change have highlighted the importance of considering resistance to biotic and abiotic agents in these programs. The Galician genetic breeding program for Pinus pinaster began in the late 80s to supply the demand of the Galician forestry sector. The selection criteria was mainly growth and stem straightness. First-generation seed orchards were established based on these traits. The feasibility of adding wood quality traits, basic density and modulus of elasticity, as selection criteria has recently been explored. Regarding forest health, the pinewood nematode (PWN), Bursaphelenchus xylophilus, is one of the most important threats to P. pinaster. In fact, this disease has caused an enormous impact, both economically and ecologically, in some Asian and European countries, where it is not native. For this reason, the study of PWN-resistance in families of P. pinaster from the Galician breeding program has also been performed. To advance in the breeding program, we focused on traits related to growth, stem form and wood quality as well as forest health (i.e., PWN resistance). Growth traits and wood quality were studied in several half-sib progeny trials, measured at age 12. Since PWN is a quarantined organism in the European Union, PWN resistance was evaluated in two-year-old seedlings under controlled greenhouse conditions. Results proved that evaluated traits were heritable at the studied age and no significant relationship was found between the most important traits, apart from the positive one between basic density and modulus of elasticity. Finally, we have defined different breeding scenarios considering the PWN resistance to compare the genetic gain obtained for each trait in each case and we have also discussed how they would impact the Galician breeding program.

Monitoring the Threat: Surveillance of Bursaphelenchus xylophilus in Croatian Forest Stands

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract:
Bursaphelenchus xylophilus, the causative agent of Pine Wilt Disease (PWD), poses a significant global threat to forest ecosystems. Although currently absent in Croatia, its potential impact necessitates proactive surveillance. Hence, we have developed a comprehensive surveillance strategy adhering to EFSA guidelines, which emphasizes early detection, rapid response, and prevention of its introduction and spread.
Our surveillance program incorporates visual inspections and pheromone traps targeting the insect-vector Monochamus genus. Unmanned Aerial Vehicle (UAV) technologies are leveraged for expansive coverage, with a particular focus on high-risk areas such as ports, nurseries, and sites with imported wood products.We place a strong emphasis on regular monitoring and data collection from Croatian forests. This data, covering aspects such as the nematode's distribution, population dynamics, and potential vectors, is crucial for implementing effective control measures such as quarantine, sanitation practices, and targeted interventions.

The surveillance program's primary objectives are to detect any incursion of B. xylophilus and monitor its potential spread. The economic and social implications of these measures are profound, aiding in mitigating potential impacts on Croatian forest ecosystems. Future prospects involve exploring additional control methods such as tree eradication and breeding for resistance. Our proactive approach aims to safeguard Croatian forests' biodiversity and economic value from PWD, providing valuable insights for informed decision-making in forest management, thus aligning with global efforts to combat this disease.

Natural subsidence of pine wilt disease epidemic in a forest stand located at the northern-limit of the disease-affected area in Japan

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: The temporal pattern of the extent of damage by pine wilt disease (PWD) often differs among the forest stands even when they are located close to each other. Although the epidemic finally leads to a severe decline of the pine trees in most cases, we occasionally encounter a case where the epidemic seems to subside naturally with a substantial number of pine trees remaining when the stand is situated in cool temperature conditions and thus usually at the frontline of the PWD-affected area. In fact, we traced a subsidence of PWD in a *Pinus densiflora* stand located in the northern-limit area of the PWD-affected area in Japan, by investigating the yearly change in the number of PWD-killed trees and the vector density in the stand. The long-lasting occurrence pattern of the small number of PWD-killed trees was considered to be attributed to the opportunistic exteriorization of latent infection of the pathogenic nematode, *Bursaphelenchus xylophilus*, as a residual effect of a past outbreak of the disease. No or only a small number of adults of the vector insect, *Monochamus alternatus*, had been recorded for years regardless of the occurrence of weakened pine trees by shading and wind- or snow-broken trees, indicating that the vector insects have less chance of immigration and manage to maintain their population in the stand. The cool temperature condition slows the symptom development of the diseased trees, and decreased proportion of summer-autumn dead trees militate against propagation of the insects. Consequently, PWD can subside naturally after an outbreak event when there is no continual immigration of the vector insect and under climatic conditions unfavorable for the efficient propagation of the vector.

Plant secondary metabolites for effective control of Bursaphelenchus xylophilus

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: Plant secondary metabolites (PSMs), small molecular products derived from plant secondary metabolism, are highly interesting due to their proven insecticidal, nematicidal or bactericidal activities. Considered a serious threat in Eurasian pine forests, the plant parasitic nematode *Bursaphelenchus xylophilus* is the causal agent of Pine Wilt Disease, for which conventional pest management strategies have not yet successfully accomplished eradication. In line with EU Agenda 2030 for sustainable development, most of the synthetic nematicides usually used are now banned from the list of recommended active substances and plant protection products (EC 1107/2009). Therefore, aiming the development of sustainable plant protection products, we evaluated the nematicidal activity of 35 PSMs against *B. xylophilus* in direct contact bioassays. Nematodes were exposed to 2 mg/mL of each PSMs during 24 h, after which mortality was determined. Overall, 11 PSMs were able to attain a mortality higher than 50%. Only four PSMs (benzaldehyde, carvacrol, thymol and octanol)could achieve full mortality.Additionally, comparing with the conventional nematicide emamectin benzoate, 7 PSMs showed higher nematicidal activities. Further studies will address the effect of the 4 PSMs in plant host and their impacts in other soil and pine tree organisms.

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Proteomics on host tree-pinewood nematode interactions

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: The pinewood nematode (PWN), *Bursaphelenchus xylophilus*, is the causal agent of the pine wilt disease (PWD) and is considered one of the most severe forest pests worldwide. During the last 20 years, advances have been made for understanding the molecular bases of PWN-host tree interactions. Major advances emerged from transcriptomic and genomic studies, which revealed some unique features related to PWN pathogenicity and constituted fundamental data that allowed the development of postgenomic studies. Proteins are the final product of gene regulation and provide the final evidence of the function of a gene. Therefore, proteomic studies are fundamental to discovering what proteins are produced and clarifying which molecules are directly involved in the parasite-host interaction. From these, the PWN secreted proteins have been of particular interest as they are directly involved in this interaction. Advanced proteomics methodologies using a robust platform for differential protein profiling, namely data independent acquisition mass spectrometry methods, were explored to analyze *B. xylophilus* secretomes stimulated with aqueous extracts from pine species with contrasting susceptibilities (*Pinus pinaster* and *P. pinea*) and secretomes of PWN isolates with different virulence. Several putative *B. xylophilus* virulence biomarkers were identified, most associated with peptidase and glycoside hydrolase activities. Additionally, proteome profiles of *B. xylophilus* inoculated and non-inoculated *P. pinaster* and *P. pinea* seedlings are being obtained and analyzed. Proteomic methodologies have been useful for understanding cellular activities, protein functions, and metabolic pathways involved in host tree-PWN interactions, shedding light into the mechanisms associated with PWN pathogenicity and host trees resistance/susceptibility.

Relationship between the pinewood nematode distribution in pine stem and embolism development

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: The development of xylem embolism in Japanese black pine (*Pinus thunbergii*) seedlings after inoculating the pinewood nematode (*Bursaphelenchus xylophilus*, PWN) was monitored by compact magnetic resonance imaging (MRI). In parallel, the nematode distribution and population structure in the 1-year-old stem of the seedlings were examined by isolating the nematodes from 1-year-old stem segments cut into the length of 1 cm by the Baearmann funnel technique.

From the MRI observations, embolism development in the inoculated seedlings was categorized into five phases according to the occurrence and the length of massive embolisms. The vertical length of massive embolisms was found to correspond to the maximum relative embolized area (REA, %) in stem cross-sections of the seedling. The massive embolism initialized from any point of the stem, not restricted to the inoculation site. Nematode population burst started when the maximum REA reached ca. 50%, and then rapidly increased within a few days. The nematode population in the xylem of the whole 1-year-old stem strongly correlated with the maximum REA in the stem, while the nematode population in the 1 cm long stem segment weakly correlated with the REA. This result can be explained by longitudinal nematode movement beyond the segments. The nematode population in the whole 1-year-old stem also highly correlated with the maximum circumferential proportion of cambial death seen in the cross-sectional MR images. Moreover, the proportion of second-stage juveniles of PWN also correlated with the REA in the xylem. In contrast, the nematode population in bark tissue did not correlate with either the REA or cambial death.

These results suggest that, in pine wilt disease, nematode reproduction in the cambial zone is a key step in the development of massive embolism and tree death.

The current diagnostic methods for pine wilt disease in Korea

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: Pine wood nematode (PWN), *Bursaphelenchus xylophilus*, is the causal agent of pine wilt disease (PWD), which results in the most destructive disease to many coniferous species. South Korea is one of the most severely damaged countries and more than thirty years have passed since PWD was first found in Busan in 1988. To date, the system of PWD investigation and diagnostic techniques has been dramatically changed and developed. NFC electronic tags are in use to prevent the monitoring blind spots, and a record management system using QR code from the monitoring and diagnosis of dead pine trees to control has been established. In addition, for rapid diagnosis of PWD on-site, we developed two on-site PWN detection methods using a recombinase polymerase amplification (RPA) assay and loop-mediated isothermal amplification (LAMP) assay. For RPA assay, the primer set sequences Bx_ITS2_F1 (5′-Biotin-GCACGTTGTGACAGTCGTCTCGCATTGTTC-3′) and Bx_ITS2_R1 (5′-FAM-TCGAGCACGAAGCCCTCTCGCCCCGCACGG-3′) were designed in order to amplify a 129 bp fragment exclusively from PWN genome. RPA assay for PWN detection was optimally conducted at 37°C for 15 min using PWN gDNA, and the detection limit of our RPA assay was 1.6pg of gDNA from PWN. For LAMP assay, the primers set was designed after aligning internal transcribed spacer sequences from the genus of *Bursaphelenchus*. The LAMP primer set sequences are BX-F3(5'-GCAGAAACGCCGACTTGT-3'), BX-B3(5'-GCGCCGTTGAAACAACATC-3'), BX-FIP(5'-CCGCGTAAAACAGATGGTGCCT+AGTTTCTGCACGTTGTGACA-3'), BX-BIP (5'-TACGCACTGTTTGTCCGTGCG+ACCAAACGGTTTAGCCGC-3'), BX-LF (5'-GCGAACAATGCGAGACG-3') and BX-LB(5'-CTTCGTGCTCGATTGTCGTGC-3'). The system proposed in this study is high-performance capable of diagnosing PWN up to 1pg, detection was optimally conducted at 62°C for 15 min using PWN gDNA. The developed rapid diagnosis methods on-site protocol follows;
Collect the wood chips from dead pine trees. Add the 1ml DNA extraction buffer in a 2ml tube containing 10 pieces of wood chips and incubate at room temperature for 10 min. After incubation, add 2μl of lysate solution to the diagnosis mixture. And amplify DNA 15 min at 37°C for RPA, or 62°C for LAMP, respectively. After DNA amplification, add the SYBR green I dye and measure the absorbance value which can distinguish the negative and positive reactions.

The geo-historical process of formation, inhibition and release of the virulence of Bursaphelenchus xylophilus

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: After the invasion of pine forests in Eurasia, *Bursaphelenchus xylophilus* which was widely distributed in North America was found with virulence. In the long geo-historical evolution of *B. xylophilus* that native from the Eastern North America, its virulence produced and was later suppressed, due to the coevolution with host *Pinus* spp. and the impact of changes in pine forest environment of the North America.
According to the distribution of Pinus fossils in different geological ages and the distribution pattern of *Pinus* spp. in present, it shows that the diversity of *Pinus* spp. has increased significantly with the decrease of the average temperature of the earth since the Cretaceous; The divergence intensity of *Pinus* spp. and its evolution level in the North America is higher than that in Eurasia. Therefore, the evolution level in the *B. xylophilus* group nematodes represented by *B. xylophilus* with virulence in the North America is also higher than that represented by *B. mucronatus* in Eurasia by the high divergence intensity of *Pinus* spp. However, in the process of coevolution with host plants, the virulence of nematode eliminated the susceptible host, further promoted the evolution of pine trees, and formed new species that could inhibit the *B. xylophilus* virulence after the earth cooled since the Holence. Obviously, *Pinus* spp. in Eurasia had no experience of coevolution with *B. xylophilus*, so that *Pinus* spp. in Eurasia cannot resist the attack of *B. xylophilus* with virulence when it invaded from the North America.
Of course, the virulence release of *B. xylophilus* is also caused by vector insects with high transmission efficiency, and the higher temperature environmental conditions in the subtropical arid areas in Eurasia, but these are not the main factors. Compared with the long geo-historical process of evolution in North America for tens of millions or even hundreds of millions of years, in the short time of invasion to Eurasia for more than 100 years, how to reduce the damage of *B. xylophilus* to Eurasia pine forests under natural conditions, we may find answers in it.

The Pine Wilt Disease in the Iberian Peninsula: 25 years after the first detection of Bursaphelenchus xylophilus

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: Pine Wilt Disease (PWD), caused by the pinewood nematode (PWN) *Bursaphelenchus xylophilus*, is a causal agent of mortality of pines (*Pinus*) in countries where it was accidentally introduced, i.e in Japan, China, Korea, Taiwan, Portugal and Spain. International trade of infected wood is the main pathway for PWD spread. In the Iberian Peninsula, *B. xylophilus* causes mortality mainly in maritime pines (*Pinus pinaster*), although small plantations of *P. nigra* and *P. radiata* were also found affected by the nematode. Efforts implemented by the Portuguese Forest Authoritiy (ICNF) follow the guidelines of the Commission Implementing Decision 2012/535/EU. These actions involve forest surveys to detect and eliminate wilting and declining pine trees, during the autumn and winter months, placing of traps to monitor and control the insect-vector (*Monochamus galloprovincialis*) during its spring-summer flight period, regulation and inspection activities to economic operators (e.g., wood transport, wood exports), and public awareness.

In this presentation, we will give a general overview of the Portuguese national strategy against this alien pathogenic nematode, with an update on the PWD management made during the last 25 years, with the overall impact in the Portuguese pine forests and the changes and improvements made along the years on the strategies and methodologies applied. The evolution of the situation in the Spanish territory, since the first detection in October 2008, will also be presented.

Finally, on-going research will also be reported, aiming not only the improvement of remote detection of wilting pines and the insect-vector trapping but also the development of innovative survey and control methods based on Volatile Organic Compounds released by the PWN and its insect-vector, within projects such as "PURPEST-Plant pest prevention through technology-guided monitoring and sitespecific control" and "Reassessing the threat posed by the pinewood nematode (*Bursaphelenchus xylophilus*) to UK forestry: exploring alternative vectors and novel detection tools".

Key words: Pinewood nematode, *Monochamus galloprovincialis*, control, Europe.

The PineWALL project – Linking pine cell wall composition and structure to pinewood nematode resistance

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: The pinewood nematode (PWN), *Bursaphelenchus xylophilus*, uses its stylet to perforate cell walls (CW) while releasing CW hydrolytic enzymes. Thus, understanding CW chemistry and structure is essential to unveil how it may influence host susceptibility to PWN. To achieve this, an innovative transdisciplinary project (PineWALL – FCT-PTDC/ASPSIL/3142/2020) was established. Saplings of *Pinus* species with different susceptibilities to PWN infection (*P. pinaster*, *P. halepensis* and *P. pinea*) were inoculated with PWN and disease progression was monitored under controlled temperatures (25°C and 30°C) and different irrigation regimes. At the end of the assays, differences in nematode reproduction factors were determined. Vibrational spectroscopy techniques (FTIR and Raman) are being applied for a global CW characterisation. Preliminary data revealed that there are significantly different CW compositional properties between PWN-inoculated and non-inoculated *P. pinaster* samples. Namely, phenolic compounds are upregulated in PWN-inoculated plants, presumably as part of defence mechanisms. Chemical analytical methods will be employed to further characterise different CW fractions. We also intend to employ immunological approaches to unveil the CW glycome profile and reveal *in muro* glycan distributions. By the end of the project, all data will be integrated to identify CW biomarkers that may be applied to predict pine susceptibility/resistance to PWN infection.

Transcriptional changes in response to 3-octanol in the plant-parasitic nematode Bursaphelenchus xylophilus.

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: The pinewood nematode, *Bursaphelenchus xylophilus*, is one of the most damaging plant parasite, causing economic and ecological losses in coniferous forestry industry. The spread of pinewood nematode (PWN) has a direct impact on natural resources and wood industry, and an indirect effect on the restrictions in the circulation of wood products from affected areas worldwide. Currently, the strategies used for PWN control are preventive. Application of chemicals to control PWN is possible but it's not a sustainable and efficient option. The search for new control strategies in line with the EU's sustainability goals highlight significant knowledge gaps.

Compounds naturally produced by plants might play an important role in nematode control. Independent experiments were conducted to evaluate the molecular response of the root-lesion nematode *Bursaphelenchus xylophilus* to 3-octanol ($C_8H_{18}O$). Nematicidal activity of the 3-octanol was accessed at a 2 mg/mL concentration for 30 minutes. Bioassays were performed following the standard direct contact methodology. Nematode transcriptomic analysis revealed that the presence of 3-octanol can have an effect (upregulation) in the expression of different genes involved in the xenobiotics biodegradation metabolic pathways and a down-regulation effect in the expression of genes related to lipid and carbohydrate metabolism pathways. This study might generate important results and understand the mode of action of these nematicidal molecules providing new targets for nematode control.

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Volatile organic compound (VOC) profiles as a fingerprint for pinewood nematode detection – Development of a new portable detection tool

T1.33 The Pine Wilt Disease dramatic impact on conifers forest across the world, today and in the future

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Abstract: Pine wilt disease (PWD) has spread rapidly and evaded pest management strategies in many Asian countries. In Europe, the first detection of its causal agent, the pinewood nematode (PWN), occurred in Portugal, in 1999. Since then, the PWN has been detected throughout Portugal mainland, Madeira Island and in Spanish pine forests from Galicia and Estremadura provinces. In the last two decades, containment and mitigation of this priority pest has mobilized extensive investment. These efforts were partially inefficient, due also to the limited efficacy of the available detection and monitoring techniques. PURPEST (purpest.eu) proposes that volatile organic compound (VOC) profiles specific to the PWN can be used to construct a VOC-based system (Sensor System) for the detection of infected material. This system has the potential to revolutionize the current methodologies by offering an alternative to the traditional collection of wood samples and screening for PWN. To accomplish this task, VOC profiles of the PWN and infected pine material will be analysed through headspace GC-MS, and then used to fine-tune sensor components for the development of optimized sensor systems and, finally, a sensor system prototype will be validated in the field and at import control sites. Implementation of PURPEST advances pest management strategies by allowing an early detection of PWD and increasing the inspection rate in pine stands and woody material from coniferous importations with a non-invasive, reliable and high throughput methodology thus preventing entry into new forestry areas.

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T1.34 Transitioning to Continuous Cover Forestry in Times of Climate Change and Energy Crisis

Continuous cover forestry for diversification of forest benefits: a case from small-scale forest farmers in Sweden

T1.34 Transitioning to Continuous Cover Forestry in Times of Climate Change and Energy Crisis

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Abstract: Politicians, decision-makers, and foresters at multiple levels highlight that climate change has become a major factor influencing forest management decisions, and there are ongoing debates concerning what type of forest management provides more opportunities for climate change mitigation and adaptation. Continuous Cover Forestry (CCF) is seen as forest management based on ecological principles with a view to avoiding degradation effects, including those triggered by climate change. However, there is a lack of studies on how to do transitioning toward CCF in countries where other forest management systems dominate.

This study aims to identify and compare the benefits attributed to continuous cover forestry (CCF) by forest farmers who are the pioneers of CCF in Sweden, and to analyze how they perceived obstacles and opportunities for transitioning towards this type of forest management. In Sweden forestry conducted by forest farmers has a long tradition; the clear-cutting model is dominating while CCF covered only less than 3%

In total, 20 qualitative, semi-structured interviews of residential forest owners were conducted during January-April 2023. The average age of interviewees was 63 years old, all with higher education. For all interviewees, except one forest owner, the income from forestry was of secondary importance. Forest owners are concerned about climate change and how to get diverse climate benefits from their forests. Our results show that forest farmers attributed multiple intangible benefits to CCF such as biodiversity, forest health, carbon storage and sequestrations, microclimate regulation and resistance to drought, aesthetical, cultural, and recreational values. Among the attributed tangible benefits were economic benefits (to reduce costs on tree planting, thinning), increased yields of berries and mushrooms, hunting, and higher timber quality. We discuss challenges (e.g., availability of small types of machinery), opportunities (e.g., ecological, aesthetical, and economic benefits), barriers (knowledge gaps, and traditions in forestry), and possibilities (e.g., subsidies and grants) for transitioning from clear-cut to CCF forest management.

Effect of Norway spruce shelter density and soil scarification method on mortality and height growth of underplanted beech, silver fir and Douglas fir

T1.34 Transitioning to Continuous Cover Forestry in Times of Climate Change and Energy Crisis

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Abstract: In Europe, 6-7 million ha even-aged, pure stands of Norway spruce grown outside its natural range are prone to natural disturbances. Climate change may accelerate these problems necessitating methods for converting these plantations into more heterogeneous forest with larger resistance towards natural disturbances. Based on an experiment on former heathland, we examined mortality and height growth of European beech (*Fagus sylvatica* L.), European silver fir (*Abies alba* Mill.), and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) planted under shelterwood of 17-19 m tall Norway spruce (*Picea abies* (L.) Karst.) at shelter densities initially ranging by basal area from 10 to 36 m^2ha^{-1} (271-1099 stems ha^{-1}). Underplanting included plots of beech (100%) and silver fir (100%) as well as plots with two-species mixtures of silver fir/beech (66%/33% and 33%/66%) and Douglas fir/beech (66%/33%). The experiment also included two soil scarification methods (patch and strip scarification). The experiment was an unbalanced factorial split-plot design, replicated in time and space, and totaling 144 plots in four blocks. The experiment was followed for 19 years during which a gradual reduction in shelter density took place although in some plots the shelterwood was removed abruptly by e.g. windthrow. Shelter densities larger than 10 m^2ha^{-1} had a minor effect on the mortality of beech and silver fir, while shelter densities larger than 20 m^2ha^{-1} resulted in increased mortality of Douglas fir. Subsequent abrupt reduction in shelter density resulted in increased mortality. Height growth decreased with increasing shelter density, more for Douglas fir than for beech, and marginally more for beech than for silver fir. For shelter densities less than 15 m^2ha^{-1}, height growth of silver fir was unaffected. Beech grew faster when mixed with Douglas fir. The soil scarification method did not influence mortality, but strip scarification resulted in marginally larger height growth than patch scarification. The shelter effect was related mainly to competition for light, while late frost and browsing were important in open shelters (<10 m^2ha^{-1}). Based on these results, recommended initial shelter densities are ≤10 m^2ha^{-1} for the establishment of Douglas fir, approximately 15-20 m^2ha^{-1} for silver fir, and around 15 m^2ha^{-1} for beech.

The trees, the people and the marteloscope – What human tree selection behaviour can tell us about CCF training requirements

T1.34 Transitioning to Continuous Cover Forestry in Times of Climate Change and Energy Crisis

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Abstract: Research into human tree selection behaviour started in the 1990s and only gradually expanded in Europe and North America. The main objective of this research field is to understand how humans – professionally and unprofessionally – interact with the trees in the forest. Human-tree interaction can be best measured when test persons are asked to select trees for various purposes, e.g. for commercial forestry scenarios, for conservation or recreation. A specialised research plot, the marteloscope, has been proposed for hands-on training but also for designing research experiments. Research results particularly of the last two decades have taught us valuable lessons about how humans with different backgrounds respond to training and to tree selection tasks. We also understand much better the subtleties of the ways how trees influence human decisions. In addition, marteloscope experiments leave a time-stamped snap shot of the current skill set of forestry staff in a given region and their agenda towards forest management. This offers strategic information for designing regional and national training programmes for fostering the uptake of new types of forest management such as CCF or conservation but can also be employed for establishing a system of quality assurance ensuring that training programmes are effective and adapt. National and international projects in Europe annually collect hundreds of data records on human tree-selection behaviour that are not properly analysed with a view to deepen our understanding of human tree-selection behaviour. Low-cost citizen-science approaches and strategic partnerships between such projects and universities could fundamentally help improve the scientific basis of training.

Transforming Sitka spruce monocultures to continuous cover forestry in Ireland

T1.34 Transitioning to Continuous Cover Forestry in Times of Climate Change and Energy Crisis

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Abstract: Clearfell forestry continues to be widely practiced, both in Ireland and internationally, partially due to a lack of growth and development data from alternative forest management options. However, it is increasingly important to maintain some forest cover since forests are often expected to provide continuous multiple benefits, such as: timber production, habitat, soil cover and recreation. Here, data is presented from two Sitka spruce continuous cover forestry (CCF) trial sites in Ireland. These sites are some of the oldest ongoing CCF trials and the results include information on stand development and potential timber assortments under transformation to CCF.

In 2010 two stands of Sitka spruce, both ready for their first thinning, were selected to investigate different approaches to transformation for CCF. The three treatments applied to three plots in each stand were: low thinning, crown thinning, and graduated density thinning. Low thinning represents an industry standard where the smallest and worst trees are removed, whereas graduated density thinning removed more stems nearer to the extraction rows (racks) and fewer stems further from the racks. The graduated density thinning racks were shifted during the second thinning. Subsequent graduated density thinnings were the same as a crown thinning; quality trees were selected and favoured.

This presentation reports on the stand development, including stem diameter distribution and tree volumes (from Ireland's Tree Volume and Carbon calculator), from 2010 to 2023. The log grades and volumes removed during the four thinnings are reported by treatment and site. Low thinning had the narrowest diameter distribution and removed the lowest volume of sawlog during the 2023 thinning for both sites. Graduated density thinning had the lowest standing volume, likely due to this treatment including heavy first and second thinnings. The results from these experimental trials will give insight into how the stand condition changes over time during the transformation process.

Transitioning southern pine plantations to continuous cover forests: Lessons from long-term stand conversion experiments in slash and longleaf pine

T1.34 Transitioning to Continuous Cover Forestry in Times of Climate Change and Energy Crisis

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Abstract: Continuous cover forestry (CCF) is not common in the southern United States, the region known for its highly productive and intensively managed pine plantations. However, increasingly, many private landowners and governmental land management agencies, who value naturally regenerating, resilient, diverse forest stands with timber production as only one among many management objectives, are seeking alternative management options that maintain continuous forest cover, such as uneven-aged forest management. Even though most silvicultural research has been focused on intensive management of plantations in the region over the past 70 years, several experiments have been conducted in the past two decades to identify techniques for effectively transitioning plantations to continuous cover. Data from the ongoing long-term, replicated, operational-scale silvicultural trials in longleaf (*Pinus palustris*) and slash pines (*P. elliottii*) at multiple sites in Florida and Alabama in the southern United States suggest that these pine stands can be effectively transitioned to continuous cover, uneven-aged stands, and that the transition can be economically as well as ecologically competitive alternative to existing even-aged management options. The transition silviculture harvest methods (e.g., group opening and single tree harvests) implemented in these experiments have been found satisfactory at naturally regenerating southern pines and maintaining stand and fuel conditions conducive to frequent fire regimes. While even-aged (clearcut-plant-clearcut) plantations may produce higher total merchantable timber in southern pines, naturally regenerating uneven-aged, continuous cover stands are efficient at producing saw timber and have been found to be more resistant and resilient to damages caused by climatic or natural disturbances, such as hurricanes in 2004 and 2018. The stands in transition have higher structural diversity and they maintain consistent pool of stand carbon. Based on data collected over two decades, this presentation will provide the current state of knowledge and the prospects of managing southern pines using CCF.

Transitioning to multifunctional landscapes in Sweden?- a place-based longitudinal case study covering five decades

T1.34 Transitioning to Continuous Cover Forestry in Times of Climate Change and Energy Crisis

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Abstract: Context: Public choice and complex global dynamics, including climate change, are driving desires for the growing suite of goods, services and values that society expects from forest landscapes. This is particularly true where intensive forestry practices have negative impacts on natural and cultural values, and on value chains dependent on multifunctional forest landscapes.

Aim: Focusing on the Swedish Tiveden forest massif as a hotspot for developing diverse forest-based value chains, this study has two aims: (1) To analyse five decades of projects and processes to support rural development through landscape planning, and alternatives to rotation forestry based on clearcutting. (2) To analyse the cross-sectoral “Collaboration Tiveden” platform for knowledge production and learning to identify barriers and bridges supporting the emergence of landscape planning and forest management systems contributing to multifunctional forest landscapes.

Methods: (1) Using grey literature, expert interviews and participatory observations we mapped efforts 1974-2022 to develop integrated landscape planning and forest management approaches to support multi-functional forest landscapes. (2) Based on focus groups with stakeholders, subsequent causal loop modelling with key stakeholders, and validation using independent data, we identify barriers and bridges supporting a transition away from industrial forestry towards multifunctional forest landscapes.

Results: Over five decades, a total of 11 projects aimed at sustaining multiple landscape values advocated comprehensive spatial planning to accommodate those. However, these ambitions failed to materialise. Systems analyses of driving forces supporting multifunctional landscapes, and independent monitoring data, clearly demonstrate negative effects of intensified forestry on natural and cultural values, on rural development, and on nature-based tourism. As a remedy attempt, a social platform for stakeholder collaboration demonstrates trials of “clear-cut-free” forest management. Nevertheless, the polarisation of forest landscapes increases, which stresses the need for both protecting high conservation value forests, and nature restoration.

Conclusions: Transitions to multifunctional landscapes require several forest management systems, and integrated spatial planning. Social learning through ongoing evaluation of place-based initiatives attempting this is crucial. Evidence-based mapping of the distribution and abundance of both material and immaterial landscape values is a prerequisite that needs to be satisfied

Variable-density thinning designs for harvester-based operations in northern Europe

T1.34 Transitioning to Continuous Cover Forestry in Times of Climate Change and Energy Crisis

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Abstract: Conversion to continuous-cover forestry (CCF) will be a major task for forest managers during the next decades. In the boreal forests of northern Europe, little experience with CCF exists and concepts for conversion to CCF are only starting to be developed and tested now. In contrast to forest management in central Europe, tree marking is uncommon in northern Europe and decisions about tree removal during thinning are made by harvesting machine operators.

Inspired by concepts for variable-density thinning (VDT) developed in Washington and Oregon 30 years ago, I developed a concept for conversion towards selection system structures. A main assumption of this concept is the creation of horizontal variation in tree sizes in young stands, where vertical tree size variation would be difficult to maintain due to the fast growth of young trees. The concept modifies the VDT concept of thinnings with skips and gaps in a way that harvester operators can assign the different treatments without prior tree marking. The concept further modifies the original VDT concept by applying crown thinning to variable density in the remaining matrix. Crown thinning is best to preserve and favor existing size variation. Crown thinnings differs substantially from the current practice of thinning from below.

The presentation will describe the design of the VDT treatment and illustrate examples from a series of demonstration plots established in Norway in 2023. Challenges for machine operators in learning and applying this new concept will also be addressed.

T1.35 Use of RNA strategies for the control of forest pests and diseases: mycoviruses and interfering RNA

Analysis of miRNAs produced by the PPC-tolerant species reveals novel target genes in F. circinatum for their successful use in SIGS technology

T1.35 Use of RNA strategies for the control of forest pests and diseases: mycoviruses and interfering RNA

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Abstract: It is known that small RNAs can be transported between plant hosts and their fungal pathogens, inducing target gene silencing in the counterpart through a phenomenon called cross-kingdom RNA interference. This mechanism of RNA-mediated communication is currently being elucidated in detail in plant-pathogen interaction models. In order to identify new and natural target genes in the pathogen, it is necessary to determine which host plant microRNAs (miRNAs) are involved in this phenomenon. miRNAs are a class of non-coding RNAs that play an important role in the regulation of gene expression through the RNA interference mechanism. This study aims to elucidate the essential miRNAs of pines that are delivered and responsible for the tolerance to the pathogen *Fusarium circinatum*. Therefore, miRNA molecules were extracted and sequenced from *Pinus pinea* (tolerant) and *Pinus radiata* (susceptible) during their interaction with *F. circinatum*. Through comparative analysis, we identified a dozen miRNAs produced by *P. pinea* that were not produced by *P. radiata*, with high sequence homology to transcripts of *F. circinatum*, suggesting that these genes would be the natural targets that the tolerant pine host specifically uses to inhibit Pine Pitch Canker (PPC) disease caused by *F. circinatum* though RNA interference. To verify the essentiality of these genes for fungal virulence, we performed knock-out experiments in *F. circinatum*, observing a reduction of virulence. Furthermore, we successfully utilized these genes as targets in SIGS (Spray-Induced Gene Silencing) technology, in which RNAs targeting pathogen virulence-related genes are externally sprayed onto plants. These RNAs can be taken up by the pathogens to silence their genes and inhibit disease formation, in our case PPC in pines.

Metabolomics of virulence and hypovirulence: Do hypovirulent Cryphonectria parasitica strains produce different metabolites than virulent strains?

T1.35 Use of RNA strategies for the control of forest pests and diseases: mycoviruses and interfering RNA

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Abstract: *Cryphonectria parasitica* causes chestnut blight disease and was responsible for the death of around 4 billion chestnut trees in North America. The disease can be controlled by applying *C. parasitica* isolates infected with *Cryphonectria hypovirus 1* (CHV-1), which decreases the disease severity. However, the method relies on using the pathogen itself, promoting the spread and establishment of the pathogen. In addition, a high genetic diversity, especially vegetative compatibility type diversity, of the pathogen makes biocontrol unsustainable. Therefore, a more sustainable approach is needed to control the disease. In this study, we hypothesized that viral infection in the fungus produces some metabolites to decrease fungal virulence. For this purpose, we infected virus-free fungal strains with CHV-1 or *Cryphonectria hypovirus 4* (CHV-4). Untargeted high-performance liquid chromatography coupled with mass spectrometry (HPLC-MS) is being done to see if some metabolites are only present in hypovirulent (CHV-1 infected) strains and not in virulent strains (virus-free strains or CHV-4 infected strains). Metabolite annotation will be performed to identify these active biochemicals. These chemicals will be further tested on virus-free strains to test their effect. By comparing metabolite profiles, we will gain insights into the biochemical factors associated with hypovirulence. These biochemicals will be available for future studies to develop bio-fungicides and help control the disease sustainably. This study will help bypass the unsustainable biocontrol method and provide an alternative to disease management.

Organic vesicles for dsRNA delivery in the control via SIGS of forest diseases, using the Phytophthora-Quercus and Fusarium-Pinus pathosystems

T1.35 Use of RNA strategies for the control of forest pests and diseases: mycoviruses and interfering RNA

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Abstract: SIGS is a plant protection strategy in which dsRNAs are externally applied to plants to induce systemic gene silencing in targeted organisms and limit disease development. Despite the multiple examples showing its effectiveness for controlling plant pathogens and pests, the instability of RNA molecules and their reduced uptake by the targeted organism are still challenges that need to be overcome before using this technology in the field. Nanocarriers, including organic vesicles, have proven effective in overcoming both challenges as they improve the pathogen uptake and protect the dsRNA from nucleases and harsh environmental conditions. We evaluated whether these organic vesicles can deliver dsRNA specific to genes relevant to the *Phytophthora cinnamomi* and *Fusarium circinatum* infection. We applied the dsRNA-loaded vesicles to the plants inoculated with the pathogen. Then, we evaluated disease progression and the expression of the targeted genes in the hosts inoculated with the pathogens. Our work shows that coupling SIGS and nanocarrier technology is a promising strategy for the environmental-friendly management of forest diseases in the XXI century.

Population dynamics of RNA viruses in declining Mediterranean forests

T1.35 Use of RNA strategies for the control of forest pests and diseases: mycoviruses and interfering RNA

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Abstract: Global change alters forestry habitats and facilitates the entry of new pathogens that don't share a co-evolution history with the forest. Due to the combination of degraded forests and urban massification, the human population is particularly exposed to new infectious diseases, such as the coronavirus pandemic. For this reason, the study of RNA viruses is essential to understand how viral flow across different hosts and forest sanitary conditions might occur, and to prevent possible outbreaks of human diseases in the future. In this work the viral diversity found in trees, insects and fungi from Spanish Mediterranean forests is described. To this extent, three habitats (*Quercus ilex, Castanea sativa* and *Pinus radiata*) showing signs of decline were sampled in two different years (2021 and 2022) and RNAseq was performed on tree tissues, insects and fungi. Viral identities were assigned by searching for matches to conserved motifs of the RNA-dependent RNA polymerase (RdRP) using Palmscan. Up to 15 viral families were identified in 2021 sampling, with Botourmiaviridae (25%) and Partitiviridae (6%) being the most abundant. Distribution of viruses across ecosystem was: *Q.ilex* (57%), *P.radiata* (27%) and *C.sativa* (16%). These data will be compared to 2022 sampling taking into account the effect that trees' health status (declining/healthy) might have on the composition of the virosphere in each of the habitats. This approach constitutes a starting point to search for novel viruses that might be participating in unknown infectious pathways within forests and potentially posing a threat to the human being.

Spray-Induced Gene Silencing (SIGS) for controlling Phytophthora cinnamomi, the causal agent of Holm Oak decline

T1.35 Use of RNA strategies for the control of forest pests and diseases: mycoviruses and interfering RNA

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Abstract: *Phytophthora cinnamomi* is an oomycete pathogen that induces root rot in several plants, including forest species such as *Quercus ilex,* causing a disease called Holm Oak decline. Currently, no effective control measures for managing this pathogen exist. Chemical products cannot be applied in EU forests, which makes it difficult to control the disease. Spray-induced gene silencing (SIGS) represents a potential environmentally friendly tool to control *P. cinnamomi.* This strategy is based on RNA interference (RNAi), which is a conserved gene-silencing mechanism inherent to eukaryotic cells. RNAi is initiated by double-stranded RNA (dsRNA), which triggers the degradation of homologous messenger RNAs (mRNAs), preventing protein translation. SIGS strategy consists of externally applying dsRNAs molecules targeting essential genes of the pathogen. While this approach is actively being developed for agricultural pathogens, its exploration in forestry, and particularly for oomycetes, remains limited. Our research group designed and synthesized dsRNA molecules to silence important metabolic pathways for the survival of *P. cinnamomi* and evaluated their efficacy on different plant tissues and seedlings. We observed a reduction in symptom severity and delayed onset in seedlings when dsRNA was applied to the roots before infection. These findings indicate the potential utility of targeting essential genes with dsRNA to manage *P. cinnamomi*. Nowadays, forests are more threatened than ever before due to globalization and climate change, and the use of this technology to control forest pathogens is a novel approach that could offer an alternative to conventional management.

Spray-induced gene silencing (SIGS): An effective strategy to control Pine Pitch Canker caused by Fusarium circinatum

T1.35 Use of RNA strategies for the control of forest pests and diseases: mycoviruses and interfering RNA

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Abstract: *Fusarium circinatum*, an invasive fungal pathogen, is responsible to cause causes pine pitch canker (PPC) disease in Pine and other coniferous tree species. *F. circinatum* being a ubiquitous pathogen is responsible to target novel hosts and influencing million-hectare loss to forest stands worldwide. Current management practices are not able to pace up the forfeiture and outbreak of PPC, therefore novel and sustainable strategies are required to manage forest disease. Our present study is aim to control pathogenic fungus *F. circinatum* through SIGS (Spray-induced gene silencing). SIGS is based on RNA interference (RNAi), a conserved eukaryotic gene-silencing mechanism naturally occurring in cells. RNAi pathway is triggered by double-stranded RNA (dsRNA), which in turn, manipulate the expression of gene by the degradation of homologous dependent messenger RNAs (mRNAs) and disrupt the functioning of protein. The exogenous application of dsRNA through SIGS allows the uptake of molecules by fungus and thus exploiting RNAi mechanism. In our studies, we designed dsRNA molecules targeting essential genes of pathogen that are important to block various imperative pathways, crucial for pathogenicity and survival of *F. circinatum.* For a quick effectivity test of our pool of dsRNA molecules that target several genes of the essential fungal pathways, inoculation assays were conducted in Spinach leaves. The leaves of spinach showed inhibition of fungal growth. Subsequently, the designed dsRNAs were also applied exogenous on pine seedlings inoculated with *F. circinatum* and it ensued inhibition of fungal growth and delayed symptoms development. *F. circinatum* was able to uptake dsRNA to trigger RNAi and it was demonstrated by confocal assays. Transcriptomics analysis also support the reduction of infection in inoculated experiments. We also demonstrated the efficacy of same designed target dsRNAs on *Fusarium graminearum* and they were found successful to reduce symptoms of infection on wheat spikelets. This is the first ever work that described the use of RNAi in forestry to control *F. circinatum.* RNAi as a novel technology, can bring an innovative paradigm in forest disease management as SIGS is proficient, effective and eco-friendly strategy that can prove a promising tool to combat PPC pathogen in forest.

Virus elimination and effect assessment in isolates of Phytophthora cinnamomi

T1.35 Use of RNA strategies for the control of forest pests and diseases: mycoviruses and interfering RNA

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Abstract: Over the past years, the presence of a variety of RNA viruses has been confirmed in a global collection of isolates of the panglobal invasive plant pathogen *Phytophthora cinnamomi*. These viruses are potentially useful as BCAs (biological control agents). To further investigate the effects of viral presence, absence and load on the biology of their host isogenic virus-free isolates were produced for comparative studies with naturally virus-infected isolates. Several virus elimination methods were combined, including monosporic and monohyphal isolation, polyethilene glycol (PEG) treatment and thermotherapy, to eliminate viruses from *P. cinnamomi*. Then, total RNA extraction and cDNA synthesis was carried out, followed by RT-PCR using specific primers to confirm whether viruses were eliminated. An *in vitro* experiment comparing virus-hosting and virus-free isolates was performed to assess significant differences in the temperature-growth relations and growth rates of these *P. cinnamomi* isolates.

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

Active Timber Management by Outsourcing Stumpage Price Uncertainty with the American Put Option

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: Timber production is an inherently risky business. Stumpage price fluctuates all the time, creating price uncertainty for forestland owners and managers. In this paper, we address this challenge by outsourcing it with an American put option to determine the reservation prices at different ages and calculate the corresponding reservation prices. When the spot price exceeds the reservation price at a particular age, the high stumpage price triggers an immediate timber harvest. The resulting harvest value and age are then incorporated into the generalized Faustmann formula to determine the corresponding land expectation value.

The simulation results showed that outsourcing stumpage price uncertainty with the American put option resulted in an average land expectation value of $6504/ha. This result is 37% higher than that of the $4745/ha under certainty assumption. But the average harvest age of 46 years is 50% longer than the 31 years under certainty assumption. Moreover, the result with the American put option approach is $101/ha less than that of the Brazee and Mendelsohn reservation price approach. To further enhance the outcome of the American put option approach, different partial put option coverages of the stand volume at age 70 were explored. A partial put option coverage of 60% of such volume resulted in an average land expectation value of $7116/ha with an average harvest age of 35.51 years, essentially the same as the $7121/ha and 35.45 years under the Brazee and Mendelsohn method. More importantly, the curvilinear relation between partial put option coverage and the average land expectation value provides intriguing opportunities to balance uncertainty tolerance and the average land expectation value. For example, an aggressive uncertainty seeking 30% partial coverage will produce a result of $6538/ha, slightly better than the $ 6504/ha of a conservative 100% coverage. Yet, the 26.85 years average harvest age of the former is less than 58% of the 46.15 years of the latter. Consequently, by balancing uncertainty and return with partial American put option coverage forestland owners become active stumpage price setters . It will usher in a new era of forest management with profound social and economic impacts.

Addressing uncertainty in forest carbon policy analysis

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: Policy analysis using forest and land sector models is sensitive to several factors that influence projections including model specification, measurement error, aggregation/attenuation bias, and uncertainty about future conditions. This paper considers the effects of modelling choices and of climate variation on carbon sink potential in the United States and estimates of potential policy efficacy. Our analysis is based on a coupled land use-carbon dynamics model we call the Carbon and Land Use Model, or CALM, that simulates land use changes between all persistent land uses on nonfederal lands and the resulting effects on carbon sequestration based on the dynamics of forest inventories for all ownerships (growth, disturbances, and harvesting) across ecological regions (we also account for carbon dynamics on other land uses). We estimate the influence of model specification choices in both land use choice and carbon components of the model on projections of national carbon sinks. Both are sensitive to how data are aggregated for modeling—i.e., the spatial scale of analysis—but also to model specification. Forest carbon projections are especially sensitive to how yield curves are specified. In addition, we consider the dual climate-driven effects of shifting forest productivity and forest disturbance regimes on these estimates. We explore model-averaging strategies for addressing risk and uncertainty in our policy modeling. However, while these sources of uncertainty may influence the precision of projections it's not clear that they alter, or bias policy prescriptions given the high social costs of greenhouse gas emissions.

Armington models within the framework of a partial equilibrium model for forest products markets

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: Trade plays an important role in the explanation of economic development, wealth, and intercultural exchange. Therefore, bilateral forest products trade is one key factor in the analysis of national and international policies and political strategies. In this context, side effects caused by shifting trade patterns, like leakage or changing production and trade structures, could undermine efforts for, e.g., climate protection or the preservation of biodiversity. The aim of this study is to analyse bilateral trade patterns in forest product markets and adapt them for scenario-based policy impact assessments within a global partial equilibrium model, namely the global forest products market model (GFPM). Currently, the model framework builds on the basic assumption of perfect competition and homogeneity of wood-based products across the world. Trade within such frameworks is only driven by prices and transport costs. However, this so-called "law of one price" (LOP) has a major disadvantage: if trade barriers or consumer preferences exist, the response of such a model may become unrealistic. Hence, we adopt and implement an alternative modelling approach, named the Armington model. The main assumptions within this framework are that (I) each country produces a certain type of good and that (II) consumers, depending on individual consumer preferences, want to purchase products from each country to a certain degree. This approach mirrors the idea of imperfect substitution between products of different origins. The key parameters in the framework are Armington-elasticities. They can be described as elasticities of substitution between domestic and foreign goods. Implemented in a partial equilibrium framework, it is assumed that these parameters will help to model more realistic response patterns for bilateral trade than market models based on the assumption of product homogeneity would. This study will outline how Armington-elasticities can be estimated for different wood-based products traded in international forest products markets, and it will be shown how these parameters can be implemented in the GFPM for scenario-based policy impact assessments.

Balancing Carbon and Costs: Unveiling the Climate Change Mitigation Potential and Opportunity Costs of Forest Lands Diverted from Forestry use

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: The revision of the Climate Protection Act in Germany has led to the adoption of more stringent climate protection targets. To accomplish this goal, specific carbon reduction targets have been established for the LULUCF sector by 2045. One potential measure for mitigating climate change and achieving LULUCF objectives is the permanent cessation of raw timber production in commercial forests. However, this cessation would also increase the risks of stand mortality due to climate change impacts as forests age. Unfortunately, there is a lack of comprehensive knowledge regarding the long-term effects of this climate change mitigation option on the various carbon pools within forests.

In order to bridge this knowledge gap, a study was undertaken to evaluate the ramifications of climate change on the storage capacity of various carbon pools within forests, as well as the associated opportunity costs of setting aside forested areas in Germany, considering diverse RCP scenarios. The study employed the Forest Economic Simulation Model (FESIM) as a tool for analysis. To facilitate our research, we have constructed a series of idealized exemplary forest enterprises by leveraging data from the German Forestry Accountancy Data Network. This approach enabled us to capture the diverse spectrum of forest production in Germany, illustrating the pronounced regional variations. The preliminary findings of the study indicate that set-aside forestland plays a crucial role in sequestering carbon dioxide. Furthermore, the study identified key factors influencing the effectiveness of set-aside forest land in mitigating climate change. Moreover, the study explored the opportunity costs linked to set-aside forest land, which refers to the foregone benefits incurred by allocating land for forest protection and climate mitigation instead of other potential uses such as timber production.

The study's outcomes aim to support policymakers and forest landowners in making well-informed decisions regarding the establishment of set-aside forest lands, while also estimating their opportunity costs. Additionally, the results underscore the importance of considering the trade-off between the beneficial and protective functions of forests and the associated opportunity costs. Furthermore, it presents a case study from Germany that can assist decision-making processes in other regions grappling with similar challenges.

Diversification of tree species selection at different spatial scales to adapt forest enterprises to climate change and extreme weather events

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: Climate change and increasing extreme weather events challenge future productive potentials of forest enterprises. Diversifying the tree species composition is a frequently discussed adaptation strategy. It promises advantages for forest enterprises through product diversification and a potentially higher biophysical stability of mixed stands compared to monocultures. However, it has been rarely studied whether diversification can mitigate the economic consequences of increasing extreme weather events at different spatial scales.

We investigated (1) how diversification strategies perform compared to other adaptation strategies under climate-driven disturbances at the stand level, (2) which consequences extreme weather events have on wood revenues at the regional scale, and (3) whether diversification across regional spatial scales buffers the economic consequences of extreme weather scenarios for large forest enterprises.

To address these questions, we further advanced simulation-optimization approaches based on Modern Portfolio Theory (1, 3). Econometric time series analysis (2) was used to inform spatial upscaling from a stand-level portfolio model (1) to a large forest enterprise with several planning units (3).

We found that proactively diversifying tree species composition, including non-native, highly productive species, outperformed reactive adaption strategies, such as bark beetle management (1). At the stand level, adjusting tree-species composition compensated for the adverse economic effects of increasing climate-driven disturbances. The econometric analysis revealed that market oversupply, rather than quality losses, decreased wood revenues after large disturbance events at the regional scale (2). Applying this result in the enterprise-level model (3), we found that the optimal species diversity decreased under increasing probabilities of extreme weather events. Under a risk-averse objective function, stand types with low investment risks were preferred. Diversifying tree-species allocation across regional spatial scales did not buffer the economic consequences of extreme weather events.

Our results underline the importance of larger spatial scales for assessing the consequences of extreme weather events on possible economic adaptation strategies of forest enterprises. Our new insights challenge the hypothesis that diversification strategies also buffer the economic consequences of climate change at larger scales. They point to the need to reduce investment risks for production-oriented forest enterprises if society seeks stable, diverse forests that provide multiple ecosystem services.

EU high resolution forest resources and mill site analysis for Sustainable Development in the Forest Industry

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: The forest industry plays a crucial role in the production of various wood-based products, ranging from lumber and paper to furniture and bioenergy. As the demand for these products continues to grow globally, questions arise regarding the ability of wood resources to meet this increasing demand. In the European Union (EU) currently over 500 million m3 of wood are harvested annually. The wood industry processes the majority of the harvested wood, but little is known about the interplay between industry demand and the availability of timber resources. In this study, it is evaluated to what extent regional wood supply meets the demands of local wood industry across the EU. To investigate this, we used the EFISCEN_space model, which offers a spatially explicit distribution of wood resources on National Forest Inventory plot level data, including assortment details about the species and diameter composition. For the demand side, we compiled the European Forest Industry Database (EUFID), which encompasses the location and capacity of 6,000 forest industry facilities, categorized into three value-chains: sawmills, pulp and paper, and bioenergy. We then compared the balance between wood supply (derived from EFISCEN-space) and wood industry demand (derived from EUFID) to evaluate to what extent regional wood supply meets the demands of local wood industry. Our study demonstrates that an optimal allocation of local wood resources may not only supply the volume needed by the sawmills, but also have a significant potential for increase. However, in such reallocation scenarios the available feedstock falls short in meeting the capacity of pulp and bioenergy mills. Through the use of high-resolution spatial models of resource supply and industry demand, analysis of the potential of bioeconomy trends becomes feasible. This contribution offers preliminary insights into the regional wood

industry chain. By assessing the compatibility between wood supply and industry demand, we contribute to a deeper understanding of this sector, by building a reliable database and methodology upon which to base future projections for a sustainable development of the forest industry.

Justifications for improving site productivity evaluations in forest planning: a Value of Information approach

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: Forecasting the development of the forest requires accurate information about the current state of the forest and the site productivity. Forest site productivity is commonly quantified as a 'site index', providing information on current and potential future stand growth. Accurate evaluations of the site index can improve growth projections and ensure effective forest planning. Previous research has detailed negative impacts on net present value estimations that could arise from inaccurate site index estimates and consequential incorrect timing of management decisions. While improved estimates of site index are possible, they require high-quality data that will substantially increase the total inventory cost. To ensure cost efficiency of the data, the value of information (VoI) should be assessed.

We quantify the VoI for a range of inventory methods for site index evaluation. The methods include a direct method based on combinations of multi-temporal airborne laser scanning (ALS) and digital aerial photogrammetry (DAP) data, a curve-fitting method based on the same data, as well as conventional practices, i.e., the site index obtained from an operational forest management inventory. The direct method predicts the site index from ALS or DAP variables, while the curve-fitting method evaluates the site index from the predicted dominant height development over time. The direct method based on ALS data is currently in operational use in the Norwegian forestry sector. However, alternative methods for site index evaluation that could potentially reduce the costs and ensure better management decisions are of interest to decision-makers.

To calculate the VoI, we use a stochastic programming model that accounts for the uncertainty in the site index estimates. The model aims to simultaneously maximize the net present value and minimize conditional value at risk, considering specific economic goals and ecological indicator thresholds. We explore the difference in VoI across the site index estimates, according to the decision maker's goals and risk aversion preferences. The results of the study will assist decision-makers to identify the best site index estimation method to use in their forest inventory that will ensure optimal management decisions.

Potential contributions of the forest sector to 1.5°C-compatible socioeconomic pathways (SSP) considering parametric uncertainties

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: Forest-based measures to mitigate climate change are increasingly recognized as critical components of emission abatement portfolios to reach the global temperature target of the Paris Agreement. The impact on forestry and wood products markets of the growing integration of forest-based measures to achieve climate change mitigation targets remains not well understood from a global perspective. This could partly be attributed to the lacking specificity regarding the targeted contribution of the forest sector in global climate change policies (e.g. nationally determined contributions (NDC)).

To address this research gap, this study calculates reductions in greenhouse gas (GHG) emissions necessary to reach country-specific emission levels described in the SSP1-1.9 scenario (1.5°C-compatible) relative to emission levels projected under the SSP2-4.5 scenario (reference) as a potential mitigation gap. In a scenario-based analysis, the impacts on forestry and wood products markets resulting from a gap reduction via forest-based measures for climate change mitigation are studied using the Global Forest Products Model (GFPM).
Across the scenarios, the gap in country-specific emission levels is closed stepwise up to 50% using different combinations of forest-based measures for climate change mitigation. For this analysis, the GFPM is extended to integrate projected carbon removals and emissions from forestry and wood products as well as related substitution effects as optimization constraints.

The effects of uncertainties related to parameters used to quantify the carbon removals and emissions from the forest sector on the impact on forestry and wood products markets are evaluated by applying Monte Carlo simulations.

This study simultaneously provides insights into the potential contribution of forest-based mitigation measures in reaching 1.5°C-compatible emission levels and explores the resulting impacts on the forest sector when parametric uncertainties are considered. In this way, this study aims at supporting the specification of emission mitigation contributions of the forest sector in global climate change policies.

Predicting bilateral trade flows in wood markets by using gravity models and neuronal networks

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: Trade data are often inconsistent and fragmented, economic shocks jolt market response behaviour, and effects ramify across sectors and countries, which are highly interwoven via international trade in a globalized economy. Therefore, uncertainty is an important factor in modelling international trade flows. One of the first attempts to deal with these issues was the gravity model of trade. These started as mere econometric models to explain bilateral trade flows and became popular in wood market analysis as they gained empirical evidence. Over time, the theoretical foundation has improved, and with it, predictions made with such deterministic models have become even more precise. Nowadays, data driven machine learning methods such as artificial neuronal networks (ANN) offer the possibility to further enhance accuracy in the predictions of complex non-linear relationships. However, the major disadvantage of such data-driven modelling procedures is that the resulting parameters of ANN cannot be directly interpreted. Thus, this "black box" approach has the potential to reduce uncertainties in the prediction of existing bilateral trade flows while simultaneously having reduced explanatory value compared to deterministic gravity models. Against this background, the aim of this study is to compare the ability to predict bilateral trade flows of ANN and gravity models. Therefore, we apply both methods to model bilateral trade flows for different types of forest products on a global scale for the same sets of data. Our results show that the data-driven ANN tends to predict existing bilateral trade flows in wood markets more accurately than gravity models and thus can help to further tackle uncertainties in general trade projections. However, forecasting with ANN is only possible in case that no structural changes are implemented in this procedure, as ANN are explicitly trained to match the existing data. This is where deterministic models can deliver more reliable results.

Profit efficiency of the Cross Timbers region in the production of ecosystem services: an application of stochastic frontier analysis

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: The Cross-Timbers is a forested region that stretches from southern Kansas to central Oklahoma and into Texas. As an essential transitional ecotone between the eastern forest and Great Plains grassland biomes, this region is crucial for maintaining biological diversity. Much of this land is not actively managed for the critical ecosystem services that benefit people living in the region. The Cross-Timbers face threats from natural and anthropogenic factors, including climate variability. The lack of proper forest management (prescribed fires and thinnings) has resulted in a reduction of wildlife habitats and water availability, and an increased risk of wildfires surrounding human development. These losses in ecosystem services are concerning given the high population pressure, with over 17 million people projected to be directly dependent on these services by 2040.

Therefore, analyzing the economic capacity of the region to efficiently use and provide natural resources is critical for improving economic wealth. Efficient forest management practices can result in increased forest productivity and profitability, leading to the development of markets for other non-timber benefits, such as carbon sequestration, hunting, biodiversity, water production, and recreational activities. These practices can position the Cross-Timbers forests as a feasible commodity for emerging natural resource markets.

To assess the economic efficiency of the region's forests, we applied stochastic frontier analysis, which measures profit efficiency. Using data from the USDA Forest Inventory and Analysis program at the forest plot level between 2004-2019, we examined the impacts of forest management practices, natural disturbances, and climatic variables on profit efficiency. Our results indicate that the Cross-Timbers forests are economically inefficient in the provision of ecosystem services. Damage caused by abiotic factors reduces profit efficiency by 3.4%, while damage caused by biological factors increases profit efficiency by 23%. The productivity of the site also increases profit efficiency by 17%. Overall, forests in this region generate negative profits when providing ecosystem services. Kansas forests generate higher and more stable profits over time than those in Oklahoma and Texas, and managing softwoods shows to be a more economically attractive alternative than managing oaks, which show the largest variability in profits across the three states.

Simulating international forest-based value chains under supply shocks – An agent-based approach

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: International forest-based supply chains face inherent risks and uncertainties stemming from diverse factors, including political and climate change, market fluctuations, and supply disruptions. Agent-based modeling (ABM) provides an approach to improve the understanding of the complex interactions between natural, social, and economic factors. ABM consists of autonomous agents and their environment, utilizing a bottom-up modeling approach where complex system states emerge from the behaviors of individual components.
We present the design of an empirically based ABM focusing on international markets within forest-based supply chains, aiming to gain insights into factors influencing resource availability. The modeling framework incorporates five distinct agent species: foresters, sawmills, intermediaries, producers, and consumers. The modelling environment consists of a forest module and four market modules. In this round-based simulation, agents either act as suppliers or demanders negotiating based on their inventories and price expectations. Each stakeholder group is highly dependent on upstream and downstream markets. Other markets and macroeconomic developments are considered but not explicitly modeled, thus defining the model boundaries. While the model is implemented with data from multiple sources, abstract parameters were determined by calibration. Simulation results were validated with historical production data of the modelled nations. Integrating empirical data can enhance the realism and relevance of ABMs, but it necessitates a thorough understanding and analysis of the input data. Challenges associated with addressing data inconsistencies are discussed.
The developed model serves as a platform to assess what-if scenarios, wherein agents follow defined sets of rules that can be modified, as for example adjusting demand, production capacities or preferrences in suppliers. This allows to test effects of various policies and agent strategies. Furthermore, the model facilitates the examination of market disruptions resulting from e.g. environmental changes. Simulating the impact of these disruptions provides insights into the system's vulnerability to changing conditions, crucial to foster sustainable development and avoiding unintended repercussions.

THE COSTS OF SUSTAINABLE FOREST MANAGEMENT IN BRAZILIAN FOREST CONCESSIONS

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: The Amazon Rainforest is the world's foremost managed rainforest for providing both timber and non-timber products. Because more improved management techniques are required, the costs of sustainable forest management (SFM) are high and different from traditional logging or legal deforestation in Brazil. Identifying and characterizing SFM costs allow defining the average production cost and determining its economic viability. Thus, the objective of the study is to define the average production cost of round wood originating from the SFM of a forestry concession in Brazil. The study area is the FLONA of Caxiuanã, more precisely the FMU III, under concession by CEMAL since 2016. The FMU III has an effective management area of 49,182.48 hectares and a cutting cycle of 30 years.That Indicates Units of Annual Production with an average area of 1,640 hectares. Cost data refers to the year 2020 and are categorized into different groups defined by the concessionaire and the research group, namely: administrative, taxes/fees, concession (price paid to the Brazilian Forestry Service for the volume of wood harvested), depreciation, insurance, interest on invested capital and operation (logistics, employees and parts and maintenance). With the collected data, the average cost of production (APC) was defined. Exploration and concession costs represent more than 71% of total costs, with wood transportation being the costliest exploration activity representing less than half of the concession cost. Of the total costs, 77.83% are variable according to wood production and 22.17% are fixed costs.That is, they do not change with the increase or decrease in production. The Average Cost of Production found is US$ 91.31 per cubic meter, which is the minimum value for selling log wood. The high presence of variable and exploration costs indicate the possibility of improving economic viability with increased productivity in the area. The high impact of the concession cost indicates the importance of a good definition of the minimum price of the logged wood in the Brazilian forest concessions.

Using large-scale forest inventory data and robustness tests to discern uncertainty in industry-related carbon effects

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: National forest inventory (NFI) data offer a wealth of information that can help assess forest conditions including carbon stocks in different pools and at multiple scales. The spatially-explicit incorporation of ancillary information such as wood products industry location can help discern how industrial activity affects total and individual carbon pools. Large data availability supports statistical inference, but methods used to infer statistical impacts are not free of uncertainty. Here, we present analyses aimed at inferring land rent curves reflected on how carbon pools within live trees, dead trees, and soils vary along distance from NFI plots to the wood products industry. We rely on data from the US National Forest Inventory and Analysis Program database with additional spatial-explicit information from the Southeastern US to infer these relationships using panel models after propensity matching algorithms. Specifically, we focus on industry-carbon relationships in the case of the wood pellet industry as a fast-growing sector of international relevance. We illustrate how model specifications and other common approaches to test the robustness of findings yield expected varying results. We discuss how differences in estimated industry-carbon relationships might point to inherent uncertainty emerging from underlying data, and how these might vary by particular carbon pool. This is of direct relevance to climate policy where best available data and analyses should help examine how the wood products industry can support a carbon neutral agenda.

Value of information in the planning of cost-effective operational forest inventories

T2.1 Accounting for risks and uncertainties in forest-based businesses, sectoral projections, and policy design

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Abstract: Operational decisions regarding the harvest of forest stands are typically informed using standing volume estimates of assortments in forest stands. Often, such estimates come with high uncertainty, and to ease decision-making, pre-harvest inventories are carried out to reduce uncertainty. However, both the prior volume estimate and the inventory data subject to measurement error constitute a source of uncertainty that should be accounted for in decision-making. Furthermore, the collection of inventory data comes with costs that may offset the gain from the reduction in uncertainty.

We present an approach for the planning of cost-effective operational pre-harvest forest inventories based on forest stand data and uncertainty information. Our approach is formulated around a sequential, two-stage Bayesian decision-theoretic planning problem involving an inventory decision and a harvest scheduling decision. The inventory decision considers the choice of the accuracy of forest inventories, which influences the harvest timing decision through the data obtained from the choice of inventory. Subject to a forest inventory budget, the developed approach can be used to find the inventory decision that maximises the value of information with respect to the harvest timing decision.

We develop a computational method for approximately solving the planning problem, and apply the developed method with realistic data derived from Swedish forest stands, obtaining optimal inventory decisions under a range of planned inventory budgets.

T2.2 At the edge: (Il)legal and (il)legitimate

A monitoring framework for planned (legal) and unplanned (illegal) deforestation to support climate change mitigation strategies in Indonesia

T2.2 At the edge: (Il)legal and (il)legitimate

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Abstract: Globally, deforestation continues to take place at alarming rates. Indonesia is one of the tropical-developing countries with relatively high deforestation rates. Indonesia has been increasingly pursuing actions to curb deforestation, as one of the key strategies in climate change mitigation. In early 2022, the Government of Indonesia (GoI) launched Indonesia's 'FOLU net sink 2030', a scenario where the absorption of greenhouse gasses (GHG) is targeted to be balanced or higher than emissions in the forest and other land use (FOLU) sector in 2030. Preventing or avoiding deforestation, particularly from illegal/unplanned sources, will be the key strategy to achieving this target. In implementing the strategy, the GoI has specifically developed a framework to identify potential locations for planned and unplanned deforestation using past deforestation data, where locations with higher deforestation possibility can be prioritized in monitoring and prevention activities. Nonetheless, the framework does not identify actual planned and unplanned deforestation which is important to support law enforcement against illegal deforestation. As an academic exercise and also to complement the framework developed by the GoI, this study developed a framework, consisting of a set of criteria and indicators, that can be used to monitor actual planned and unplanned deforestation in Indonesia. The criteria and indicators were developed based on the definition of planned and unplanned deforestation adopted by the GoI and the national laws and regulations. Criteria used to monitor planned deforestation include: burning done by traditional communities/indigenous peoples; business licenses; social forestry; and national priority projects. Criteria for monitoring unplanned deforestation are uncontrolled forest and land fires; and forest encroachment. The application of the criteria may lead to different results in different contexts. Indonesia may face some challenges in applying this framework, namely: potential overlapping land-use rights; the development of burning maps, and data and information accessibility. In addition, this study should also be complemented by a test trial of the framework using spatial analysis.

Keywords: Deforestation; Illegal Deforestation; Legal Deforestation; Climate Change Mitigation; Indonesia

Addressing timber (il)legality in the Western Balkan: Stakeholder perspectives on the EUTR and the new Regulation on Deforestation-free Products

T2.2 At the edge: (Il)legal and (il)legitimate

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Abstract: Some Western Balkan countries are among high-risk timber exporting countries as they are considered to comprise the corridor of illegal timber and timber products from the East to the West. In general, research on deforestation and illegal forest activities in Balkan countries received less attention compared to other high-risk regions and countries, such as tropical ones. Although some studies focus on the legal aspects associated with forest management, timber harvesting and processing in the Western Balkan countries, they mostly target the topic just partially (e.g., focusing on trade data and trends) or pay attention to the role of existing policy tools (e.g., forest certification) in coping with the problem. This paper aims to approach timber legality issues in the Western Balkans from a different angle. Building on public policy and environmental governance studies, we approach the issue of timber legality in the Western Balkans by investigating the coherence of the national policy frameworks of five selected Western Balkan countries (i.e., Slovenia, Croatia, Serbia, Montenegro and the Republic of Srpska - BH) to the European Union Timber Regulation (EUTR) requirements. By adopting a multiple embedded case study design, we investigated national policies and regulations related to the prevention and tackling of illegal logging, as well as those dealing with the trade in timber and timber products in targeted countries and conducted a qualitative content analysis of retrieved documents to check the extent to which EU requirements are covered. Moreover, interviews with more than 30 key informants were performed across selected countries. We analyzed interviewees' perceptions about EUTR and the forthcoming EUDR looking into five main dimensions, i.e., awareness, transparency, information flow, resources, and challenges of ensuring timber legality. Following actor-centred institutionalism we further distinguished institutional and actors-oriented factors influencing the transposition of EUTR and forthcoming EUDR requirements into national policies and forest management practices. Our contribution will offer a comparative gap analysis about EUTR and forthcoming EUDR requirements' incorporation within the national policy frameworks of targeted countries as well as an overview of common and opposing perceptions on timber legality and legitimate forestry practices of key stakeholders in five Western Balkan countries.

Leveraging legality along China's and Vietnam's timber supply to reduce deforestation

T2.2 At the edge: (Il)legal and (il)legitimate

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Abstract: Illegal and unsustainable markets for timber species have significant detrimental impacts on biodiversity and can have severe consequences for indigenous peoples and local communities who depend on nature for their livelihoods. These illegal wood markets disrupt ecosystems, fuel organised crime and corruption. When governed effectively, legal and sustainable wood-based markets incentivise and contribute to biodiversity conservation, enhance the livelihoods of IPs and LCs and benefit other stakeholders involved in the supply chains.

Achieving good governance of nature markets requires a combination of international cooperation, national laws and regulations, established financial mechanisms, market-based initiatives, accurate, up-to-date data and information, traceability and transparency.

TRAFFIC approached these timber-related issues through leveraging stakeholders along the supply chain. TRAFFIC is implementing a project, funded by NORAD NICFI that leverages China's and Vietnam's significant market role in the timber supply chain from source countries in the Congo Basin, to reduce unsustainable forestry operations and illegal timber trade.

In China, which bought 67% of global tropical logs in 2018, the project prioritises three approaches:

- with customs and enforcement agencies, using tools and training to verify timber legality entering China
- with the private sector, leveraging TRAFFIC's relationships with major timber trade associations to enhance industry standards and incorporate legality verification systems into purchasing
- with China's huge public procurement that includes wood-based products, public procurement auditors to verify timber legality along the supply chain

Vietnam, another key importer of timber, shares similar approaches to building capacity of customs and forestry staff to verify imported timber legality; and work with the wood-based private sector to enhance industry standards.

At the source countries of Cameroon and the Republic of Congo, TRAFFIC is building enforcement agencies' capacity to verify timber legality and track revenue from legitimate forest sources. With community networks, it assists community forestry operators to operate and export legally, increasing income while managing forests sustainably. A timber tracking tool will reduce opportunities for corruption and help customs identify legal/illegal timber shipments at the borders.

Along the supply chain, knowledge products, work with the financial sector and support for communication/coordination between agencies will increase detection and investigation, further deterring illegality.

Mapping (i)legality: Spatial Assessment of athorized, and illegal suppression of native vegetation in the State of São Paulo, Brazil

T2.2 At the edge: (Il)legal and (il)legitimate

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Abstract: Deforestation of tropical forests and native vegetation poses a significant threat to biodiversity conservation. In Brazil, the protection of native vegetation is governed by a complex legal framework that permits authorized suppression under specific circumstances. However, remote sensing data often indicate that a substantial portion of deforestation exhibits signs of illegality, while studies comparing the dynamics of total, authorized, and illegal suppression of native vegetation remain scarce. Addressing this knowledge gap, our study aims to provide a spatially explicit analysis of three databases related to native vegetation suppression in the state of São Paulo: (1) authorizations for vegetation suppression issued by the government's environmental licensing agency, (2) areas of illegal deforestation that have been effectively surveyed, and (3) the overall extent of native vegetation suppression and restoration. We collected and processed data from the São Paulo government and the Mapbiomas initiative spanning the period from 2009 to 2020, utilizing a geographic information system (GIS) environment for analysis. During this period, a total of 189,547 hectares of native vegetation were deforested in the state of São Paulo, while 673,000 hectares underwent restoration, indicating a net increase in native vegetation coverage. Among the deforested areas, 62,229 hectares (32.83%) were found to be associated with illegal deforestation, resulting in environmental enforcement actions and penalties, while 7,688 hectares (4.05%) were authorized for legal suppression. Despite the enforcement efforts targeting approximately one-third of the total deforestation events, an alarming 119,630 hectares (63.11%) of the deforested areas exhibited signs of illegality. Our study also identified distinct temporal and regional patterns in the dynamics of total, illegal, and legal suppression of native vegetation across the territory. Notably, the majority of native vegetation suppression in the state of São Paulo is attributable to illegal activities, suggesting the need for enhanced command-and-control measures to effectively reduce deforestation rates. This is particularly critical in regions characterized by a high concentration of illegal deforestation. Our findings underscore the urgency of strengthening enforcement actions to curb unlawful deforestation and protect the integrity of native vegetation in the state of São Paulo.

Putting numbers on (un)certainties in the traceability-illegality-risk nexus: the case of Pará, Brazil

T2.2 At the edge: (Il)legal and (il)legitimate

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Abstract: Timber extraction is a key proximate driver of forest degradation in primary and naturally regenerating forests across the Amazon. Yet we still lack elementary understanding of the supply-chains that link consumers across the world to timber extraction and associated socio-ecological impacts. Here we use data from Brazil's systems for licensing, origin control and commercialization of timber products as well as remote sensing-derived data on forest disturbances due to logging, quantifying (un)certainties and documenting (ir)regularities to assess the degree of illegality-risk of timber from native forests. We focus on the case of Pará – a top timber producing state in Brazil and contested forest frontier – using timber transport data, logging permits substantiating these, and observed forest exploitation for the period between 2009-2019 to quantify connection between reported activities (i.e. volume commercialized, area authorized for extraction) and observed forest activity (i.e. area of forest exploited). While nearly all roundwood entering the supply chain in this period can be linked to existing logging permits, only about half of the volume can be connected to a polygon that delineates an area authorized for logging. Further, only 22% of forest area identified as exploited (through remote sensing) overlaps spatially with authorized areas.The remaining exploitation displays different degrees of illegality risk, with varying levels of uncertainty in links to logging permits and upstream supply-chain actors. 16% of exploitation falls completely outside the Environmental Rural Cadaster (CAR) areas (including in protected areas and indigenous territories), carrying the highest illegality risk. By documenting limitations of the existing traceability systems, this study provides inputs to the debate surrounding the effectiveness of existing environmental regulations in Brazil, identifying loopholes in existing systems that need to be addressed in order to improve policy implementation. It also provides practical insights on how shortcomings in transparency and data quality of the the existing traceability system can be overcome to help identify illegality risks.

The EU Deforestation Regulation's perceived legitimacy

T2.2 At the edge: (Il)legal and (il)legitimate

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Abstract: The aim of our presentation is twofold. First, we theoretically contribute to legitimacy scholarship by expanding the theoretical concept of legitimacy beyond the EU and its Member States, assessing the role of legitimacy in EU policies affecting external states. Second, we empirically analyze how the perceived legitimacy of EU external action-oriented trade policies by EU and third-country state and non-state actors influenced the new EU Deforestation Regulation's (EUDR's) regulatory design and potential effectiveness in driving desired behavioural changes of target actors and halting global deforestation and forest degradation. The EU adopted the EUDR in 2023 to close regulatory gaps in not regulating supply chain sustainability, neither of timber and timber products nor agricultural commodities. The EU does not have the jurisdiction to regulate legal and sustainable production processes abroad and can only influence those through demand-side and supply-side oriented policy instruments such as trade rules, trade agreements, and conditional development support. EU trade rules could support cleaning up EU supply chains and help meet the EU's climate neutrality target, as defined in the European Green Deal. However, trade and market leakage incentives to divert trade flows of illegally and unsustainably produced commodities to less regulated markets can reduce potential global environmental impacts. The perceived legitimacy of legislative interventions is assumed to affect behavioral changes. Legitimacy requirements for political procedures beyond the state level are well-researched in the context of the EU issuing authoritative decisions that bind its Member States. However, EU decisions and policies like the EUDR also affect states beyond the EU. Drawing on legitimacy scholarship, key informant interviews, and a review of key policy and legislative documents, we analyze the EUDR's perceived legitimacy and potential effectiveness as an external action-oriented EU trade policy from the perspective of EU and Indonesian state and non-state actors.

Who defines legality? The competing legitimacies of EU, national and traditional laws in Ghana's cocoa forest landscapes

T2.2 At the edge: (Il)legal and (il)legitimate

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Abstract: This paper examines the political ecology of competing discourses around legality, social justice and legitimacy across international to local scales. It draws on the indicative case of the European Union's recently enacted deforestation-free regulation (EUDR) banning the import of cocoa and other key commodities found to be produced through deforestation and/or violation of forest laws, and struggles over legal and traditional tree tenure on cocoa forest landscapes in Ghana.

This research is grounded in analysis of 93 formal submissions to EUDR consultations by different stakeholder groups, combined with case study research in two cocoa forest landscapes in Ghana, involving 44 interviews, participant observation and 32 focus groups. We examine different stakeholder framings relating to the relative social justice and legitimacy of the EUDR and/or national and customary tree tenure laws in Ghana. In regards to the EUDR, we find a diversity of international stakeholders in support of the EU's prohibition on both legal and illegal deforestation, as well as requirements for in-country legal compliance. In other words, these international actors support the unilateral imposition of the EU's normative priorities for forests on external countries in ways that may exceed national laws, while also demanding strict enforcement of national laws. Within Ghana, we find government actors supporting the state's centralized control over native trees on cocoa farms. Farmers, in turn, perceive injustice in the state's implementation of existing tree tenure laws. Meanwhile within the context of the EUDR, farmers cannot produce cocoa on their privately owned forestlands post the cut-off date established by the EU. Within such a context, international laws such as the EUDR that impose additional sanctions on local use of forest resources, while reinforcing exclusionary state laws, risk exacerbating inequalities in access and benefits from forest resources, and deepening local perceptions of injustice and illegitimacy.

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

Heterogeneous Utilization of Domestic and Imported Wood Resources in the Republic of Korea

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: In the case where the pattern of wood resource utilization within a country varies depending on its origin, the activity data used for wood carbon accounting should be collected separately for domestically produced and imported wood. This distinction is crucial due to economic, technical, and cultural variations in the usage of domestic and imported wood, which further reflect stakeholder interests and industry context in natural resource utilization. We performed a comprehensive material flow analysis distinguishing between domestic and imported wood. The methodology captures all stages from harvesting and manufacture, to use and disposal, shedding light on each utilization flow. This approach allows identifying areas where efforts are required to enhance resource efficiency, and provides valuable data for calculating carbon storage in harvested wood products, contributing to the national greenhouse gas inventory. In our analysis, we compared the utilization patterns of domestic and imported wood concerning carbon storage efficiency. Further, new indicators for raw wood and production self-sufficiency were introduced to assess the global impact of specific wood products utilized in Korea. The findings were used to infer potential applications of carbon storage accounting methods within the context of Korea's wood usage. Our analysis revealed that domestic wood, primarily used in fragmented product production, displayed medium-term utilization and low carbon storage potential. Conversely, imported wood, procured from higher quality sources, was used for long-term products like construction materials, offering higher carbon storage potential akin to global averages. The indicators of domestic raw wood and production self-sufficiency showed significant skewness across different wood products. This study offers valuable insights for policymakers in devising strategies to enhance carbon stock and improve the efficient utilization of wood resources.

Analysis of Carbon Emission Reduction Effects of Timber Construction

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: The effect of reducing carbon emissions of timber buildings can be defined as the carbon storage effect of wood as a building material and the substitution effect of carbon-intensive materials such as steel or concrete to wood, which is a carbon neutral material. The carbon storage effect in timber building can be easily estimated by accounting the amount of wood used. However, the carbon substitution effect can be evaluated by comparing the amount of greenhouse gases emitted when a building of equal scale and design is constructed with wood and other building materials.

This study was conducted to showcase the contribution of mitigating climate change by expanding the long-term use of domestic wood resources. A standard model for wooden houses in Korea was developed to expand the demand of domestic wood resources. The area of standard models is 84 m2, 108 m2, and 136 m2, and are designed to apply domestic structural glued laminated timber as structural members. The amount of wood used in the model was 25.4 m3, 29.7 m3, and 41.3 m3 for each model, including structural members and panel products. The amount of equivalent carbon dioxide emitted during the manufacturing and construction stages of raw materials was 27.4 tCO2, 34.1 tCO2, and 48.4 tCO2, respectively. In order to analyze the effect of reducing greenhouse gas emissions of timber buildings, the concrete structure with the same design with the model was developed. As a result, concrete building emitted 57.7 tCO2.62.8 tCO2 and 93.3 tCO2 at the construction stage.

As the results reviewed in the study, when a concrete building was substituted to a timber building, it showed a carbon dioxide emission reduction effect of about 0.3 tCO2 per m2. The increase of timber construction using domestic wood has proven to reduce climate change by replacing carbon-intensive materials such as concrete or steel, a major building material. This study is significant in quantifying carbon emission reduction effects by replacing building materials with forest based structural materials.

Anticipated carbon mitigation from a potential establishment of a domestic mass timber supply network in the United States

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: As a sustainable and cutting-edge building solution, mass timber construction has recently attracted more attention in the United States. Mass timber use in construction aligns with the rising demand for environmentally and energy-friendly structures. A few benefits of mass timber include lowered carbon emissions, quicker construction times, and improved aesthetic appeal. Given the limited domestic supply of mass timber especially cross-laminated timber, importing it from other regions, including Canada, Europe, and New Zealand, is currently unavoidable. Using life cycle assessment (LCA), this study aims to evaluate the potential environmental benefits of manufacturing and supplying mass timber domestically compared to the business-as-usual case, where most of the current U.S. mass timber demand is met through imports from Europe and Canada. A lower carbon footprint and other reduced life-cycle environmental impacts are anticipated due mainly to reduced transportation distance and the optimized domestic mass timber supply chain network The findings from this study will help forestry stakeholders and regional planners understand the scope of economic and environmental benefits attributable to establishing a domestic mass timber supply network.

Keywords: Life Cycle Assessment, Transportation Emissions, Supply Chain, Sustainable Forests, Local Economy

Assessing global climate change mitigation strategies based on Life Cycle methods, forest modelling and National Forest Inventory data

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: Pathways to reach climate targets that limit global warming typically include the contribution of forests to provide resources that can replace fossil-based materials and energy, and to act as a carbon sink. To assess national and global biomass and bioenergy demand given different climate change mitigation policies, both global demand models as well as models for national forest resources and product uses must be applied.

In this study we analyzed three global biomass and bioenergy demand scenarios that would limit global warming to 2°C above pre-industrial levels and their outcome in terms of climate impact at the national level for Sweden. The methodological approach included global demand estimations based on simulations by GLOBIOM and simulations of the development of the Swedish forest resource conditioned on the global demand estimates. Time-dependent life cycle assessment (LCA) was used to quantify the climate impact, accounting for biogenic carbon including harvested wood products, forest value chain emissions and avoided emissions from substituted products. Consequential LCA was applied where scenarios were assessed in relation to a baseline, representing current forest management and current demand for wood for energy and products. Besides the demand scenarios, we also assessed a maximum potential harvest scenario.

The harvest level of all global demand scenarios was higher than the baseline throughout the simulations, but clearly below maximum potential harvest during the first 35 years. The demands were met, except in the most intense bioenergy scenario where harvest exceeded growth after ca 70 years. The increased harvest levels compared to the baseline reduced the forest carbon sink in all studied scenarios, while the carbon in harvested wood products increased. Higher harvest levels coupled with higher consumption of products and energy resulted in a *net warming effect* compared to the baseline, when only accounting for biogenic carbon balances. However, given that the increased output of biogenic products and energy was used to replace fossil-based products and given our LCA-settings, all studied scenarios resulted in *net cooling effect* compared to the baseline. These contrasting results highlights the importance of assumptions about substitution for the outcomes of climate impact assessments of forest systems.

Climate effects of forests and wood industry - Tightrope walk between chances and pitfalls

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: The contribution of forests and wood products to mitigate global CO_2 emissions is highly debated in science and policy. The climate services of forests are influenced by forest management and timber use. Quantitative studies on carbon sinks in the forest and timber sector show a wide range of forest management and timber use scenarios. They range from reduced management with increasing carbons stocks in forests, to increased harvesting with the aim of substituting fossil resources.

In 2010, a Swiss study concluded that in the long term, scenarios with slightly increased forest management, subsequent production of long-living products with possible end-use for energy achieved the highest climate service. In our recent study, results for Switzerland are ambiguous. For this study, we combined a model framework of Massimo/Yasso07 for Switzerland and Globiom/G4M to account for the European effects. We explored the difference between national and European perspectives and further studied the effects of discounting displacement factors. If future production of steel and concrete will become less CO_2-intensive due to decarbonization of industrial processes, displacements factors of today will most probably be reduced in future.

Preliminary results show that discounting displacement factors can shift the scenario results completely. Moreover, only considering the national perspective produced rather different scenario results than also accounting for the European forest.

We conclude that both the handling of displacement factors in the light of future climate policy and the national versus international trade balances and system boundaries are crucial to simulate global climate integer scenarios for the forest and timber sector. Main gaps we see in considering different approaches such as the production or the consumption approach. However, compliance with international negotiations and national incentives often promote national production approaches, only. Further, increasing risks of drought, biotic diseases and windthrow should be better reflected in the models.

In an ongoing project we therefore develop a national dynamic carbon-accounting framework for woody biomass, timber products and their substitution effects for fossil material and energy. In this study we plan to incorporate changing disturbance regimes in forests, new possibilities for long-living material use, material recycling, and different accounting approaches.

CO2 emission factors and carbon pay back for forest biomass for energy

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: District heat and electricity production in Denmark has over the last 30 years seen a significant transition from fossil fuel to renewables in the form of biomass, wind, and solar energy. Forest biomass make up the majority of renewable energy consumption but the ability of forest bioenergy to mitigate global warming has been questioned due to concerns over the risk of over-exploiting forest resources and the temporal shift between CO_2 emissions from wood combustion and re-sequestration of CO_2 in new forest biomass.

Building on a consumption-based accounting framework, we modelled the temporal carbon dynamics of wood chips and wood pellets supply chains for 12 utilities in Denmark covering 67% of wood chips and 96% of wood pellet consumption. A wide range of utilities in terms of size, sourcing countries, biomass origins, and heat and power production were included. Furthermore, we analysed the carbon debt and payback time of the 12 utilities' fuel transition from coal or natural gas to forest biomass.

As forest ecosystems are highly dynamic, estimates of CO_2 emissions attributable to the use of forest biomass for heat and electricity are meaningless without specification of temporal scope. We found a specific CO_2 emission for the average use of forest biomass in Denmark of 28 kg CO_2 GJ^{-1} in a 30-year perspective and 5-10 kg CO_2 GJ^{-1} in a 100-year perspective.

Transitions from fossil to forest fuel generates a carbon debt. For transitions from coal to biomass, the carbon payback time ranged from 0 to 13 years indicating that carbon emission benefits were achieved at the latest 13 years after transition. Relative cumulative net carbon emissions 30 years after the fuel transition, RCCE(30), ranged from 0.29 to 0.85 corresponding to emission savings of 15–71% relative to continued use of coal. For fuel transitions from natural gas to biomass, the carbon payback time ranged from 9 to 34 years and RCCE(30) from 0.81 to 1.03.

Contributions of wood to decreased environmental load of construction sector

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: Making and using materials for building construction is responsible for environmental impacts that are increasing due to population and wealth growth. The most effective ways to decrease the impacts of construction would be not to build at all or to renovate existing structures rather than to demolish and rebuild. If new construction cannot be avoided, the associated environmental impacts should be minimized. Wood is generally understood to cause less environmental impact than other materials. However, wood has limited global potential in construction due to limitations on the scale of production. Global concrete production, as an example, is volumetrically at least 10 times larger than the production of wood products for construction applications. Thus, it is not realistic to envision volumes of wood that could fully replace concrete. The smaller environmental impacts of wood use have inspired other materials improving their performance. While wood is no real threat to the continued use of other materials in terms of volumes, it does offer the exemplar for the greening the construction sector. Sustainably sourced wood can act, and has acted, as a 'pacesetter' in the race to develop greener construction. While wood's role in substituting fossil-intensive materials has been subject to active scientific work recently, its pacesetting role in greening the construction sector's huge environmental load is poorly understood, so far. For the forest products industries, the business case is a paradox: inspiring other businesses into improvements will decrease the relative advantage of wood, given that the wood sector's opportunities for further greening are modest. In general, the greening investments should be allocated in sectors with expectedly greatest or most rapid impacts. All materials will likely be needed in the future. There is a great chance to improve the greening speed of the whole construction sector offered by wider adoption of already available environmental frontrunner solutions. The immediate impacts would be smaller environmental footprint of the construction sector and more time to develop better solutions.

Estimating GHG substitution effects in the building sector based on LCA data and statistics in line with IPCC requirements

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: The greenhouse gas emissions associated with the use of the renewable material wood can be divided into three main effects. On the one hand, The biogenic CO_2 emissions and their removals in sinks associated with the two carbon pools "forest" and "Harvested "Wood Products" as part of the biogenic carbon cycle. The third impact relates to the other emissions of the wood processing industry as part of the manufacturing sector.

The quantification of these climate relevant effects is carried out by means of various calculation methods on different scale levels with mostly different system boundaries (land or product system) and concerns temporally and spatially divergent dimensions (retro- and prospective effects). However, a well-founded and robust analysis of the climate relevance of the forest-based sector must always take into account all effects and impacts. This, in particular, applies to the estimation of possible indirect greenhouse gas reduction effects (substitution potentials) associated with the use of wood. For this purpose, several sources of data must thus be consistently combined with each other in accordance with the relevant methodological requirements.

Whereas the biogenic CO_2 emissions and their removals are best estimated in line with the the methodological requirements of the Intergovernmental Panel on Climate Change, the non-biogenic emissions of the wood processing industries cannot be determined with methods provided for national greenhouse gas inventories. This is why other approaches must be used. For this purpose, the internationally standardised Life Cycle Assessment method provides a sound basis. Especially for the construction sector, a European horizontal set of standards allows for consistently assessing the environmental performance of building products and buildings, including their Global Warming Potential.

The presentation shows how potential emission reduction effects associated with an increased utilization of wood in the contruction sector can be assessed in line with requirements of Intergovernmental Panel on Climate Change and those international Life Cycle Assessment standards from the construction sector on the basis of a combination of i) standard-compliant and representative Life Cycle Assessment data of real existing wooden buildings and their functional equivalents ii) national building statistics, and iii) well-founded housing market forecasts.

Global projections for carbon storage and substitution benefits in forest products in alternative market and policy scenarios

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: Forestry and the forest sector directly and indirectly contribute to climate-change mitigation. The use of harvested wood products (HWPs) can result in greenhouse gas emission savings if these products replace materials with a higher carbon footprint. Also, wood products may delay the release of carbon stored in trees after harvest, thus lengthening the time carbon remains stored and increasing the mean volume of carbon stock connected to a forest stand during its economically feasible rotation time. This study examines carbon substitution and storage benefits on a global scale and at the EU level. The assessment of forest sector development relies on the FORMEQ model, which is a partial economic equilibrium model for the global forest sector. The calculations are based on alternative medium-term scenarios owing to the significant uncertainties surrounding the future of the global forest sector. Factors such as geopolitical and economic turbulence, as well as environmental and economic policies such as trade embargoes, the EU biodiversity strategy, and climate policy regulations related to the forest sector can have substantial implications for the sector. Carbon storage calculations employ default parameter values from the Intergovernmental Panel on Climate Change guidelines, whereas avoided emissions are calculated using carbon replacement factors derived from recent studies. Without the substitution benefits resulting from the use of HWPs considered in this study (paper and paperboard, textile fibers, and mechanical forest industry products), global greenhouse gas emissions could have been up to 6% higher at the beginning of this decade. In addition, the HWP pool acted as a carbon sink, its carbon storage increasing approximately 317 Mt CO_2/a globally. In the baseline scenario, global substitution benefits increase to approximately 2.6 Gt CO_2 by 2030, whereas the aggregated HWP sink changes only moderately. Environmental policies that reduce harvest levels decrease the carbon storage and substitution benefits of HWPs. Several uncertainties are associated with the data and projections used in the calculations, and their impacts are assessed and discussed.

Greenhouse gas mitigation potential of wood products: A global multi-model assessment

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: Recent literature highlights the important role of forests in long-term climate action. Mitigation options in forestry include improved management of existing forests, stock preservation through avoided deforestation, reforestation/afforestation, and use of forest biomass in bioenergy systems. However, missing from most climate policy projections is a more explicit accounting of carbon stored in wood products. Wood products can provide a significant source of carbon storage in long-lived pools, and could potentially replace emissions-intensive building materials. However, we have limited information on the extent of wood product supply across long-term global climate policy scenarios, including how long-lived wood products interact with bioenergy and terrestrial carbon sequestration policies.

We build on a Forest Model Inter-Comparison (For-MIP) analysis of more than ninety scenarios using three detailed global forest sector models of (Daigneault et al., 2022). For-MIP projections reflect variation in both future socioeconomic change (SSPs) and climate policy ambition, reflected through relative concentration pathways (RCPs). In these forest sector pathways, total wood product supply increases over time, ranging 0.5 – 8.0 Billion m^{-3} by end of century. Hardwood product C increases for most, but not all scenarios, as the allocation of pulpwood to bioenergy in some scenarios reduces C storage in products despite the increase in removals relative to the baseline. However, carbon sequestration intensity of forests increases over time in almost all modeling scenarios, implying opportunities to co-produce terrestrial and wood product C storage.

Finally, we use projected bilateral trade flows from modeled scenarios to estimate regional product carbon consumption over time, and then link this with the IIASA IAM-SSP database to assess wood product carbon storage relative to cumulative anthropogenic emissions from the energy and industrial sectors. We explore drivers of regional variation in this mitigation factor to understand how socioeconomic and policy factors affect the sector's net mitigation potential and contributions to decarbonization goals relative to investments in energy and industry. Our regionalized results provide valuable policy insight on the potential role of long-lived wood products in decarbonization scenarios. We discuss policy implications and directions for future research, including the importance of considering permanence tradeoffs in mitigation policy design in forestry.

How can innovative engineered wood products contribute to climate change mitigation?

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: The building sector along its life cycle is responsible for a significant share of national greenhouse gas emissions. Manufacture of traditional construction materials, inefficiently isolated buildings or end of life demolition are life cycle phases with relevant emission sources in this sector. Wood has been demonstrated to be a sustainable construction material suitable to reduce the environmental impact of the building sector since it grows naturally, it is thermally efficient and can be reused and recycled.

After a literature review on wood product modelling, the CASTLE_WPM model was published incorporating key functionalities to estimate carbon stock changes of harvested wood products. This model was useful to identify lifespan and recycling rate as key parameters to define climate change mitigation strategies. This work and other literature identified a high climate change mitigation potential when extending lifespan of low-quality wood products traditionally employed for short-lived uses. The application of later CASTLE_WPM model versions incorporating the substitution effect identified an expiry date of this substitution effect due to decarbonisation pathways in line with the Paris Agreement commitment.

Based on this knowledge, a new research line started to evaluate the potential use of low-quality pine wood from Mediterranean forests, commonly employed to produce short-lived pallets for transportation of goods, as construction material. Manufactured prototypes, tested and demonstrated in operational environments, already showed the potential use of Cross Laminated Timber made with local maritime pine combined with cork as isolation material for structural and non-structural elements. To test its reusability, fabricated modules were assembled and disassembled to be reassembled on different locations.

Future research directions at the Forest Science and Technology Centre of Catalonia aim to build on this knowledge to develop new bio-based products and evaluate the potential use of local wood for innovative construction solutions. Wood combinations from different Mediterranean species (soft and hardwoods) and sources (virgin, reused and recycled), as well as bio-based glues, will be employed to manufacture and test innovative engineered wood products. In parallel, life cycle analysis of the current construction materials employed at local scale will serve to quantify the substitution effect of the engineered wood products developed.

Impacts of Forest Management in Protected Areas in SR on Carbon Balance in Harvested Wood Products

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: Sustainable forest management is an internationally established holistic concept that is able to dynamically adapt to changing conditions, including responding to climate change. Prioritizing certain ecosystem services over others can have a direct impact on the ability of forests to fulfil their functions in a balanced manner. The efficient utilisation of wood, as one of the forest products produced within the SFM process, aimed at the production of harvested wood products (HWP) has an additional added value in the form of their substitution for other fossil-based materials and fuels. At the same time, it improves the contribution of the sector to the carbon balance. The ongoing transformation of national parks in Slovakia, is characterized by the transfer of management of public forest lands from the governance of the Ministry of Agriculture and Rural Development of SR to the Ministry of the Environment as well as by the creation of new no-management zones, envisages leaving up to 75% of the area of national parks without any human interference. The aforementioned change in the care for forest ecosystems will affect, among other things, the production of wood. In addition to social and economic impacts on the affected rural areas and the availability of wood for related industries, the expected reduction in wood production and supply will also result in a change in the volume of carbon stored in HWP. The aim of this paper is to quantify the impacts of management changes in national parks on the volume of carbon in HWP due to the reduction of the available of wood raw material. The analysis is based on empirical data and forecasts of the development of standing volume and level of timber harvesting as a result of the expansion of the no-intervention management regimes. Input data on the available volume of wood were redistributed into the roundwood quality categories based on the current and predicted structure of assortments. The standard IPPC procedures were used for conversions and calculations into outputs. The volume of carbon stored in the HWP by 2023 is compared with its projected scenario by 2030 under changed forest management.

Including time and future technologies in substitution factors of wood use – towards a framework for dynamic-prospective Life Cycle Assessment

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: Wood use is a popular climate change mitigation strategy due to the dual advantage of product carbon storage and substitution of fossil-based alternatives. Yet, the future climate benefit of wooden products is highly uncertain because of the time-dependency of the type of product, the substituted material, the production technology, end of life and the decarbonization of the broader economy. The climate benefit of wood products in forestry assessments is typically assessed with substitution factors, which are derived using comparative Life Cycle Assessments (LCA) of the wood product and the replaced conventional product. Previous research on the temporal sensitivity of substitution factors has strengthened the consensus that LCAs for wood products should be dynamic, considering the timing of carbon sequestration, storage, and release. In addition, recent developments in prospective LCA have allowed to incorporate future economy-wide decarbonization effects into Life Cycle Inventory databases, yielding background data for scenario-based LCAs at distinct future years.

This work proposes a novel framework to link the use of prospective Life Cycle Inventory databases with dynamic Life Cycle Assessment. It showcases why it is necessary to combine both dynamic and prospective LCA to obtain an accurate, time-explicit assessment of the current and future substitution effects of wood products. The proposed prototype approach uses the life cycle inventory from the corresponding time-specific database for each time-specific process in the product system to calculate the dynamic LCA. This approach is novel as it treats time consistently across all four life cycle assessment steps: goal and scope, life cycle inventory, life cycle impact assessment and interpretation. The method is demonstrated with wood products but it is applicable to any product or system. Obtained results are compared with the results of static, dynamic and prospective LCAs, each applied individually. The proposed framework can help to gain greater certainty on future substitution impacts and climate change mitigation potential of wood and wood-based products, as well as guide policymakers to the most climate-smart uses of wood. One future application is to link this method to a wood flow analysis of the European Union to quantify future substitution effects on a continental scale.

Long-lived wood products, a life cycle assessment to minimize environmental impacts and maximize climate mitigation

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Abstract: The use of long-lived wood products, over non-renewable alternatives, is increasingly being suggested as a way to lower CO_2 emissions and increase carbon storage. By utilizing wood for long-lived applications, i.e. in construction, furniture etc., its carbon content can stay locked away from the atmosphere for decades. In the meantime the growing trees in the regenerating forest will take up CO_2 from the atmosphere.

This study aims to identify optimal uses of (long-lived) wood products to reduce overall environmental impacts, with a particular focus on increasing carbon storage and thus climate change mitigation. The lifetime environmental impact of several, market relevant, long-lived wood products will therefore be compared to that of non-renewable alternatives. The selection of the long-lived wood products will be based on a literature review and stakeholder consultations within the 'ClimbForest' project (Horizon Europe), with a specific focus on the construction sector. This sector has a large growth potential for the use of long-lived wood products, as well as the potential to replace carbon intensive products like concrete and steel. Data on forest management, tree species distributions, harvesting techniques and value chains will also be obtained from the stakeholder consultations in order to create a set of realistic European case study areas.

A cradle-to-grave life cycle assessment (LCA), following the ISO 14040 and 14044 guidelines, will be used to calculate the lifecycle environmental impacts. In order to approach real markets as closely as possible a consequential LCA methodology will be used. The results will be analyzed and presented following the product environmental footprint (PEF) guidelines set out by the EU.

In line with recent findings in literature, we expect to generally see lower life cycle emissions for the long-lived wood products compared to their non-renewable alternatives. The aim is to identify the products and production methods whose potential emission savings are the greatest. The obtained results will be used to formulate policy recommendations and advice to the forestry sector on the optimal production, distribution and use of wooden forest products from an environmental impact standpoint.

Net Zero, Climate Positive Supply Chains for the Pulp & Paper Industry

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: The world's wood is sourced from the harvesting of tree plantations, some of which are certified as sustainably managed under long rotations, or the clearing of natural forests. Globally, 25% of global GHG emissions are attributed to deforestation and land use change. 10% of global deforestation is attributed to wood products, with pulp being a component. Pulp production utilizes a kraft process that is characterized by high energy, water, and chemical inputs, and generates significant air and water pollution. In 2021 the pulp and paper sector was responsible for about 190 Mt of CO2 emissions, about 2% of all emissions from industry and a historic high. As paper production is projected to increase through 2030 this footprint can be expected to continue to rise, and have climate change impacts along the length of the supply chain.

As a result of these pressures, the pulp & paper industry is primed to transition to a new model that offers a solution for a sustainable feedstock and green manufacturing.

EcoPlanet has developed a resource base of sustainable bamboo reforestation projects, set to remove >10Mt of CO2e over the next 10 year period. The sustainable thinning of the planted bamboo provides a vast potential resource that is carbon positive and deforestation free. On the upstream side, along with technology partners, we are pioneering a green manufacturing strategy centered on a net zero, zero waste biorefinery pulping technology. Biorefineries are to be developed adjacent to each restoration initiative, eliminating the multiple transportation steps of the current supply chain, and associated GHG footprints. This innovative new generation technology will enable the production of a high quality bamboo pulp and associated paper products that allow the pulp and paper industry, to transition to a climate positive strategy, along the length of the supply chain.

This presentation will discuss the innovation associated with the technology, the carbon savings of the pulp production, and the carbon removal benefits of the bamboo resource itself, towards a holistic, climate positive landscape that can be both scaled and replicated to meet growing market demand for paper and in the future, textile products.

Next generation carbon stock and stock change modelling in wood use: towards contributing to climate change mitigation pathways

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: Ambitious goals are set globally to reduce greenhouse gas emissions and achieve climate neutrality by 2050. This necessitates urgent societal and economic reforms, as well greenhouse gas reductions across all sectors. Wood use plays a critical role but estimating its contribution to climate change mitigation is hampered by limited information notably on the final uses of wood. Consideration of the final uses of wood and their lifespan is crucial since it influences the carbon storage and determines the substitution potentials. To address this knowledge gap, we conducted a dynamic material flow analysis for Europe that connects existing statistics on the production, consumption, and trade of semi-finished products to final uses.

We employed the Open Dynamic Material Systems Model (ODYM), which has been calibrated to track wood flows and temporary carbon storage in harvested wood products while taking their final uses into account, in accordance with the Intergovernmental Panel on Climate Change guidelines. Our findings will provide an understanding of how wood has been used in the European Union from the 1900s to the present, from wood production to final uses (construction, furniture, paper and packaging, energy, chemicals, and others). This dynamic material flow analysis is carried out as a first step towards a better understanding of the dynamics of the wood carbon stocks and flows in the European Union, with the goal of linking it to Life Cycle Assessment tools and approaches to quantify substitution effects.

On the origin of substitution impacts from wood use: A supply vs. a demand perspective

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: Climate change mitigation assessments of the forest sector from a system perspective include balances of biogenic carbon in (i) forests and (ii) wood products, as well as fossil greenhouse gases from (iii) forest supply chains, and avoided emissions, i.e. (iv) substitution impacts. For (i), (ii), and (iii) established assessment methods exist, yet for (iv) no universal approach is given. However, whether and when, e.g., a certain forest management may lead to a net climate benefit as compared to an alternative can be highly dependent on the substitution impact. A common approach in assessing the substitution impact is that of applying a supply-perspective, i.e., "from-the-forest-to-the-wood-use", often by using substitution, or displacement factors. The supply-perspective, however, suffers from two major shortcomings: (i) it presupposes information as to the shares of different applications of intermediate or final wood products, something which is seldom, or outright never, at hand, and (ii) there are no safeguards against unfeasible outcomes in terms of the amount of different wood product applications/functional units. Wood product substitution effects can thus easily be overestimated. In order to address these inconsistencies, a demand-perspective for modelling climate change mitigation potentials of wood use can be applied. In contrast to the former, this perspective follows "from-the-wood-use-to-the-forest", targeting a specific wood product application/functional unit, e.g., multi-family housing construction or textile fibers. By that, this approach does not require knowledge about intermediate or final wood product shares, and, making the outcome in terms of the amount of the application/functional unit explicit, provides checks for unfeasibility. Here the estimation of substitution, or displacement factors is an optional feature. With the case of increased wood use in Swedish multifamily-housing construction based on official housing projections, this project gives an example of a substitution impact and climate change mitigation assessment from a demand-perspective for a targeted wood product application.

Optimization of wood shifts and wood substitution impacts from a system perspective

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: Wood-based products contribute to climate change mitigation through substitution effects. Substitution effects can be generated by increasing harvest, which is limited in a sustainable forest management and can have negative effects on the forest carbon pool, or by changing import or export patterns, which influences the carbon balance of other countries. Substitution effects that are not subject to these limitations can be achieved by altering wood utilization patterns that generate additional substitution effects by increasing the amount of wood in industries with high substitution effects and decreasing in industries with low substitution effects.

Both short-term and long-term effects of altered wood utilization patterns need to be considered. On the one hand, substitution effects might change over time due to a changing energy mix. On the other hand, altering wood utilization patterns leads to changes in the carbon storage pool of harvested wood products. This raises the question of how to distribute wood over the wood utilization system in the best way in terms of climate change mitigation.

The System Dynamics Model "WOODSIM" is used to quantify substitution effects on a market level including value chains from the forest to all wood-processing industries. Additionally, a harvested wood product pool model is applied to show carbon storage effects. A simulation-based optimization is performed for the Case Study of Austria where the sum of avoided GHG emissions through substitution effects and carbon storage effects is maximized. Sensitivity analyses show the influence of assumptions and data uncertainties on the results.

Results will show the wood utilization patterns generating the highest Global Warming Potential savings and will provide information about where wood should be used to be most beneficial for climate change mitigation. Further research should also consider implications of altered wood utilization patterns on the social and economic dimensions of the system. Trade-offs between the dimensions of sustainability need to be considered.

Salvation by substitution? Identifying substitutes for wood-based textile fibers

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: The estimation of substitution impacts relies on a host of market assumptions. Some of the most critical uncertainties include, which non-wood products do the wood-based products substitute for, and to what extent. This study introduces a systematic framework for identifying the existence and rate of substitution based on microeconomic theory and econometric analysis, taking the case of staple fiber market.

Four datasets and three theoretical models were applied for a set of empirical model formulations. The theoretical models included i) a linear approximate almost ideal demand system (LA-AIDS), ii) a conventional demand equation quantifying cross-price elasticities, and iii) an ad hoc formulation quantifying the response of the consumption of RCFs to the consumption of alternative textile fibers. The empirical models for the latter two theoretical models included OLS in first differences, autoregressive distributed lag (ARDL), and vector error correction (VECM) models. The selection of empirical models was informed by tests for non-stationarity, cointegration, autocorrelation, multicollinearity, normality and heteroskedasticity.

The results point to regenerated cellulosic fibers (RCFs) being imperfect substitutes for cotton with an empirical substitution ratio of 13-34%, and mostly independent from the demand for polyester with an empirical substitution ratio of 0-18%. With a substitution ratio of 1:1, the marginal substitution impact would be -1.43 tonnes of fossil carbon avoided per tonne of biogenic C contained in RCFs (tC/tC). With the empirical substitution ratios, an additional unit of RCFs produced leads to an increase of fossil emissions of 0.12-0.71 tC/tC. The explanation is that only part of the RCF supply replaces alternative materials, while the rest merely increases overall textile supply and thereby the overall fossil emissions. This result highlights the difficulty of decoupling the environmental footprint of the textile sector from the growing consumption by substitution alone.

Empirical substitution ratio points to historical evidence, and may not necessarily reflect future market conditions, given evolving product properties, prices, and preferences. For novel wood-based textile fibers, the substitution ratio may be higher and the fossil emission lower. The empirical substitution ratio can, however, be used as a reasonable baseline for identifying substitute products and the closeness of the substitutes.

Sustainability Impacts of Wood- and Concrete-Based Frame Buildings – a Lithuanian case study

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: In recent years, wood has received increased interest in the European building sector. The trend is driven by the recognition that wood, as an environment friendly material, can contribute to bioeconomy development and climate neutrality by 2050. In Lithuania, the main construction material among residential and public buildings is cement, even though Lithuania has a strong wood-based industry and sufficient timber resources. On the other hand, Lithuania has a strong cement industry, which gives an opportunity to compare wood- and concrete-based building materials sustainability impacts throughout the production value chain – from raw material extraction to manufacturing using the same method, while documenting and assessing the material sourcing stages consistently and transparently. In Lithuania, multi-storey wood-based building is still at the level of policy and political discussions. Therefore, the presented research focuses on quantification and comparison of the sustainability impacts of both wood- and concrete-based building materials value chains and provides applied scientific knowledge relevant to decision-makers and in this way contributes to mitigation of the climate change. In this study, we designed two- and five-floor wood- and concrete-based building material alternatives in order to compare the impact of the construction size on sustainability values. In discussion with study partners twelve environmental, social, and economic indicators were selected to perform the sustainability impact assessment of selected building materials and designed buildings. Building materials were compared by using a decision support tool ToSIA. The relevant data was gathered from local, well-known companies in the national and international arena. Findings revealed the potential of glue-laminated timber frames as a more sustainable alternative to precast reinforced concrete in the construction of public low-rise buildings in Lithuania, and they showed great promise in reducing emissions and increasing the sequestration of CO2. An analysis of environmental and social indicators shows that the replacement of precast reinforced concrete frames with glue-laminated timber frames in the construction of low-rise public buildings would lead to reduced environmental impacts, alongside a range of positive social impacts.

Sustainability of mass timber school buildings of the United States gauged by comparative Whole Building Life-Cycle Analysis

T2.3 Contribution of wood-based products to climate change mitigation: State-of-the-art and research directions

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Abstract: School facilities are vital to communities of the United States because they primarily provide the space to educate youth from kindergarten through high school (K – 12) and secondarily provide assembly spaces and emergency shelter from natural and human-induced disasters. The magnitude of public infrastructure dollars spent on school facilities is second only to highways, yet the generally poor condition of school buildings across most of the United States reflects underinvestment and a lack of cohesive building and maintenance strategies. Over a third of schools, furthermore, rely on portable buildings to meet increasing demands. While mass timber buildings currently represent a minute fraction of school facilities and construction overall, case studies specific to K – 12 schools have been growing, and there is ample research and development to demonstrate the resilience of mass timber structures to a variety of wind, seismic, and blast hazards. Mass timber framing, trusses, panels, and modular assemblies offer the versatility needed for a variety of classrooms, laboratories, meeting rooms, and emergency shelters commonly built on school grounds. Through comparative Life-Cycle Assessment of mass timber and hybrid structural systems of steel and reinforced concrete masonry, this study demonstrates that global warming emissions and the amount of energy consumption of school buildings may be cut as much as one third, while other quantifiable performance aspects are improved, through greater use of mass timber school buildings.

T2.4 Developing digital drivers for risk mitigation in forest supply chains

Blockchain Technology in Forest Supply Chains

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: Blockchain technology has the potential to revolutionize the forestry industry by providing a transparent and secure method for tracking and verifying the origin and movements of forest products.

By enabling secure tracking of forest products, blockchain can improve the forestry industry. Transactions in the supply chain can be recorded in a decentralized ledger. This increases transparency and traceability, helping to combat illegal logging, deforestation and fraudulent labelling.

The technology can also streamline processes and reduce errors and fraud, leading to cost savings and increased confidence in the sustainability of products.

Blockchain also has the potential to track CO2. But there are challenges, including ensuring accurate data and engaging actors.

However, it is important to note that the implementation of blockchain technology in the forestry industry is still in its early stages, and there are challenges that need to be overcome such as ensuring the accuracy of the data recorded on the blockchain and ensuring the participation of all relevant stakeholders in the supply chain.

In the joint project "Blockchain technology as a driver for the digitalization of forestry", potentials are being specified, the technical prerequisites are being worked out and the potential and acceptance of the market participants are being determined through a large representative survey.

The presentation will present the results of a feasibility study on the use of a blockchain-mapped supply chain for the entire forestry and timber industry, from forest to customer.

At the same time, the follow-up project to implement a prototype blockchain application in wood supply chain will show initial results, opportunities and challenges.

In addition, the technical and software requirements and possible implementation options for the use of blockchain technology in forestry business processes will be discussed. Furthermore, the results of the nationwide survey among different actors in the forestry-wood chain are explained and classified.

Climate resilience in boreal wood supply – developing technologies and emerging enablers

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: In later years the topic of supply chain resilience has received increasing R&D focus. In the forest sector, supply operations in the boreal zone have always been subject to seasonal restrictions for site availability. The gradual increase in temperatures over time has driven a corresponding development of harvesting and transport practices. However, acceleration of climate change in the north during recent decades has required increased agility in management of supply operations.

This presentation starts with a review of recent frameworks developed for capturing climate-driven risks and relating these to managerial response on strategic, tactical and operational levels. In this context the development of long-distance multimodal supply systems and sector-wide digital infrastructures provide stable channels for material- and information flow as a foundation for increased structural flexibility. At the same time developing digital technologies offer the potential for increased operational agility.

The presentation covers recent work with developing digital technologies and positions them in the framework in terms of their role for enabling climate resilience in boreal wood supply. The empirical results cover the potential effects of integrating current digital maps sources with operations data as well as grid-based weather data and satellite radar. In this context, making the jump from static to dynamic prediction of trafficability with correspondingly flexible decision support emerges as a bottleneck for both operational efficiency and environmental sustainability.

Decision making aware of uncertainty – how does it affect operational decisions in the Swedish large-scale forestry?

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: In a forestry striving for higher precision, accurate pre-harvest inventory is required. However, conducting precise inventory is both resource-intensive and time-consuming. Current pre-harvest inventory practices in the forestry industry are merely basic in the sense that only the mean values, such as estimated stand volumes, are collected. The resulting lack of information about standard deviations within forest stands complicates the decision making of individual planners, who currently must rely on their skills and domain knowledge to interpret the data and adjust for uncertainty. To make more informed decisions, new practices are needed in which uncertainty is systematically collected and accounted for, as well as minimized in some relevant sense. The latter requires tools for cost-effective allocation of pre-harvest inventory resources.

To evaluate how a possibility to account for and minimize the uncertainty would influence the decisions of planners, a group of forestry professionals were presented with a prototype tool for multicriteria decision making, designed and developed in the project. The tool enables decision-makers to balance pre-harvest inventory costs with planning accuracy. In this particular prototype, the planning accuracy relates to the expected deviation of an annual harvest plan to the monthly industry demand.

With the use of this type of tools, our ambition is to enable forestry professionals to make decisions while systematically taking uncertainty into account. While this tool is primarily concerned with pre-harvest inventory, the methods are applicable for other decisions throughout the value chain. By utilizing these results it will be possible to make informed decisions and, when the uncertainty is minimized in some relevant sense, cost-effectively increase the precision in the value chain.

Developing and managing logging entrepreneurs for a resilient forest supply chain

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: In today's global landscape, it has become a common practice to engage independent small and medium enterprises (SMEs) for forest harvesting and transport operations. The decision for forest companies to rely on SMEs instead of in-house capacities can be influenced by various factors, including market conditions, company strategies, and labor market considerations. Nonetheless, it is widely acknowledged that forest entrepreneurs offer several economic, financial, productivity, and flexibility benefits (Eriksson et al., 2017; Erlandsson and Fjeld, 2017).

From an economic and financial standpoint, the employment of entrepreneurs has enabled companies to reduce operational costs and allocate or generate capital more effectively. Furthermore, subcontracting SMEs bear the immediate consequences of demand fluctuations and market conditions. On the productivity and motivation front, studies have shown that the utilization of entrepreneurs leads to increased performance and motivation (Drolet and LeBel, 2010).

More recently, there has been discussion regarding both the advantages and limitations of wood supply systems relying on independent SMEs (Johansson, 2023). This presentation aims to provide an overview of the current knowledge surrounding wood supply systems and logging entrepreneurs. It will explore the means and strategies available to adjust wood flow and propose a framework to address the expected impacts of demographic shifts, technological advancements, and disruptions in fiber supply.

If the primary motivation for employing SMEs was to enhance productivity and cost control, their future role within the forest supply chain could potentially involve facilitating better interoperability and establishing more robust delivery systems.

Dynamic recovered-wood-system-simulation model for a sustainable material recovered-wood use on a regional scale

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: The necessary transformation from a fossil-based to a bio-based economy suggests an increased use of wood with new market players. In this context, a circular wood economy is essential for an efficient resource utilization and long-term carbon sequestration. Currently, however, about 80% of the recovered wood produced in Germany is used for energy generation and only about 20% for material applications. For a quick implementation of innovative circular utilization pathways, however, the complexity of the recovered wood system is not fully understood due to a lot of influencing factors.

Therefore, our goal is to build up a dynamic recovered wood system simulation model, which can be used for regional scenario assessment exemplified by the case study of Bavaria, Germany. In scenarios, e.g. regulatory or incentive approaches, competing uses, supply risks and feedbacks on the forest wood supply will be analyzed and recommendations for political and industrial decisions will be derived.

We will present the first modelling approaches, following the steps (1) identification and selection of the most relevant influencing factors regarding legal regulations, technical implementation, market effects, environmental impacts, stakeholder involvement, social acceptance, etc., (2) analysis of their interactions and feedback mechanisms, (3) development of the agent-based regional recovered wood market model, and (4) evaluation of different recovered wood innovation pathways developed by project partners.

Enhanced control of wood supply chains based on Apps of wood stacks measurements

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: Uncertainties in wood supply caused by weather changes, such as prolonged dryness, must be mitigated in particular in Portugal where forest residues and wood stacks stored in the forest could represent an increased risk of forest fires. Knowing the precise location and volume of wood stacks in the field is important for both: a) optimal supply chain planning (minimizing operational costs); b) forecasting priority intervention areas with an increased risk of fire, and c) ensuring traceability of the wood along the value chain. In order to provide the required information in time, new technologies based on photo-optical stack measurement running in portable devices and smartphones have been tested. This study extends these tests beyond the state-of-the art by doing an extensive comparison amongst innovative technologies and with traditional wood stack methods in use in Portugal. Hence, this study aims to a) determine the accuracy of stack measuring for different smartphone applications for Iberian Eucalyptus and Maritime-pine, and propose the most suitable; b) assess the productivity, and cost-benefit of these apps; c) propose a new methodological approach to estimate the net volume and weight of log stacks, making use of the most suitable app. The tests consist of field measurements performed with different applications, assessments of net and gross volume measured with the apps. The manual method is based on the German standard of stack manual measurements. Furthermore, the estimated volume will be compared with Lidar technology and 3D modelling of wood piles using a DRONE. The productivity will be estimated based on time study measurements. Preliminary results indicated a reduction of circa 60% in time-consuming measurement with the apps. However additional tests are required to conclude about the accuracy of the measured apps. The wood supply managers in some of the forest industries in Portugal will be involved in this study to provide their experts knowledge and assist in the cost-benefit analysis. This will be instrumental to conclude about the more suitable method for the Portuguese forest sector which could improve the wood stock control supporting the chain resilience and minimize the risks caused by adverse weather conditions.

Integrated modelling of strategic forest management and industrial capacity planning for a more resilient and sustainable forest sector

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: Sustainability is a fundamental goal of Canadian forest policy. In practice, implementation of sustainable forest management (SFM) in Canada is distributed across strategic forest management planners and industrial fibre procurement planners. The current SFM paradigm implicitly assumes that forest harvesting activities are sustainable as long as aggregate harvest levels remain below annual allowable cut (AAC) volumes determined by strategic forest management planners, yet recent studies have shown that this assumption does not always hold true. Maintaining the status quo SFM planning process may leave the Canadian forest sector (and Canadian ecosystems and society) exposed to risk of sustainability failures (e.g., fibre supply shortages, mill closures job loss, ecosystem degradation, reduced economic opportunities for future generations).

Thus, a shift in the way we approach and implement SFM is necessary to ensure continued integrity of Canadian forest ecosystems as well as a thriving and sustainable forest products sector. The current SFM paradigm features poorly aligned goals and large information gaps between government and industrial agents in the planning process—these misalignments and information gaps are poorly documented, and their net effect of the SFM planning process is poorly understood. Using a systems engineering approach, we document these gaps and explore innovative solutions for integrated modelling of strategic forest management and industrial capacity planning in the Canadian forest sector.

Activities in this ongoing research program include: development of a flexible, re-usable, open-source, reproducible modelling framework that can be used to simulate the net cumulative effects of status quo distributed planning processes; adaption of existing methods or implementation of new mathematical and data-centric modelling methodologies (e.g., simulation, optimization, hybrid simulation-optimization, machine learning and artificial intelligence methods, etc.) to model hypothetical new planning processes and business models; development and integration of powerful open-source forest carbon modelling tools to track cradle-to-grave net carbon emissions directly within the integrated SFM planning process; case studies in various Canadian jurisdictions.

Mitigating wood quality decay risks by weather data powered transport decision support

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: Climate crisis induced forest calamities such as windstorms followed by insect infestations challenge wood supply chain management. To fulfil increasing production amounts in a more sustainable, resilient, and quality-preserving manner, wood logistics decisions need to incorporate plenty of data (e.g. weather, road trafficability). Discrete event simulation proved to be an excellent means for a digital representation of wood supply chains. Further strengths in facilitating stakeholder participation and establishing credibility through visualization enable the implementation of quantitative decision support. Consequently, a virtual wood supply chain environment containing dynamic altitude zone-based risk forecasts for blue stain and insect infestations was developed. Unimodal and multimodal wood supply chains were simulated to track sawtimber quality development from roadside stocks to the wood-based industry. This enabled identifying and modelling the relationship between lead time and wood quality devaluation as well as applying this knowledge to evaluate innovative transport strategies. Complete avoidance of wood value loss can be achieved if transport capacities are synchronized with harvesting capacities to keep lead times short. Increasingly frequent and extensive forest calamities limit those coordination capabilities and produce salvage wood amounts that dramatically exceed regional available transport capacity. Under these circumstances, strategies using wood quality forecasts significantly outperform those currently being used by preventing, on average, 57% of the sawtimber devaluation. Moreover, 73% of the devaluation can be avoided if up to 25% additional truck transport capacity is deployable in peak periods of wood devaluation risks. If no additional self-loading truck transport resources are available, still 67% of the devaluation can be prevented by using the bottleneck resource of self-loading trucks more efficiently through transferring 20% of the sawlogs to rail wagons leading to a more sustainable and resilient wood procurement.

OPTIMIZING THINNING SCHEDULING, CARBON STOCKS, AND WOOD SUPPLY IN MEDITERRANEAN PINE PLANTATIONS UNDER THE RISK OF FIRE

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: Carbon pricing can be essential in promoting adaptive silviculture in Mediterranean pine forests. Commercial thinning in these forests can improve carbon sequestration and stocks, contributing to climate change. However, thinning scheduling decisions must also consider the risk of fire that affects these pine forests every year. Fires can critically impact the supply of timber products from these plantations and result in increased carbon emissions, offsetting the benefits associated with carbon sequestration. Thus, this scenario with increased uncertainty requires more robust planning approaches along the supply chain that can react and secure the delivery of products demanded by end customers. This paper presents a solution approach that combines optimization with Monte Carlo simulation to optimize the stand's thinning schedule and maximize Net Present Value (NPV) over a 10-year planning period. In addition to harvesting and transport costs, the model included revenue from two sources: sawlogs and biomass extracted during the thinning and credits from carbon stocks at the end of the planning period. The study area is in Andalusia, southern Spain, totalling a forest area of nearly 30,000 ha. Airborne Lidar data and allometric biomass models were used to estimate above-ground forest biomass, including commercial timber and carbon stocks. Airborne Lidar and Satellite imagery were also used to develop fuel and fire risk models, which in turn, were used as input in the thinning scheduling and supply chain model. The analysis focused on the impact of carbon prices on NPV, optimal thinning schedules, flows of sawlogs and biomass products to customers, and carbon stocks at the end of the planning period. Carbon prices and fire risk also impacted the flow of sawlogs and biomass delivered to end customers. These results reveal that thinning schedules, wood supply, and NPV are very sensitive to carbon prices and damage by fire.

Towards an innovative digital architecture for more resilient forest-based supply chains

T2.4 Developing digital drivers for risk mitigation in forest supply chains

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Abstract: Supply chain planning aims to balance wood flow availability and consumption, thereby minimizing operational costs and raw material deterioration/value loss. In reality, wood availability is subject to seasonal restrictions and fluctuations (in quantity and quality), which can be amplified by climate-driven hazards such as forest fires. Hence, forest industries are interested in knowing how they can design and coordinate supply chain operations to become more resilient and better respond to those extreme events that likelier will be intensified by climate change.

The foundation for this is a novel digital architecture anchored in Business Analytics and Decision Support Systems, which integrates and processes data flows from multifold sources, to predict the impact of the disturbances at supply chain level and define contingencies for rapid operational response, ensuring robust supply. The key elements of this architecture are a) the *tower view* that consolidates information along the value chain to provide an instant “snapshot” vision of the entire supply chain, with emphasis on wood flows, capacity and stocks; b) the *decision theatre* that provides the intelligence layer enabling insight on the impacts of disturbances as well as the simulation of possible contingencies actions.

This study with present the detailed architecture and technical specification of these key components, based on a literature review and benchmark of existing models and methods. The outcomes will be instrumental for developing an initial prototype that can be applied in the pulp and paper supply chain in Portugal, in a region that has been historically affected by forest fires.

T2.5 Economics of forest plantations in Latin America: advances, challenges and opportunities

Comparison of weight in three sections of Eucalyptus under natural drying conditions

T2.5 Economics of forest plantations in Latin America: advances, challenges and opportunities

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Abstract: One of the factors that has a significant influence on transportation costs of forest products it its weight. The main objective of this study was to compare the weight loss of different log sections from green weight to dry weight under natural drying conditions. Based on an inventory and considering the normal distribution of diameters, 33 individuals from a forest plantation of hybrid clones of *Eucalyptus grandis x E. urophylla* in Itacurubi de la Cordillera, Paraguay, were selected. The selected trees were harvested, and three logs were extracted from each individual at 0.3m to 1.3m, 5m to 6m, and 10.05m to 11.05m. The measurements were weighed to obtain the green weight with bark, and subsequently, they were weighed 19 times in an open-air environment from 2 days after harvest, to 225 days after harvest at varying intervals, with a higher intensity near the harvest date. Once the weight was stabilized, the percentage of weight loss was determined. The results showed that, on average, after 225 days of harvest, 44.77% of weight was lost in section 1, 44.37% in section 2, and 43.50% in section 3. Having in count these results we can determinate that the weight loss in harvested forest products is quite significant, and it is necessary to consider these results when deciding the optimal time for transportation.

ECONOMETRIC MODEL FOR AGRICULTURAL LAND PRICES BASED ON DETERMINING FACTORS OF THE MICRO-REGION OF CANOINHAS, SANTA CATARINA, BRAZIL

T2.5 Economics of forest plantations in Latin America: advances, challenges and opportunities

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Abstract: Collecting real field information for land prices is a costly activity, demands time, care with sample selection, and may represent expectations more than land prices themselves. The modeling helps in understanding the dynamics of the land market, in order to enable the design and application of a set of policies capable of making the land market more transparent and effective, seeking to reduce the asymmetries of market information between sellers and buyers. Considering that each region of the country has its particularities, there is no single, standard model applicable to the entire Brazilian territory, but rather a consolidated and widely tested methodology. The aim of this study was to apply a multiple linear regression model for agricultural land prices based on their determinant factors in the microregion of Canoinhas/SC, Brazil. The model had the land price (Lp) as the dependent variable, and the exchange rate (camb), inflation rate (sel), leasing price of land for soy (arrend), regional agricultural GDP (GDPagr) and the Regional Price Index (IPR) as independent variables (PIBagr). The assumptions of the model were tested, meeting the reliability requirements and multiple linear regression analyzes were carried out. The results showed high significance of the regression model, with coefficient of determination (R2) = 0.820, explaining 82.0% of the variance, and the model: Lp = 29195.298 + (3137.469*camb) + (-353.511*sel) + (11.862*arrend) + (-

0.010*GDPagr) + (-138.714* IPR). All independent variables had an impact as a determining factor on the dependent variable (land price), with leasing being the factor that most contributed, along with the Regional Agricultural GDP and the Regional Price Index, which indicate advances in regional agricultural production and greater demand by lands. Understanding the behavior of the exchange rate and inflation rate can help predict the future land market. It is recommended the periodic evaluation of these variables and their projections, as an additional tool for understanding the dynamics of the regional land market, developing strategies that can generate better conditions of competitiveness, especially for small producers, avoiding loss of interest in agricultural activity.

Key words: land, linear regression, price

EVALUATION OF THE EFFECTS OF PRICE, EXCHANGE, AND VOLUME ON THE GROWTH OF REVENUES FROM BRAZILIAN EXPORTS OF WOOD PRODUCTS

T2.5 Economics of forest plantations in Latin America: advances, challenges and opportunities

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Abstract: Brazil has advanced in export volume but has not been able to increase prices over the last decade for wood products. This work seeks to contribute to the understanding of this conflicting scenario, evaluating the growth in the revenue of Brazilian exports of these products during two periods: 2011-2015 and 2016-2020, as well as decomposing its effects in price, exchange rate, and volume. The method applied was the *shift-share*, widely used to identify determinants of sectoral and regional economic growth, being a precursor to the approach in the analysis of forest sector exports. Historical series for 5 (five) categories of wood products were analyzed, with export data from the Ministry of Economy. The historical series of nominal exchange rates from the Institute of Applied Economic Research (IPEA) was used. The real effective exchange rate (RER) followed the methodological note of the IPEA. All product categories analyzed had positive effects in terms of volume, for both periods, with a greater proportion in the second being driven by the exchange rate, although with a loss in real price, failing to offset inflation. The only exception was wood manufacturers, a product with higher added value, which presented gains in volume, exchange rates, and price. The volume effect was the most relevant, followed by the exchange rate as a result of the appreciation of the dollar against the real against the exchange rate and control of inflation in terms of the divergent effects on the national and international scenario. The price presented negative variations in export revenue, with a decline over the period. In addition to the added value of exported products, world stocks and levels of consumption may have contributed negatively to this scenario, affecting all categories of exported products, except for manufactured wood products, the only category that did not reflect such justifications.

Keywords: export; shift-share; wood

How MNE operations shaped the process of industry emergence and SME development in Uruguay's pulp sector?

T2.5 Economics of forest plantations in Latin America: advances, challenges and opportunities

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Abstract: The development of the Pulp Industry to a global, multinational business has enabled the emergence and growth for numerous small and medium sized enterprises (SMEs). These SMEs have adjusted their business and obtained different positions and roles within the multinational Pulp Industries complex business environments. The impact of MNEs on developing economies has been largely studied by examining the productivity changes generated by spillovers which have produced mixed results. In this study we expanded this research by unraveling the content and outcomes of the interaction between MNEs and local actors during the process of MNE-led industry emergence. We focus on a single industry setting, - Uruguay's forest-based pulp sector. In particular we aimed to answer the question *how MNE operations have shaped the process of industry emergence through various spillover mechanisms, linkages, and externalities*? The data consists of interviews with managers and CEOs of companies in the Uruguayan pulp industry and SMEs operating in this value chain: eucalyptus seedling nursery, silviculture, harvesting, and wood logistics. The SME interviews included descriptions of the start-up process of the firm and how the firm developed its business model and perceives its role in the industry's global value network. In addition, we interviewed experts in key public and private institutions and organizations involved in the forest industry in Uruguay. These interviews concentrated on describing the industry and its development in Uruguay, the socio-technical regime of the pulp industry, and the future perspectives of the industry as well as the megatrends affecting it. In addition to the interviews, secondary sources, including scientific articles, statistics, reports, firm websites, and local newspapers were analyzed. The findings shed light on how the pulp industry in Uruguay followed a path-dependent evolution triggered by MNEs presence and establishment of local linkages with business and public actors. The study also developed information for the policy-makers about the conditions when MNE operations create long-term economic and social consequences.

Structure of pulpwood markets in Latin America: a study case of price strategies

T2.5 Economics of forest plantations in Latin America: advances, challenges and opportunities

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Abstract: The forestry sector in Uruguay has increased relevance in the last decade. The pulp value chain shows the greatest development based on attracting foreign direct investment. Its final product represents 75% of the annual value of the sector's exports. One of the challenges faced nowadays is the spatial dispersion of the roundwood supply within the country relative to industry's location which increase logistic costs. Worldwide, the pulpwood market is characterized by an oligopsonic structure, with strong incentives to exercise market power to reduce costs, mainly transportation costs. The asymmetric information between pulp industries, public sector and small forest producers leads to the use of FOB price as proxy of timber price in investment projects, supply negotiations and market regulation, ignoring other types of price's strategies. The objective of this presentation is to describe the current pulpwood market in Uruguay and to discuss alternatives prices strategies. One of the challenges faced in the study was the data available. Therefore, simulations were conducted to fill these gaps. Results show that from the supply side there are several producers with different characteristics and from the demand side there are mainly two mills. In addition, the mills own their own forests, and have different agreements with producers. Finally, it is shown that both companies have similar price discrimination strategies. These results should be considered when implementing land-use planning policies that could affect the distribution of the resource in relation to the location of industries. Furthermore, production cycles and land-use planning affect roundwood availability. Then, although genetic improvements and silvicultural innovations to shorten production cycles, favoring roundwood availability, the potential will be determined by the site.

Wealth and income generation in the forestry value chains in Minas Gerais, Brazil

T2.5 Economics of forest plantations in Latin America: advances, challenges and opportunities
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Abstract: Globally, Brazil is one of the most important producers of wood products from forest plantations. The area devoted to forest plantations in Brazil is rapidly increasing, driven by climatic conditions suitable for high productivity, land availability, and strong market demand. Since most of the harvest is exported, wood production brings important macroeconomic benefits. However, knowledge of the economic impacts of forest plantations at regional and local levels remains limited. This study investigates this issue by analyzing the economic impacts of tree plantations across Minas Gerais, the state with the largest plantation area in Brazil established since 1980. This study focuses on the main forestry sectors – forest plantations, wood products, furniture, and pulp and paper – and how they interact with other important economic sectors to generate wealth for different income classes from both production and consumption. I employ a multi-regional input-output model with a Miyazawa extended framework covering 13 regions, 16 sectors, and 10 income classes. This is a novel approach for sub-state forestry sectors in Brazil. Results show that forestry sectors are important for income generation in the state, especially for lower income classes. More industrialized regions receive income from either an increase in production or in consumption; the resulting income is concentrated in the top income class. Although the impact of income generation through forest plantation expansion is small, most of it remains in the same region in which the plantation is located and principally accrues to lower income classes. These results are consistent with previous findings linking forest expansion to less poverty over time (Afonso, R. and Miller, D.C. *Forest Policy and Economics 133 (2021): 102618*). Conversely, the cellulose and paper sector pays higher salaries, but most of the wealth leaks to other regions both inside Brazil and out. These findings help provide a foundation for policies that promote forestry industry's role in fostering economic growth in remote and less developed areas and it also sheds light on understanding Brazil's forestry value chain.

T2.6 Ensuring healthy trees for high quality wood products

Electric Resistance Tomograph (ERT): Innovative non-destructive method in analysing interiors of standing trees in tropics

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: Electric Resistance Tomograph (ERT) was first applied to trees in 1998 to study internal details. Experiments using ERT were started to determine fungal decay inside the trees, to estimate sapwood and heartwood width for many temperate species. However, for the first time an innovative non-destructive method in analysing interiors of standing trees using Electric Resistance Tomograph (ERT) for tropical timber species has been developed. Our main aim is to understand the internal wood structural details using 2D and 3D images of Electric Resistance Tomograph (ERT). Combined effects of resistivity offered by heartwood and moisture content in the sapwood developed a non-invasive 2D and 3D cross sectional images with colour differentiation from dark brown (high resistance) to blue (low resistance). The resistivity pattern for some species consisting of high resistivity in the inner part of the stem with lower resistivity on the outside are mostly due to changes of wood moisture content in heart wood and sap wood. Efforts have been made in economically important timber species like sandalwood and red sanders to standardize the ERT equipment in estimation of heartwood content in standing trees. In sandalwood the resistivity pattern varied from 60 to 1739.7 ohms and ERT estimated heartwood is showing 90 % similarity with observed heartwood diameter. Similarly, resistance ranged from 69 to 2945 ohms for red sanders and ERT estimated heartwood is showing 92 % similarity with observed heartwood diameter. Added to this, Electric Resistance Tomograph (ERT) can be used to analyse moisture distribution and current flow in the tree trunk. ERT also has been successfully used to estimate tree trunk decay, differentiating the sapwood-heartwood boundary, detecting and understanding hollowness in standing trees in tropics. This technique can be applied to visualize the heterogeneous distribution of resistivity in stems, mainly affected by the different physical characteristics of trunk and this can greatly vary between species to species in both ER magnitudes and patterns. The method has the advantage of being non-destructive, and relatively speedy at a low cost.

An ecological assessment of insect pests in Moringa oleifera Lam. progeny trials in Kenya

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: Abstract

Insect pests damage crops and trees resulting lower yield and quality of trees and crops worldwide. *Moringa oleifera* Lam. (Family: Moringaceae) has many potential health benefits and ability to cure several ailments in both humans and animals but suffer attacks from various types of pest and diseases. A survey of insect pest infestation on *M. oleifera* growing in three progeny trials under different eco-climatic conditions found in Kibwezi, Kitui and Ramogi (Kenya) was undertaken. The three trials were established in October 2019 (Kibwezi and Ramogi) and November, 2020 (Kitui). The trials have ten replicates each with seven families from 13 accessions of *M. oleifera* collected from different agro-ecological zones of Kenya, with families completely randomized within the replicates. We examined different parts of the *M. oleifera* plants, such as flowers, fruits, leaves, stems and trunks for symptoms of insect damage. The progeny trials contain thirteen provenances (eight naturalized Kenyan populations and five exotic accessions). Plant samples were visually examined in the field and with the aid of a stereomicroscope in the laboratory. Although *M. oleifera* produce phytochemicals that act as biopesticides, the plant is attacked by a significant number of pests that thrive on its nutritious parts. Our results show that *M. oleifera* is attacked by a number of pests. Notable pests of potential economic importance included: *Noorda blitealis* and *Eupterote molliefera* (Lepidoptera), leaf and flower defoliators; *Gitona distigmata* Meigon damage green pods; a tree girdler-*Paranaleptes reticulata* (Coleoptera) pruned the branches; termites (*Microtermes* sp. and *Odontotermes* sp. (Isoptera), foraged on live and dead moringa tissues; an unidentified stem borer that caused up to 45 cm length and diameter range of 8-15 mm tunnels in the leading tree stems. Thus, our preliminary insect pest survey indicates that *M. oleifera* in Kenya is attacked by plant hoppers and stem borer. Although infestation was estimated visually at 10%, and therefore at low economic thresh hold level, pest management strategy should be developed as *M. oleifera* is already gaining popularity in most east African countries and the world at large, in food and nutrition safety programmes.

Keywords: Insect pests, *Moringa oleifera*, progeny trials.

Establishment of serological detection methods for novel emaraviruses in oak and ash trees

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: The emerging group of emaraviruses (order *Bunyavirales*; family *Fimoviridae*) is strongly increasing in recent years with species that infect a variety of host plants. These worldwide occurring, plant pathogenic viruses, recently summarized by Rehanek et al. (2022), are naturally transmitted by gall mites and contain a segmented, single-stranded, negative-sense RNA genome. It comprises a core of four genome segments (RNA1-RNA4), with each RNA encoding a virus-specific protein (Rehanek et al. 2022).

In Europe, numerous novel emaraviruses have been described in important deciduous trees species of forests and urban green. In common oak (*Quercus robur* L.) and common ash (*Fraxinus excelsior* L.), two emaraviruses associated with characteristic virus-suspected leaf symptoms were identified by high-throughput sequencing (HTS). The common oak ringspot-associated virus (CORaV) and the ash shoestring-associated virus (ASaV) represent distinct species within the genus *Emaravirus* and are widespread in different European countries (Rehanek et al. 2021; Gaskin et al. 2021; Svanella-Dumas et al. 2022). While RT-PCR is established as the standard diagnostic method for the detection of most emaraviruses, serological detection methods, especially for forest tree-infecting emaraviruses are rarely available. GST-tagged-P3 proteins of CORaV and ASaV were expressed heterologously and purified for immunization in order to obtain polyclonal antibodies against the viral nucleocapsid proteins encoded by RNA3. Leave samples from oak and ash trees were collected at different locations Europe-wide. Applying obtained antibodies we developed diagnostic ELISAs for the CORaV and ASaV detection in the economically important tree species oak and ash. Screening results are presented.

Evaluation of wood decay proportion and dynamic modulus of elasticity by acoustic tomography

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: Sugar maple wood is highly prized for its appearance and structural applications. However, the incidence of decay in maple trees decreases their value and degrades their wood properties. Fifty-three trees were sampled from two sites to investigate the potential of acoustic tomography to detect decay in sugar maple trees and to assess its impact on the wood's mechanical properties. Acoustic tomography determined the proportion of decay and evaluated the dynamic (DMOE) modulus of elasticity of the sampled sugar maple stems. The sound propagation speed in wood and its density determined the DMOE. In addition, eighteen maple trees were sampled and felled from two other sites to validate the potential of acoustic tomography for predicting the wood's mechanical properties. Parallel compression and flexural properties were measured on clear wood samples. The DMOE was also measured by acoustic tomography and ultrasound methods to investigate the relationship between the wood moduli of elasticity measured by destructive and nondestructive methods. Acoustic tomography accurately predicted the proportion of decay in maple trees. The DMOE measured on trees correlates well with the static and DMOE measured on destructive samples. Decay decreased the mechanical properties by up to 60%, depending on its stage.

Identification of cell structure related vibration characteristics of wooden plates by high resolution laser scans

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: The vibrational properties of wood are of special interest for the production of some of the most valued timber products like music instruments. Therefore this study was carried out with special emphesis on the identification of anatomical key factors for the vibrational behaviour of wood as a basis for adapted forest management practices. The vibrational behaviour of wooden plates from Norway spruce (*Picea abies* (L.) Karst.) with transverse, radial, and tangential oriented impact planes was studied under controlled conditions. The square plates with a side length of 300 mm and a thickness of 5 mm were fixed on all four sides and set into vibration by means of a pendulum. The vibration of the plate was directly measured by line scans carried out by a high resolution laser scanner. The spatial resolution of the system was 31 µm, the accurracy of the measurement was +/- 0.6 µm. The vibrational behaviour of the plates was analysed in terms of the frequencies, the amplitudes, and the damping of the overlapping waves identified in the vibration spectra by means of Fast Fourier Transformation analyses. The anatomical structure of the wood from the area under investigation was studied by means of light microscopy. The comparison of the vibration spectra obtained from measurements carried out in earlywood and latewood zones of the plates showed that the distribution of earlywood and latewood in the plates had a significant influence on the vibrational behaviour of the plates. The analyses of line scans parallel to the grain and along radial and tangential oriented cell walls indicated differences in the vibration characteristics between radial and tangential cell walls of the tracheids. The results are discussed with regard to the wood structure of Norway spruce and the outstanding importance of this timber species for the production of resonance wood.

IMPROVED INDEXING METHOD FOR SELECTION OF SUPERIOR GENOTYPES OF MELIA DUBIA CAV.

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: *Melia dubia* Cav. is a fast-growing multipurpose tree species occurs in Northern Himalayas, North Bengal, Western Ghats, Sikkim, and other parts of India under various afforestation schemes for fodder, timber and industrial woods. It is known as money spinning tree due to its great economic returns. Identification of superior genotypes of *Melia dubia* under different ecological conditions with promising characteristics such as growth, productivity and stability will enhance productivity to maximum level to meet ever-increasing demand by establishing commercial plantations. Information on genetic structure and diversity of tree provide base for efficient utilization of genetic resources to comprehend potentiality for maximizing growth and yield. During present study, selection and screening of promising genotypes of *Melia dubia* was carried out by applying index method of selection with minor modifications. The multitrait selection resulted in higher expected response and combined information on all traits of interest into a single index. Moreover, it became useful as each trait played an important role and all individuals were ranked according to one scoring system. A total of 788 genotypes were screened based on height, collar diameter, diameter at breast height, clear bole height, straightness, and branching behaviour. Out of these, 61 genotypes were selected with index value of 100. Similarly, significant improvements could be contemplated in various forestry tree species by screening promising genotypes using proper selection method(s).

Keywords: *Melia dubia*, multitrait, superior genotypes.

Influence of Crown Defoliation Degree on Value of Produced Norway Spruce (Picea abies (L.) Karsten) Roundwood

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: Norway spruce (*Picea abies* (L.) Karsten) is the second most common coniferous species, with a share of 2.3% in the total wood stock of Croatian forests. Almost 60% of Norway spruce trees in Croatian forests have crown defoliation to some degree, indicating often poor health condition of spruce trees. Bark beetle outbreaks in Croatian forests resulted in the massive death of Norway spruce trees and decreased value of produced logs. This research aims to investigate the assortment structure and value of produced assortments from healthy trees and trees affected by crown defoliation caused by some biological factor and climate changes. The research was conducted in the summer of 2022 during a salvage felling of Norway spruce in the Gorski Kotar region (N45.647754, E14.578801). Sampled trees were classified as a »healthy« tree (if crown defoliation was not higher than 10%), as a »3b« tree (if crown defoliation was between 80–99%), and as a »dead« tree (crown defoliation was 100%). Trees that were damaged during earlier timber extraction were not included during the tree selection. After a tree was cut down and logs were produced, they were measured, and roundwood scaling was done according to the HRN standard. According to the price list used by the biggest Croatian state forest company (which manages 75% of all forest land in Croatia), the average value of each defoliation degree was calculated. In total, 55 -Norway spruce trees were recorded, and their breast-high diameter was 10–74 cm. The whole technical usability was the highest in the category of »healthy« trees (82.4%), followed by »3b« trees (81.5%), and the lowest was in the category of »dead« trees (78.2%). The average value of produced assortments was 57.90 EUR/m^3 in the category of » healthy « trees, 58.96 EUR/m^3 in the category of »3b« trees, and 45.18 EUR/m^3 in the category of »dead« trees. Considering the decrease in technical usability and the average value of the assortments essential produced from dead trees compared to the healthy trees, and trees in the category »3b«, it is essential to recognize weakened trees and use them before value could decrease significantly.

Precision forestry for reducing the impacts of root rot in boreal forests

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: Root rot caused by Heterobasidion spp. causes severe growth decline, root and stem decay and carbon balance losses in Norway spruce forests across Europe. Root-rot spreads from tree to tree through root contacts and by spores that colonize fresh cut stump surfaces - both mechanisms benefitting from industrial forestry and tree-root injuries. Once established, root-rot eradication requires several decades and a change of tree species. We used geo-located tree-level cutting data from hundreds of harvesters around Finland, a tree-root rot model, and novel statistical methods to study mechanisms, risks, and economically optimal regeneration strategies of root-rot infected stands in southern Finland. We were guided by a vision that someday harvester data could routinely be uploaded to central database and used for sustaining and improving forest health, more diverse regeneration strategies, and resilience. Root-rot infected trees were clearly more clustered than the trees normally are, a process which we explained with a Bayesian model containing the root-contact model. This lays foundations for precision forestry, as economically the most profitable spruce can be planted on uninfected patches, while rest of the area can be planted with other species. We further optimized the stand regeneration strategies by balancing economic and mitigation goals for root-rot infected stands. Warm conditions, high root-rot incidence, site fertility and interest rate favoured replacement of spruce with birch after clear cut, while at the opposite side of the gradient, Scots pine was favoured. Spruce mixtures remained the most competitive in the middle of the gradients. The results of spatial and economic-ecological analyses were encapsulated into an AI-based tool that was able to generate a regeneration recommendation for any new stand with harvester data. Risk maps based on harvester data for Southern Finland were consistent with those based on forest inventory data, but showed finer detail, and patchiness in the range of 10 km. Harvester data, when combined with root-rot identification and modelling provides excellent opportunities for precision forestry and risk mapping. The next challenge, as shown by our stakeholder consultation process, is to create common rules and databases for storing harvester data and for using these data in practice.

Relationship between decay of Populus tremuloides caused by Phellinus tremulae and tree age

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: Trembling aspen, *Populus tremuloides*, can become infected by the heart rot fungus *Phellinus tremulae*, leading to decay of standing trees. Prior to fungal infection, carbon is sequestered in the stem of the tree as it is actively growing; however, following infection by *P. tremulae*, trees can transition from a carbon sink to a carbon source as heartwood is decayed and carbon dioxide is released to the atmosphere through the decay process. Losses to decay also reduce wood quality. Through repeated observations of established field trials, it was observed that *P. tremulae* incidence increased at the stand level with increasing stand age. In a laboratory study, we determined the optimum temperature for decay under controlled temperatures by assessing mass loss of inoculated aspen blocks over time. We also assessed basidiospore dispersal by the fungus within stands containing infected trees. Through these experiments the optimum decay temperature was determined and we found that basidiospores are present throughout the growing season. It is difficult to determine the amount of carbon lost to decay as *P. tremuloides* stands age; however, this process has been observed at every plot within the study area, suggesting that harvest should be timed to minimize losses to *P. tremulae* while maximizing wood quality.

Resistography as low-invasive method for early detection of Fistulina hepatica in wood-productive plantations of Castanea sativa

T2.6 Ensuring healthy trees for high quality wood products

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Abstract: Sweet chestnut (*Castanea sativa* Mill.) is one of the most profitable forest species in southern Europe because of its high-quality wood and fruit production. This species is facing a generalized silvicultural abandonment in the north-east region of Spain since the 1980's, caused by Chestnut Blight (causal agent *Cryphonectria parasitica* (Murril) M.E. Barr) and by uncertain market conditions. In the 1990's Chestnut Red Stain (CRS), a heartwood discoloration caused by the fungus *Fistulina hepatica* (Schaeff.) With., became another economic concern. At early stages, the structural properties of the wood seem not to be affected, nevertheless, the timber's economic value drops up to 70% by preventing its use as quality saw timber or veneer. CRS causes uncertainty to forest managers since it could only be detected when the stands are thinned or cut. CRS can be detected through molecular methods but it is costly. The main objective of this work was to develop an efficient detection method to provide an easy and reliable tool to detect the presence of *F. hepatica* in early stages of productive periods. A total of 75 trees were analysed through molecular methods to determine the presence of *F. hepatica*. After that, an IML-RESIF300-s resistograph was used to characterise the wood of sampled trees. Thirteen wood-quality indexes were calculated and their correlation with the presence of the pathogen was evaluated using linear mixed models. We found clear differences between healthy and diseased trees in four indexes: 1)maximums average; 2)minimums average; 3)maximums average minus total average; 4)absolute minimums. The results support the hypothesis that, although CRS does not impact seriously the wood properties at early stages, it modifies them enough that its presence can be detected through inexpensive and fast mechanical methods. This will allow forest managers, to evaluate the incidence of CRS, target thinnings and adjust rotations accordingly.

T2.7 Fast growing trees in support of sustainable bioeconomy

Biomass production in the second rotation of poplar plantation – effects of thinning strategies

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: Poplars plantation have shown an ability to provide large volumes of biomass on agricultural land during the first rotation cycle with planted trees. However, there is limited knowledge about poplars biomass production during the second rotation, established by re-sprouting after the final felling. Here, we analysed the effects of different thinning strategies on the biomass production in the second rotation plantation of poplar clone OP42 (*Populus maximowiczii* Henry × *P. trichocarpa* Torr. and Gray) in Southern Sweden. Four treatments with different thinning intensities were applied at the age of seven years after clear felling: (1) unthinned with an average stand density of 6000 stems ha^{-1}, (2) light thinning with removal of every second tree row to a density of 3000 stems ha^{-1}, (3) medium thinning from above to 1100 stems ha^{-1}, (4) heavy thinning from above and removal of every second tree row to a density of 550 stems ha^{-1}. Assessments of stem wood volume/biomass production were based on volume functions, using stem diameter and tree height measurements at a two-year intervals during 11 years, post-thinning. All thinned stands had a gradual increase of the mean annual increment of a standing volume/biomass production (MAI) throughout the entire study period. MAI of the unthinned treatment peaked at 30.1 m^3 ha^{-1} yr^{-1} (10 ton DM ha^{-1} yr^{-1}) after four years, followed by a slight decrease. After 11 years, MAI and a standing volume/biomass production did not differ significantly between unthinned, light and medium thinning, with the average MAI of 26.1 m^3 ha^{-1} yr^{-1} (8.7 ton DM ha^{-1} yr^{-1}) and the standing volume/biomass production ranging from 443 to 486 m^3 ha^{-1} (148-163 ton DM ha^{-1}). Additionally, thinning with a medium intensity produced higher total stem wood volume/biomass (including living, dead and trees removed by thinning) compared to the other treatments. Our results also indicated a gradual reduction in the stem number for the unthinned and light thinning as a consequence of self-thinning. This study suggests that the second rotation of poplar plantations can be considered as an alternative to planted poplar stands in Sweden, demonstrating great potential to produce substantial amounts of biomass.

Climate-sensitive modelling of Poplar Short-Rotation Coppice for a Low-Carbon Bioeconomy

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: The production of woody biomass as a source for energy and/or bioproducts is widely recognized as a crucial resource in the transition towards sustainable energy systems.
Producing lignocellulose biomass, such as from short-rotation plantations and increasing the potential use of lignocellulosic biomass as bioproducts are among the most promising opportunities in the forest-based sector. Climate-sensitive forest growth models can be used to calculate future estimates of biomass yield under changing environmental conditions. Process-based models are considered promising in this context.
From this perspective, this study deal with lignocellulose biomass produced from poplar Short Rotation Coppices (SRC) systems under Mediterranean conditions in order to assessing the potential of these plantations to contribute to a low-carbon bioeconomy. We simulate biomass growth of a complete plantation cycle of 12 years (4 rotations 3 years each) taking into consideration the effects of 50% reduction in irrigation (T50), compared to optimal irrigation (T100) on the productivity and carbon stocks of these poplar plantations in Spain. The simulation was conducted in an area where prior information from a three-rotation trial was available to validate the obtained data. To achieved this, an adapted version of 3-PG model to poplar at high density, incorporating species-specific parameters for the genotype 'AF2' (*Populus* × *canadensis* Mönch) was used. In addition to calculate biomass production, stem, leaf and root were also analysed for their carbon sequestration potential. A reduction of 25% and 28% of stem and root biomass was found in the first rotation when 50% water irrigation restriction was applied (T50). After the establishment of the root system, in consecutive rotations the reduction in productivity was comparatively less pronounced for all biomass fractions (stem, root and leaf). The above and below-ground C stocks of a standard poplar SRC system under Mediterranean conditions and 12-year plantation cycle (4 rotations of 3 years each) play an active role in mitigating global warming (10 Mg C ha^{-1} yr^{-1}) but even this is relevant under restrictive water irrigation conditions (8.2 Mg C ha^{-1} yr^{-1}).
This study enhances awareness regarding the potential of poplar short-rotation coppice (SRC) systems in contributing to a low-carbon bioeconomy

Differences in the Timing of Growth Cessation as a way of Selecting Poplar Clones for Various Climate Conditions

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: The current and future demand for woody biomass will increase, thus require an increase in the productivity of the current forest systems. There is also a need to search for alternative tree species as a complement for two of the most common tree species in Swedish forestry, Scots pine and Norway spruce as they are now subjected to severe pathogen and insects outbreaks. *Populus* and their hybrids are one alternative due to their high growth potential and short rotation, reaching at optimal conditions volume production of 30 m^3 $h^{-1}yr^{-1}$ under a rotation length of 20 years.

Several studies have shown that poplar clones have high variability in growth rate between clones. During the last decades, a large effort have been made to identify *Populus* clones with high and secure biomass production at different climatic zones.

In this project, we will develop new selection methods to identify poplar clones adapted to the present and future climate to secure a high biomass production.

We are going to use timing in growth cessation in fall as a method to identify poplar clones adapted to a specific climate condition. As a first step we will identify variation in growth cessation among 120 commercial available poplar clones and thereafter discuss how this can be used to maximize production capacity by using the entire growth period (timing of growth cessation in fall) in a common-garden experiment.

Distribution, Benefits, and Risk of Spreading Alien Forest Tree Species in Lithuania

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: The understanding of the role of alien tree species in forests varies among different interest groups. This presentation addresses the question of whether alien tree species can provide greater economic benefits or result in ecological damage.

The study raised the following research questions: to map the distribution of alien tree species in the country; to estimate the invasiveness score of tree species that have crossed the naturalization barrier; and to evaluate timber supply potential of alien tree species in Lithuanian forests.

Maps displaying the distribution of alien tree species were created based on data from the state forest cadaster, referring to the year 2017, which was compiled using information from stand-wise forest inventories. The same data source was used for the volumes and other dendrometric characteristics. The invasiveness score was assessed following the first part of the Victorian pest plant prioritization process methodology, which focused solely on spread.

The study identified 23 alien tree species growing in Lithuanian forests, of which 13 are conifers and 10 are broadleaves. The area of stands with alien tree species accounts for only 0.7 % of the total forest area. These alien trees have produced a total of 531800 cubic meters of wood, with the largest volume shared by *Larix* at 265,558 cubic meters. In terms of stand productivity and economic efficiency, growing alien species such as *Populus sp., Larix sp., and Quercus rubra* appear to be competitive or even more attractive compared to native tree species. However, three tree species - *Acer negundo, Prunus serotina,* and *Robinia pseudoacacia* - have crossed the naturalization barrier and are included in the list of Lithuanian invasive plants. Among these, *Acer negundo* exhibited the highest invasiveness score of 0.79, while *Robinia pseudoacacia* had the lowest score of 0.35. It is recommended to avoid these invasive tree species in Lithuanian forests.

Does fertilization effort pay off at harvest? A case study from 50 years old birch plantations for sustainable bioeconomics

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: Producing additional wood raw material in a relatively short time can be achieved by forest trees plantation. Ensuring high-quality planting material they reach an early peak in average growth of total production. Forest plantations are usually established with fast-growing species – not always native.

This study evaluated the production effects of plantation of the silver birch (*Betula pendula* Roth) using various agrotechnical and agro-melioration treatments in different habitat systems. The evaluation of production effects was conducted based on analysis of selected growth and development traits, which included: survival rate, average dimensions (DBH and height), silvicultural quality, and the average growth in total production volume.

Timespan of this study covers period 1971-2022. Four plantation experimental plots were established in habitats of different fertility with different variants. To eliminate variation in growth conditions, each variant was repeated four times in a random block design. The survival rate of the trees was recorded after the end of the growing season. Determination of the silvicultural quality was conducted using the modified Schädelin biological classification. The average annual increase in total production was determined for each measurement period.

The most productively effective was the variant of full ploughing and fertilisation with potassium, phosphorus, and nitrogen. After 20 years of growth, it has the highest percentage of best-quality trees and the lowest percentage of worst-quality trees. Trees growing in this variant are characterised by the largest average dimensions. Volume and average growth are slightly lower, but this variant has the lowest number of trees per unit area.

Intensive soil cultivation had a positive effect on birch survival. No significantly better success rate was observed in variants with peat ballast or full ploughing. In low fertility habitat, the variant of planting in cavities with peat and NPK fertilisation around the seedlings gave the best results. The average values of the analysed traits achieved in this variant do not differ significantly from the variants with more intensive soil cultivation. For degraded habitats, soil preparation should include full ploughing, mineral fertilization and peat topping. The latest is particularly important as it gives better results than intensive mineral fertilization.

DYNAMICS OF CARBON STOCKS OF BIRCH PLANTED ON PREVIOUS NORWAY SPRUCE SITES

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: The increasing demand for tree biomass and byproducts in Sweden is triggering the interest in replacing slow-growth species. The substitution of traditional tree species, such as Norway Spruce (*Picea abies*), for a fast-growing species is aimed and also has a high ability to mitigate the climate impacts in the short term. Birches (*Betula spp.*) are the main fast-growing species naturally regenerated in Sweden and present this potential. The general objective of the study was to simulate carbon stocks above and belowground of Birches, growing in previous Spruce forests after the clear-cut, using different management strategies. The period evaluated was 180 years, meaning that Birch had three rotation periods of 60 years (with two thinnings at 20 and 40 years) and Spruce had two rotation periods of 90 years (with three thinnings at 40, 60, and 80 years). The simulations were done using the CO2FIX model which has Yasso soil dynamic model integrated into the software to predict carbon stocks both in the tree biomass and soil (total carbon stock). Experimental data were used in the simulation for both non-genetic improved species. The results indicated that Birch had about 85 MgC/ha of total carbon stock after the first rotation period, while Spruce spent 80 years to reach the maximum of 80 MgC/ha of total carbon stock. The soil carbon stock was initially equal for both plantations (40 MgC/ha), but after 180 years they had about 45 and 35 MgC/ha, for Birch and Spruce, respectively. We can conclude that Birch has the potential to substitute Spruce plantations in shorter rotations acting like quick carbon sinks in both soil and biomass. Nevertheless, future research is needed on product substitution effects, testing genetically improved materials, and different management strategies to support smart-climate decisions for a large-scale implementation.

Enhancing knowledge-sharing on fast-growing trees: the expertise of the International Commission on Poplars and Other Fast-Growing Trees (IPC)

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: Enhancing knowledge-sharing on fast-growing trees: the expertise of the International Commission on Poplars and Other Fast-Growing Trees (IPC)

Protecting, restoring, and adapting planted forests, including especially those composed of fast-growing trees, is a prominent nature-based solution in the transition towards carbon-neutral economies, sustainable landscapes, and better livelihoods. Fast-growing trees are growing roughly more than 10 m^3 per hectare and year, with a capacity of high annual increments already in a young age; which is the reason for the high land use efficiency that can be achieved with these trees.

Within the framework of FAO, a specific treaty-based statutory body, the International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC), is dedicated to fostering the sustainable management of fast-growing trees. This Commission works as a science-policy implementation platform. Established in 1947, it is a proven model for international technical cooperation in forestry which can contribute achieving the global sustainability goals. Traditionally, the IPC focused on poplars and willows, but in 2019, the IPC broadened its scope to all fast-growing trees that sustain people and the environment.

This new IPC mandate envisages an expansion to new regions and countries, enlarging the geographic, biological and technical scope of the IPC by including a wider range of fast-growing genera/species with similar attributes in terms of industrial and energy uses and environmental applications compared to poplars and willows. Thus, the new IPC mandate will support the sustainable provision of wood and ecosystem services by transferring the long-term expertise and the lessons learnt on poplars and willows to other fast-growing species in forestry and agroforestry systems of tropical countries and strengthening the contribution of fast-growing trees to food security, sustainable livelihoods and land use in rural areas.

Evidence of adaptability and genetic potential of pine hybrids for commercial plantation forestry in Kenya

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: *Pinus patula* has been among the major plantation species grown in Kenya over several decades. However, narrow range of commercial plantation species in the country, risks associated with climate change, and need to improve productivity per unit area have necessitated screening of new pine germplasm. Our study evaluated survival and growth performance of 13 pine hybrids in Kenya at the age of 12 years. Significant differences were observed among hybrids for survival, height, diameter at breast height (dbh) and volume ($P < 0.001$). The average survival rates across the sites was 60 % and varied from 26 % to 87.8 %. Mean tree height varied from 13.3 for *P. caribaea* x *P. elliotii* hybrid to 17.5 m in *P. patula* x *P. tecunumanii* hybrid with a mean of 14.4 m. The dbh range from 20.2 cm in pure *P. patula* to 24.7 cm in *P. patula* x *P. tecunumanii* hybrid with a mean of 22.8 cm. The mean volume was 0.228 cm^3, ranging from 0.165 cm^3 (*P. patula* x *P. gregii* hybrid) to 0.322 cm^3 (*P. patula* x *P. tecunumii* hybrid). In each trial, the best-performing hybrid clones grew better ($P < 0.05$) than pure *P. patula*. Relative performance of the best hybrid clones showed consistency in ranking for growth across the sites. The study also revealed low genotype-by-environment interaction showing stability of the hybrids across environments. Overall, the findings show that *P. patula* x *P. tecunumanii* (low elevation) and *P. patula* x *P. tecunumanii* (high elevation) hybrids had better performance than the pure species and other hybrids. This indicates the potential of these hybrids as alternative plantation species to *P. patula.* However, a comparison of growth performance showed statistically significant differences ($P < 0.001$) among clones within the sites indicating that site specific hybrid clones should be considered during selection. We recommend that the two superior hybrids could be considered for pilot plantations in major pine plantation areas in Kenya.

Keywords: Improved productivity, growth performance, genotypes, pines, pine hybrids

Expanding the Potential of Populus Species for Biomass Production: Clonal Selection for Boreal Forests Conditions

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: The future increased demand for biomass as a renewable energy source necessitates an increase in biomass production. In this context, fast-growing broadleaf species i.e. *Populus* species, offer significant potential due to their high production rates and short rotations. While traditionally planted on agricultural land, recent interest has emerged in utilizing different tree species on forestland as an alternative to Norway spruce (*Picea abies L.*) which is severely damaged by climate change and insect outbreaks.

The boreal forests are spanning across Scandinavia, northern Russia, China, and North America, and are characterized by podzol soils with acidic pH levels. The acidic soil pH poses challenges to plant growth, including increased plant mortality caused by excessive protons (H^+) that is linked to elevated aluminium (Al) levels, leading to inhibited water uptake and nutrient deficiencies. Previous studies have shown large variations in aluminium tolerance both within species and between *Populus* species. Consequently, the successful cultivation of *Populus* species in boreal forest sites requires the selection of *Populus* genotypes (clones) with tolerance to aluminium.

In this study 75 poplar clones (*P. deltoides x P. nigra, P. maximowiczii x P. trichocarpa, P. maximowiczii x P. nigra, P. trichocarpa x P. trichocarpa and P. maximowiczii x P. deltoides*) were screened to their tolerance to aluminium toxicity at varying aluminium concentrations. The results revealed variations in performance, with certain clones exhibiting higher relative growth and relative root biomass, indicating a genetic basis for aluminium tolerance. To evaluate their performance in practical forestry, the top and least-tolerant clones were grown in greenhouse conditions in a gradient in soil acidity from acidic forest soil to neutral agricultural soils. This result will give insight into the interaction between soil acidity and aluminium tolerance of poplar clones. Furthermore, the outcomes of this study will enhance our understanding of methodology in clonal selection towards aluminium tolerance and future breeding strategies in *Populus* species, specifically concerning their adaptability to boreal soil conditions, thereby expanding the potential for sustainable biomass production for the future.

Mixing tree species to increase tree performance – Synthesizing 23 years of research in the world's largest platform of tree diversity experiments

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: International ambitions for massive forest restoration are high. To make these investments sustainable and resilient under future climate change, science is calling for a shift to planting mixed forests. But what is the scientific basis for promoting diverse plantations, and what is the feasibility of their establishment and management? The largest global network of tree diversity experiments, TreeDivNet is uniquely positioned to answer these pressing questions. Building on 428 peer-reviewed TreeDivNet studies, combined with the results of a questionnaire completed by managers of 32 TreeDivNet sites, we aimed to answer the following questions: (i) How and where have TreeDivNet experiments enabled studying the relationship between mixing trees and their performance? (ii) What are the key knowledge gaps in our understanding of the relationship between tree diversity and performance? (iii) What practical insights can be gained from the TreeDivNet experiments for operational, real-world management?

We developed a conceptual framework that identifies the variety of pathways through which tree performance is related to local neighbourhood diversity and mapped the research efforts for each of those pathways. Experimental research on forest mixtures has mainly focused on direct tree diversity effects on productivity, with fewer studies focused on indirect effects mediated via biotic growing conditions (e.g. soil microbes and herbivores) and resource availability and uptake. Tree diversity effects on the abiotic growing conditions (e.g. microclimate, soil properties) and resource-use efficiency have been less well studied. The majority of experiments is situated in temperate forests, while (sub)tropical forests, and boreal forests in particular, remain underrepresented.

TreeDivNet provides evidence in favour of mixing species to increase tree productivity while identifying a variety of different processes that drive these effects. The design, scale, age, and management of TreeDivNet experiments reflect their focus on fundamental research questions pertaining to tree diversity-ecosystem function relationships and this focus complicates the translation of findings into management guidelines. Future research could focus on (i) filling the knowledge gaps related to underlying processes of tree diversity effects in order to better design plantation schemes, (ii) identifying optimal species mixtures, and (iii) finding smart solutions to give experimental mixed plantations a more management-oriented focus.

New varieties of fast-growing trees for sustainable production of biomass under climate change conditions in temperate climate region – field results

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: For sustainable biomass production and provision ecosystem services of fast-growing trees (FGT) an assortment of new cultivars is needed which could replace current in case of expected decline of production potential due to growing biotic and abiotic risks (pests, deseases, climatic extremes, pollution etc.). In our contribution we present results of long-term testing of new cultivars of FGT in conditions of the Czech Republic which is characterized by variety of soil types and transitional oceanic-continental weather.

For early evaluation of new FGT cultivars in field conditions we have used network of small experimental plots (clone/cultivar tests) on more sites in the 1990th. Our current assortment in experimental plots consists of 40 poplar and 11 hybrid/allochtonous and native/autochnous poplars and willows including willows Rokyta′, ′Stvola′ and ′Vetla′ and poplar ′Kaktu′ form our breeding. As a control in experimental plots we use poplar clone Max-4 (*Populus nigra* × *P. maximowiczii*), which is the most often planted in Central European (85% of SRC in Czech Rep.). We have measured periodically production and biometric parameters of tested trees (yield, height, survival rate) and studied influence of climatic and biological factors on their growth e.g. recent droughts periods (2016-2019: sum of precipitation -213mm; average annual temperature +1,8°C from climatic normal).

From our long-term field testing we can conclude that there are good alternatives to the most common poplar clone Max-4 witch have different genetic origin, better yield potential and also better adaptation to climatic and ecological condition of Central Europe also with regards to expected predictions of climate change. Namely we can mention poplar cultivars ′AF8′, ′AF13′, ′AF2′, ′AF24′, ′AF28′, ′Bakan′, ′Kaktu′, ′Monviso′, ′Skado′ or ′Vesten′ and willows ′Rokyta′ and ′Tora′. Some of these cultivars were yielding up to 50% more biomass than Max-4 in our experiments. Many of them performed better also during drought period (3-4years) in which yields decreased in our experiments between 18 and 52% from expected amounts (yield curves). Effect of the research gap have to be taken into account which includes lower quality of agronomy and pest control when growing new cultivars in real field conditions.

ontribution of the IUFRO task force “Resilient Planted Forests Serving Society & Bioeconomy” to societal debate and science frontiers

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: Planted forest covering only 7 % of the globe’s land surface contribute more than 40 % of timber production with demand expected to increase significantly. These forests also contribute actively to land protection and restoration and provide many important ecosystem services.

This essential resource is facing many challenges: political, related to climate change responses; environmental with climate change, pest and diseases, abiotic risks increasing all over the world; social, associated with competition with other land uses and public perceptions of forests; and finally economic. Managers lacking technical support to face these challenges while, in some places of the globe, communities still struggle with the trade-offs between agriculture and forest land use.

The task force “Resilient Planted Forests Serving Society & Bioeconomy”has addressed some of these points through papers and events. Three aspects will be covered in this paper. As the resource provided by planted forests is essential for bio economy it is important to produce new perspectives on how these forests will evolve globally to respond to changing wood markets Secondly, as planted forest are based on genetic resources selected by the forest manager origin and genetic resources have been addressed related to climate change.. Finally on the societal challenge of perception we will show how the New Generation Plantations approach applied in Europe can contribute to dialogue and depolarisation of opinions.

Responses of swine manure for seven willow species distributed in Eastern Japan

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: In east Asia, short rotation coppice system was developed for production of renewable energy, and two willow species distributed in boreal region was utilized. However, other willow species was not utilized. To establish a short rotation coppice system at temperature region of east Asia, we planted cuttings of *Salix eriocarpa*, *S. gilgiana*, *S. gracilistyla*, *S. integra*, *S. sachalinensis*, *S. serissaefolia* and *S. subfragilis* distributed in eastern part of Japan. On the cultivation, compost made by swine manure, which was low cost and sustainable fertilizer was added. We established control (no addition), low manure (5 Mg ha^{-1}), and high manure (10 Mg ha^{-1}) treatments, and seven willows were raised for two growing seasons. The density of clones was 10,000 cuttings ha^{-1}.

Swine manure was contained high concentration of nutrients, and all of willow species were accelerated their growth by addition of swine manure after two growing seasons. The averages of annual biomass production of seven willows grown under control, low manure, and high manure treatments were 0.2 Mg $ha^{-1}yr^{-1}$, 5.3 Mg $ha^{-1}yr^{-1}$, and 8.5 Mg $ha^{-1}yr^{-1}$, respectively. Especially, high manure treatment of *S. sachalinensis* and *S. subfragilis* showed large biomass, and their value per year was 14.1 Mg $ha^{-1}yr^{-1}$ and 13.7 Mg $ha^{-1}yr^{-1}$, respectively. On two species under high manure treatment, *S. sachalinensis* had the thickest shoots, and *S. subfragilis* had the tallest shoots. These growth characteristics of *S. sachalinensis* and *S. subfragilis* were originated from their high biomass production. We concluded that *S. sachalinensis* and *S. subfragilis* were potentially feasible candidates for short rotation coppice system in the temperate regions of east Asia.

The Mid-Atlantic Sustainable Biomass Consortium (MASBio): Delivering sustainable and feasible biomass for a value-added product system

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: The goal of this project was to deliver sustainable and feasible biomass for value-added product system in the Mid-Atlantic region of the U.S. through implementation of the Mid-Atlantic Sustainable Biomass Consortium (MASBio). This integrated and transdisciplinary research, education and extension project will facilitate and foster development of the bioeconomy and rural prosperity in the region. Specific project objectives to achieve the project goal include; (1) recognize and demonstrate feasible, sustainable and cost-effective approaches to soil amendment and feedstock production to increase yield of biomass agroecosystems on reclaimed and marginal lands, (2) demonstrate efficient and effective harvest and logistics strategies for an optimized, integrated agricultural-forestry feedstock supply chain for continuous industrial procurement, (3) develop and optimize multiple bioproduct conversion processes through collaborations with industry partners, (4) improve the sustainability of the biomass supply for value-added products with best management practices (BMPs), (5) conduct system and scale-up analyses using robust artificial intelligent (AI)-based data analytics, (6) engage the next generation of biomass products leaders through education and internship programs, (7) engage with stakeholders to promote bioeconomic development through extension outreach programs. Significant differences in cultivar performance have been noted across marginal agricultural sites and reclaimed mine lands (Caterino et al. 2017; Nobert et al. 2016). Soil amendments using biochar and fertilization had mixed effects for plant growth and survival. Biochar (poultry litter) increased growth during the establishment year by 80% (Nobert et al. 2016), whereas controlled release and traditional inorganic fertilizer blends had limited impacts after two growing seasons (Caterino et al. 2019). Growth of switchgrass varieties on reclaimed lands have achieved dry matter yields of greater than 3 tons/ac per year and on some sites Cave-in-Rock switchgrass has achieved more than 22.4 Mg/ha (Scagline-Mellor et al. 2018). Hybrid willow trials on marginal land have shown biomass yield of 8-12 odMg/ha. This integrated and transdisciplinary research, extension project will facilitate and foster development of the bioeconomy and rural prosperity in the region.

The Role of Fast-Growing Trees in Agroforestry Systems: Perspectives from the IPC of the United Nations' Food and Agriculture Organization

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: Agroforestry systems (AFS) are sustainable land management systems that consist of agricultural crops and/or livestock intentionally integrated with woody species on farmed fields or in forested areas. AFS provide environmental, economic, and social benefits that contribute positively to sustainable development and other societal goals, including improvement of bioeconomies. Fast-growing trees (FGTs) such as acacia (*Acacia* Mill.), casuarina (*Casuarina* L.), eucalyptus (*Eucalyptus* L'Hér), gliricidia (*Gliricidia* Kunth), leucaena (*Leucaena* Benth.), melia (*Melia* L.), pine (*Pinus* L.), poplar (*Populus* L.), and willow (*Salix* L.) maximize the benefits from AFS within short timeframes (< 30 years). The International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment (IPC, https://www.fao.org/ipc/en/) is a treaty-based statutory body placed within the framework of the Food and Agriculture Organization of the United Nations (FAO) that has decades of leadership in FGTs and AFS. The IPC serves as a knowledge and capacity development network and offers a science-policy-practice platform that converts science-based approaches into practice. The IPC facilitates technical knowledge exchange on research and sustainable management of FGTs through the guidance, activities, and networking of five working parties (WPs): **Genetic Resources** (WP-GEN), **Production Systems for the Bioeconomy** (WP-PRO), **Environmental and Ecosystem Services** (WP-ENV), **Policy and Livelihoods** (WP-POL), and **Communication and Outreach** (WP-COM). We will highlight the potential of the IPC and its WPs to contribute to sustainable development and adoption of FGTs within AFS on a global scale, and will discuss the role of FGTs in AFS, along with barriers and opportunities for adoption that may impact the bioeconomy. To do so, we will present three international case studies: 1) diversifying traditional crop rotations through on-farm planting of short-rotation trees (India), 2) the

benefits of pollarding poplars and willows to provide stock fodder (New Zealand), and 3) short rotation coppice (SRC) combined with poultry breeding and homegardening (Czech Republic). We will discuss opportunities for the IPC to enhance the global knowledge exchange on FGTs in AFS, including the role of agroforestry in the sustainable bioeconomy, as well as technical services offered by the IPC to assist mobilization of new partners and resources.

The role of planted forests in the bioeconomy

T2.7 Fast growing trees in support of sustainable bioeconomy
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Abstract: The bio-based economy idea emerges from societal concerns and expectations for sustainable sourcing, to curb the use of fossil-based and non-renewable materials and reduce environmental impacts. This agenda will require a substantial growth and carefully planned development of the planted forests, through an integrated approach where a diversity of planted forests systems is properly planned into the landscape, and whereby forest and farm communities can deliver a diversity of products, for a diversity of modern and traditional uses and reuses. This will require planted forests to fully embrace the social and environmental dimensions that, if not addressed, could drive negative perceptions of plantations by local populations and global consumers.

The presentation will address key questions, such as : how can commercialization best bring socioeconomic benefits back to local communities that can become central agents of the bioeconomy? Where to plant what, and which tools and approaches for that? How to ensure legitimacy and inclusive and evidence-based decision in developing plantations into landscapes? What potential for agroforestry systems, trees on farms, and well-designed diverse tree species planted forests that can provide diverse uses, ecosystem services and habitats connectivity for wildlife populations?

It will propose key elements for a coordinated approach between developing bioeconomy and planted forests, through policies and incentives, market and product regulations, value chains coordination, innovations, and capacitation, including of local actors, and consideration of environmental and social factors. If well managed, the successful integration of planted forests into the bioeconomy can be one key example on how to synergize economic development with environmental stewardship.

Value creation and distribution of benefits along the Acacia mearnsii woodlot charcoal value chain

T2.7 Fast growing trees in support of sustainable bioeconomy

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Abstract: As the demand for energy consumption increases in urban cities of Ethiopia, a rapid land use transition and expansion of smallholder plantations has occurred in the highlands of Ethiopia. Specifically, Acacia mearnsii woodlots dominate the smallholder agricultural system. Drawing on a randomly selected sample of 148 producers and snowball sample of 52 traders, primary data on value addition, economic benefit and contribution to livelihood was collected from value chain actors using a semi-structured questionnaire. The data was supplemented with 7 key informant interviews, 6 focus group discussion and field observations. The results revealed that charcoal produced from the smallholder Acacia woodlots extend from the Fagita Lekoma district to the capital Addis Ababa and other major cities such as Bahirdar and Gondar. Several value chain actors are engaged in the Acacia cultivation, charcoal production, transport and sales, which creates employment opportunities along the value chain and a rural urban linkage. The direct charcoal value chain actors include seed collectors, seedling producers, woodlot producers, charcoal producers, daily labourers, brokers, commission agents, wholesalers, retailers and consumers. Indirect actors such as the Woreda Offices of Agriculture, Finance and Trade are engaged in the facilitation and regulation of the value chain. Smallholder producers gain an average annual income of 1936 USD contributing to 35% of their annual household income from the woodlots and charcoal alone. The average annual net income was 4952, 6560, 4612, 30184, and 2120 USD for local intermediates, brokers, local collectors, wholesalers, and retailers, respectively. The royalty fee for exported charcoal is the major contributors of government revenue in the district. The results also indicated an upward skew of benefit distribution. The total relative commercialization margin was 58%, indicating that actors involved in product marketing received a larger share of the final market price, while farmers that engaged in plantation and charcoal making activities received 42% of the end market prices. In conclusion, the market-driven production of Acacia woodlot profits value chain actors and generates rural government revenue, while also contributing to employment creation, rural livelihoods and well-being.

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

Afforestation of abandoned farmland by hybrid poplar: Effects on plant communities, soil organic carbon and microbial communities

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: The ever increasing international demand for wood products puts a lot of pressure on natural forests, being exploited always further north from urban centres and mills. Simultaneously, Québec's northern rural areas are experiencing a decline in agricultural activity, leaving many lands abandoned well suited for afforestation with fast-growing plantations.. Furthermore, afforestation of abandoned farmland is seen as one strategy among others for mitigating the consequences of climate change by increasing carbon sequestration in soils and woody biomass. However, in the absence of active reforestation, secondary succession takes place on abandoned lands that gradually but slowly evolve into forest ecosystems. These abandoned farmlands are also likely to sequester large quantities of carbon and eventually allow the establishment of forest species. We therefore wondered whether reforestation of abandoned farmlands with hybrid poplars was an appropriate solution for promoting carbon sequestration and the establishment of forest species while providing large quantities of wood. To address this issue, we sampled 16 near mature hybrid poplar plantations associated with adjacent non-afforested areas in which we measured soil carbon stocks, understorey vegetation diversity and soil microbial communities. We expected to see a reduction in biodiversity in the plantations compared with non-afforested land and a strong variation in microbial communities due to the disturbance caused by reforestation operations and initial weed control of plantations. However, we also expected the plantation soils to contain more organic carbon due to the rapid growth of the trees. Overall, we believe that the effects of reforestation abandoned farmlands will depend on the previous land use that preceded afforestation and the stage of the secondary succession when plantations were installed. Our initial results suggest that hybrid poplar plantations did not accelerate recolonisation of the environment by forest species, and that ruderal species persist within the plantations. Even though afforestation with hybrid poplars had little or no effect on plant biodiversity, it is nevertheless a useful tool for intensive wood production to release the pressure on native ecosystems of the boreal forest.

Agroforestry phytoremediation buffer systems: nature-based solutions in the Great Lakes Basin, USA

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Fast-growing trees such as poplars (*Populus* sp.) and willows (*Salix* sp.) are integrated into nature-based solutions in temperate ecosystems more than any other genera. Poplars and willows are adept at greening and cleaning brownfields, mine sites, landfills, and other contaminated areas across the urban to rural continuum given their extensive root systems, elevated biomass productivity, and ability to regulate their water use. This combination of traits is ideal for phytoremediation, the most common phytotechnology worldwide, which utilizes trees to enhance ecosystem services across degraded landscapes. Exploiting processes taking place in the soil, roots, wood, and leaves of the trees to immobilize, degrade, and extract contaminants, phytoremediation alleviates anthropogenic impacts to water quality and quantity as well as soil health. The need for such nature-based solutions is prevalent in the Great Lakes Basin of eastern North America, a vast region covering more than 777,000 km^2 (i.e., 1.5 times the total area of Sweden), containing 20% of the global freshwater supply (i.e., 95% of the United States' surface freshwater), and providing nearly 35 million people in the United States and Canada with a multitude of ecosystem services. To address this need, USDA Forest Service researchers and their partners developed the largest field-based, phytotechnology monitoring and testing network in the world, consisting of sixteen agroforestry phytoremediation buffer systems (i.e., phyto buffers) at landfills within the Lake Superior and Lake Michigan watersheds. We will provide information on the establishment success of these phyto buffers, as well as on their ability to provide ecosystem services. In particular, we will present mid-rotation (i.e., seven years after planting) results for biomass production and carbon storage of twelve poplar clones grown at six of the phyto buffers in southeastern Wisconsin, USA. We will highlight differences in biomass and carbon among the clones and their four genomic groups (*Populus deltoides* Bartr. Ex Marsh 'D'; *P. deltoides* × *P. maximowiczii* A. Henry 'DM'; *P. deltoides* × *P. nigra* L. 'DN'; *P. nigra* × *P. maximowiczii* 'NM') and will translate these research results into practical recommendations for nature-based solutions that are geographically robust, being regionally designed yet globally relevant.

Bamboo, a solution based on nature, is embodied in the practice of near Natural landscape by means of healing

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: "Bamboo" is not only a global but also an oriental Viridiplantae. It is a fast growing and green sustainable material and a solution based on nature. At present, there are not a few human beings in the global state of Suboptimal health. Our staff engaged in ecological environment landscape, combined with the reflection before and after the epidemic, tried to explore a way to build a healthy, harmonious and natural circular operation of the natural environment in the process of planning and updating various urban centers and urban and rural green space, create a landscape close to nature, heal people and nature, and promote the survival and healthy growth of all things. This report combines a number of different types of practical projects (exhibition garden, flower border, bamboo landscape construction, blocks) in Shanghai (Chongming Island), Chengdu (Qinglong Lake), Beijing (Wangjing Peony Bamboo Garden) and other places in China, and uses "bamboo", a solution based on nature, to make full use of its material properties on the one hand, and use its natural properties on the other hand to scientifically match with native garden plants and flowers, It not only conforms to the meaning of time planting, but also deduces the use of healing plants, carries out practices close to Natural landscape, and brings people a beautiful and healthy living environment.

Biomass production potential of hybrid aspen and silver birch plantations on former agricultural land

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: The short rotation plantation forestry (with focus on wood for energy use) on former agricultural land has great potential to produce biomass and mitigate climate change. Silver birch (*Betula pendula* Roth) and hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) trees are pioneering species in post-industrial habitats. Various fertilizers (both organic and inorganic) containing heavy metals have been used on former agricultural lands. For example, phosphorus fertilizers contain several heavy metals (Cu, Zn, Mn and Mo). Literature data suggest that heavy metals cause a wide variety of changes in plants. Exposure to toxic metals negatively affects plant–water balance (e.g. root permeability, stomatal opening). The aim of the study is to assess the dynamics and interactions of heavy metals (Mn, Cu, Pb, Zn, Cd, Cr, Co, Fe, Mo, Ni, As) in plant-soil system of silver birch and hybrid aspen plantations on former agricultural land at the end of the potential rotation cycle (+20 years). We want to know which factors affect the uptake of heavy metals by trees. The hypotheses of the study are; (I) the quantity of heavy metals (Mn, Cu, Pb, Zn, Cd, Cr, Co, Fe, Mo, Ni, As) changes with the age of birch and aspen, and (II) the quantity of the components varies between bark and wood. The findings will help to understand the changes in the tree-soil growth environment and prognosticate possibilities of using hybrid aspen and silver birch for afforestation of former agricultural land. The study includes 22 hybrid aspen and 11 silver birch stands growing on former agricultural lands with different soils types all over Estonia. Concentration of heavy metals (like Cd, Cr, Cu, Fe, Mn, Ni ja Zn) in older wood (formed 11-21 years ago) is higher than in younger wood (formed during the last decade. Higher amounts of heavy metals have been accumulated in stem wood (Cr, Cu, Ni, Zn, Mn, Fe) than in bark biomass (except Cd). This research is supported by the Estonian Research Council grant PRG1007 and European Commission's Horizon 2020 programme under grant agreement No 101000406 (project ONEforest).

Cadmium accumulation by Phragmites australis and Iris pseudacorus in floating treatment wetlands

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: The detrimental effects of urbanization, industrialization, mining, and stormwater runoff on ecosystems have led to growing concerns regarding water pollution worldwide. Floating treatment wetlands (FTWs) offer a sustainable solution by utilizing plants to accumulate and immobilize pollutants from wastewater. This study aimed to evaluate the influence of Cadmium (Cd) on the growth parameters (height, biomass, root length, and chlorophyll content), anatomical characteristics, Cd accumulation in biomass, and the capacity of *Phragmites australis* and *Iris pseudacorus* to remove Cd in the presence of nitrogen (N) and phosphorus (P). Seedlings of both plant species were grown in simulated stormwater in FTWs at the department of Sanitary Enegineering, Gdansk University of Technology Poland for 50 days. The simulated stormwater artificially amended with varying concentrations of Cd, along with a constant N concentration of 4 mg L^{-1} and P concentration of 1.8 mg L^{-1}. The experimental treatments included a control (Cd_0), as well as Cd_1, Cd_2, and Cd_4 mg L^{-1}. *P. australis* produced the highest plant height, root length, and total dry biomass production in the Cd_2 treatment, while the chlorophyll index (CCI) exhibited the greatest increase in the Cd_4 treatment compared to the other treatments. For *I. pseudacorus*, maximum values for plant height, total dry biomass production, root length, and CCI were observed in the Cd_1 and Cd_4 treatments, respectively, compared to the other treatments. Cd accumulation analysis revealed that *P. australis* accumulated the highest Cd concentration in roots (1821.59 μg · $(0.05\ m^2)^{-1}$) than shoots (334.65 μg · $(0.05\ m^2)^{-1}$) in Cd_4 treatment. Similarly, *I. pseudacorus* also exhibited the highest Cd accumulation in roots (4900 μg · $(0.05\ m^2)^{-1}$) as compared to shoots (609 μg · $(0.05\ m^2)^{-1}$) under the Cd_4 treatment. The translocation factor for both species was observed to be less than 1, while the bioconcentration factor was greater than 1, indicating their potential for phytostabilization. In conclusion, our findings demonstrate that *P. australis* and *I. pseudacorus* could be implemented in FTWs to remediate contaminated waterbodies, restrict the movement of pollutants into unpolluted sites, and effectively remove Cd and nutrients from the water column.

Carbon and energy balance in poplar plantations fertilised with pelleted sludge

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Transformation towards a circular economy and sustainable land use requires improved availability of locally and regionally produced woody biomass. The Nordic-Baltic poplar feedstock is used for heat and electricity production or mixed with other tree species in pulping industries. Still, the potential use includes building materials, refined fuels, and nature-based circular models for recycling nutrients and carbon storage. This project developed a full-scale circular economic model based on recycling pelleted sludge from the wastewater plant in Vilnius, Lithuania. The short-rotation poplar plantations were established on 900 hectares of abandoned arable and marginal land, representing a vital element of an integrated solution for recycling the processed and biomass yield improvement.

To analyse the energy and carbon balance of the sludge recycling system, we developed a growth model for three production levels in 20-year rotations with 10.7-12.9 tonnes of dry biomass per hectare and year, assuming a yield increase of 10% and 20% as a result of sludge fertilisation. In addition, we analysed the soil carbon storage across different types of land use, including cropland, grassland, and the land converted with poplars, hybrid aspen, and birch. The data was collected between 2000 and 2020 on seven locations in Sweden, including plots 10 to 35 years old.

Our results showed higher soil carbon storage under poplars and grasslands than cropland, while birch plantations accumulated less soil carbon than all other alternatives. The energy balance was slightly higher in the unfertilised system due to using pelleted sludge as fuel in waste incineration plants. However, fertilised systems were better at sequestering CO_2, reducing the greenhouse effect over 100 years due to higher soil carbon storage. The poplar plantations established in Lithuania with productive clones could reduce the amount of CO_2 in the atmosphere by 1.2 to 2 tonnes and produce 207-248 GJ of heat energy per hectare per year. However, to meet the heating needs of all apartment-block houses in Sweden while reducing the amount of CO2 in the atmosphere by approximately one million tonnes per year, up to 450,000 hectares of poplar plantations would be required.

Ecosystem services from Populus bioenergy plantations - evaluation of soil health

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Short rotation woody crops such as *Populus* species and their hybrids are important components of the bioenergy landscape in the US. These trees grow quickly both above- and belowground and have the potential to increase soil carbon storage and sequestration, providing additional ecosystem services beyond biomass feedstock. To understand the relationship between productivity and soil carbon and nitrogen, two experimental plantations were established in Mississippi, USA with five *Populus* taxa (*Populus deltoides* × *P. deltoides* (D×D), *P. deltoides* × *P. maximowiczii* (D×M), *P. deltoides* × *P. nigra* (D×N), *P. deltoides* × *P. trichocarpa* (D×T), *P. trichocarpa* × *P. maximowiczii* (T×M), representing more than 100 unique clones. Soil carbon and nitrogen were measured annually at depths from 0 to 30 cm, along with tree productivity. Half of the experiment was coppiced on a two-year cycle.

At the end of four growing seasons, growth differences were observed among taxa while soil carbon and nitrogen differences were not. D×D clones had the greatest biomass index (BI = diameter at breast height^2 x height) regardless of site or coppice history. In non-coppiced stands, average D×D clonal BI (696.5 ± 30.4) was 1.2 to 6.1 times greater than other taxa and in coppiced stands (127.8 ± 5.4) was 1.8 to 2.6 times greater than other taxa. Across all taxa and coppice treatments, soil carbon increased by 18% and soil nitrogen increased by 34% from the initiation of the trial. Aboveground productivity was not strongly correlated to changes in soil carbon and nitrogen stocks within taxa, coppice treatment, or soil depth ($R^2 < 0.10$). As such, this study suggests that Populus plantations have the potential to increase carbon and nitrogen storage in soils independent of biomass productivity. Results also suggest that coppicing has no immediate detrimental impacts to soil nutrients and that plantations will continue to store carbon in belowground pools. As such, belowground inputs (e.g., root exudates, turnover) may be more important sources of carbon in bioenergy plantations compared to losses from aboveground biomass removal, especially when coppicing occurs post leaf fall.

Evaluation of physical, mechanical and anatomical properties of Melia volkensii – a fast maturing species grown in drylands of Kenya

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: *Melia volkensii* an indigenous tree species growing in arid and semi arid areas in Kenya has shown promise as a fast-maturing species. Its timber is highly valued for furniture, joinery and interior panelling. This study investigated the wood quality of 10, 12 and 14- year-old *Melia volkensii* trees grown at Tiva, Kitui. Height and diameter at breast height were taken before the trees were felled. The wood properties studied were basic density and the stem analysis which comprised of; the ring width, heartwood/sapwood ratio, roundness and decentering. The variation of mean tree height and basic density against age was not significant with the mean height being 9.86m and basic density ranging between 341-561 Kg/m^3. However, the difference in diameter at breast height was significant where the maximum and minimum was 25.9 cm and 16.7 cm. The volume of wood was notable and significant with age – the older the tree the higher the volume. At 14 years the average volume was over 40% more that at 10 years. The heartwood ratio was highest at age 14 at 79±5 % indicating its high marketability with over 75% heartwood. The percentage decentering was lowest at age 14 years at 116±7 %. Generally, a negative correlation was found between pilodyn and basic density of 0.54 which was consistent with the gradual increase of basic density across the grains from pith to bark. This study has shown that Melia volkensii is not only fast maturing but has great potential to offer nature based solutions in the drylands of Kenya

Explore the Mechanism of Fast Growing Bamboo and Promote Internode Elongation

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Most tropical and subtropical bamboo species have high biomass, short maturity period of bamboo timber and great carbon sink function. Bamboo is a very important fast-growing renewable resource to reduce global wood pressure. Moso bamboo (*Phyllostachys edulis*) has one of the fastest growth rates among all plants. The shoot can grow as fast as 1.2 m/day at peak growth and reach heights of 20 m in 45–60 days. The length of bamboo internode and plant height determine the yield of bamboo timber. However, how to obtain long internode by means of breeding and cultivation has been an unsolved problem.

We analyzed the plant height growth law of the Moso bamboo, with more 5 million hectares, representative bamboo species in China, and studied the effect of hormone treatment on the change of internode length. The main pathway of auxin synthesis in Moso bamboo was local auxin biosynthesis. The main sites of auxin synthesis were identified by immunofluorescence. In situ hybridization analysis of YUC gene further identified the tips of bamboo shoots and young bamboo sheath as the main sites of auxin synthesis. Major auxin synthesis, transport and signal transduction genes were identified. Auxin was involved in plant height regulation through plant hormone pathway, amino acid biosynthesis pathway, protein processing pathway and energy metabolism pathway at the levels of transcription, translation and post-translational modification. Targeted metabolomics analysis based on MRM (multi-reactive ion monitoring) revealed that auxin co-regulates internode elongation with ETH (ethylene) and GA (gibberellin). The analysis of PheAUX/IAA34, a key auxin signal transduction factor, showed that it could interact with JA (jasmonic acid) signal transduction factor PheTIFY28 and participate in plant height regulation. These results revealed the crosstalk among auxin and GA, ETH and JA.

With a price of about RMB 300 yuan per hectare, hormone treatment offers a low-cost way to improve the economic and ecological benefits of bamboo forests. The cloning and functional identification of key genes provide genetic resources for molecular breeding of bamboo.

Exploring the potential of multifunctional fast-growing tree plantations using geoexplicit modeling

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Strategically introducing fast-growing tree plantations in intensively managed agricultural landscapes can supply biomass to the bioeconomy while mitigating a number of environmental impacts. However, the environmental benefits in any given location depend on landscape specific biotic and aboitic characteristics. To understand the suitability of multifunctional production systems in specific locations and the overall potential at larger scale, spatially explicity methods are necessary.

Here, we summarize the outcomes and experiences of multiple recent studies in which we have modeled the potential for multifunctional production systems based on fast-growing tree plantations and grass at the European scale. Our models cover > 81,000 sub--watersheds in EU27 + UK (Europe) and can identify and quantify suitable areas for three production systems: riparian buffers, windbreaks, and grass in rotation with annual crops. For each sub-watershed, the models quantify suitable areas for the production systems, based on existing environmental impacts and current land-use, and the corresponding (i) biomass--and protein supply, (ii) soil organic carbon sequestration, (iii) reductions in nitrogen emissions to water, (iv) wind erosion, and (v) water erosion. The models also provide information about possible flood mitigation.

The results indicate that both nitrogen emissions to water and soil loss by wind erosion can be decreased to acceptable levels by establishing riparian buffers and windbreaks, respectively, on a very limited land area—provided that fast-growing trees are established and managed in a suitable way, in suitable locations. The environmental co--benefits are in several cases notable—in some cases exceeding the estimated mitigation needs. The effects on agricultural production can vary substantially, depending on the degree of land-use change and biomass end-use. Incentivizing widespread deployment will require supportive policy measures that acknowledge the value of environmental benefits as well as new local biomass markets.

We will also introduce ongoing research efforts to understand how fast-growing tree plantations can support biodiversity by strengthening ecological connectivity, using novel modeling approaches.

From growth to carbon: evaluating the impacts of fast-growing trees on soil organic carbon storage

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Increasing soil organic carbon (SOC) storage is one of the promising solutions to mitigate climate change. Fast-growing trees are a potential tool in this context as they rapidly accumulate C in their biomass and could transfer more organic matter (OM) into the soil. However, the relationship between aboveground productivity and SOC storage remains poorly understood. Five clones with different growth rates were selected from a 14-year-old hybrid poplar plantation located in New Liskeard, ON, Canada. We collected soil cores at 87.5 and 175.0 cm distance from the stem and at 0-20, 20-40 and 40-60 cm soil depth for soil C concentration analysis. The most productive clone DN2 (*Populus deltoides* x *P. nigra*) stored less SOC (83 Mg ha^{-1}) between 0 and 60 cm depth than the mid-productive clones 1079 *(Populus* x *jackii* (*P. balsamifera* x *P. deltoides*)) and 915005 (*P. maximowiczii* x *P. balsamifera*) (95 and 96 Mg ha^{-1} respectively), while the least productive clone 747210 (*P. balsamifera* x *P. trichocarpa*) also had a lower SOC stock (85 Mg ha^{-1}) compared to the other clones, but not significantly. SOC stocks were not correlated with aboveground productivity but differed between clones. Total SOC stocks increased by 6 % when the sampling distance was closer to the tree stems. The difference in SOC stocks between clones was mostly observed at the 20-40 cm depth suggesting the significant effect of roots on SOC storage. Soil C/N ratios were significantly different between clones at 0-20 and 20-40 cm depths suggesting differences in OM decomposition rates between clones. There could be a trade-off between aboveground productivity and litter decomposition rate and the species selection is important to increase SOC storage.

Great Lakes Phyto: An international partnership developing phytotechnologies as nature-based solutions for rural and urban communities

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: The Great Lakes of eastern North America provide substantial ecosystem services to nearly 35 million people in the United States and Canada. In addition to supplying clean and abundant water, the Great Lakes provide jobs, food, and energy; moderate the climate; deliver outdoor recreation opportunities that enhance community livelihoods; and offer diverse habitat for plants, wildlife, and fish. Despite these economic, social, and ecological benefits, human activities have resulted in disturbed terrestrial water cycles, diminished water quality and quantity, and loss of habitat, thereby threatening the ecosystem services provided by the Great Lakes. While some engineering approaches have been successful at reducing ecological impacts of human activities, tree-based systems are cost-effective alternatives that offer sustainable solutions for mitigating these impacts. Therefore, in response to environmental challenges faced by the Great Lakes region, USDA Forest Service researchers and their partners developed and installed a network of sixteen agroforestry phytoremediation buffer systems (i.e., phyto buffers) throughout the Lake Superior and Lake Michigan watersheds of the Great Lakes Basin, USA. By reducing untreated runoff and groundwater and filtering contaminants, the goal of these poplar and willow-based buffers is to reduce non-point source pollution entering the Great Lakes tributaries and nearshore waters. As a direct result of the establishment of this regional phyto buffer network, researchers, land managers, industry professionals, regulators, government officials, and community members from around the world formed Great Lakes Phyto, an international partnership that develops phytotechnologies to enhance ecosystem services in rural and urban communities. Great Lakes Phyto seeks to reduce impacts from degraded lands and waters in the Basin by using phytoremediation and associated phytotechnologies that maximize the social, ecological, and economic benefits provided by the Great Lakes. Since its formation in 2016, Great Lakes Phyto has strived to enhance quality of life, stewardship of ecosystem services, and profitability for landowners through the development of phytotechnology best management practices. We will highlight current efforts of Great Lakes Phyto, focusing on numerous applications of fast-growing trees as nature-based solutions for cleaning and greening the environment.

How does understory vegetation diversity and composition differ between monocultures and mixed plantations of hybrid poplar and spruce?

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Although monocultures are important for timber production, they have often been perceived as biological deserts. Thus, mixed plantations have been suggested as a way to enhance biodiversity because of their inherent compositional diversity. However, there is no consensus on the impact of mixed plantations compared to monocultures on understory vegetation diversity and composition. The objective was to assess how differences between monocultures and mixed plantations of fast-growing hybrid poplar (*Populus* spp.) and spruce (*Picea* spp.) species established 20 years ago on abandoned farmlands and a forest site influence understory vegetation (vascular plants, bryophytes, and lichens) diversity and composition. We also evaluated the effects of plantation type on bryophyte and lichen diversity and composition in tree microhabitats: soil, tree bases, and tree trunks. We found a total of 115 understory vegetation species including 50 vascular plants, 46 bryophytes and 19 lichens species. We found similar understory vegetation diversity in spruce and mixed plantations, greater than in hybrid poplar plantations. We also found that mixed plantations harbored more bryophyte species compared to hybrid poplar plantations as the addition of spruce in mixed plantations created microhabitats and conditions which were favorable for their establishment. Our results also showed that short-rotation hybrid poplar plantations in mixed plantations favored the occurrence of epiphytic lichens and could provide temporary habitats for lichens. We also found that the dissimilarity in the microhabitats created by hybrid poplar and spruce in mixed plantations promoted the establishment of both terrestrial bryophytes and epiphytic lichens. Finally, our results highlight that vascular plant composition was more sensitive than bryophyte composition to the land-use history as abandoned farmland sites were composed of more ruderal vascular plants, while the previously forested site was composed of species typically found in the surrounding natural forests. Our study advances our understanding of how monoculture and mixed plantations affect understory vegetation diversity and composition and highlight the importance of considering land-use history.

Hybrid Poplar for Alternative Veneer Source, Carbon Credits, and Water Conservation in the Appalachian Mountains, USA

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Hybrid poplar (*Populus* spp.) is grown globally for bioenergy, value-added products, sawmill, and veneer. We have cultivated selected poplar clones that grow well in the mountains of western North Carolina (WNC) and yield high-value veneer wood logs within 8-12 years. This area supports a robust industry of short-rotation fir production for Christmas trees but is faced with soil pathogen and climate-warming challenges. Veneer poplar is an alternative high-value crop to mountain bottomlands, slopes, and ridges that no longer support fir production and need water and soil management control. To increase confidence in commercial deployment, both productivity and profitability models were developed to assess economic viability for existing mills, producers, consultants, and markets. An existing 3-PG productivity model for hybrid poplar across the Piedmont and Coastal Plain of North Carolina was adapted to WNC-specific conditions and coupled to a WNC poplar-veneer enterprise budget to produce an feasibility and profitability tool using a publicly-accessible google sheet. An added feature is cost comparisons between veneer-poplar cultivation and current agricultural production yields and profits from pasture, hay, and pumpkin crops. The cost comparison includes estimation of carbon credits for poplar growth on former pasture or row crop agriculture. New programs for federal water conservation also provide incentives. There is landowner interest in alternative forestry-markets in WNC, particularly lands once in cultivation for profitable Fraser fir and now unusable due to the soil pathogen *Phytophthora*.

Industrial wastewater for lignocellulosic biomass production: A Green and Circular solution

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Biomass is an important raw material for the development of a sustainable bioeconomy, and the plantations that generate it can also play a key role in short term carbon sequestration in the context of global change. The use of specific short-rotation plantations for biomass production, such as *Salicaceae*, ensures a reliable and complementary supply in areas where needed. Under Mediterranean conditions, and increasingly in other climate zones given the ongoing climate change, irrigation appears to be essential for the survival and productivity of these plantations. However, current water resource challenges make this a critical problem. Therefore, the use of wastewater emerges as a promising solution, effectively reusing a valuable resource and representing one of the most impactful ecosystem services these plantations can provide, alongside their carbon sequestration capacity.

In this context, two consecutive greenhouse trials were conducted under controlled conditions to compare the suitability to produce biomass using two different wastewater from the agri-food industry (brewery), both sourced from the same Wastewater Treatment Plant (WWTP): first trial with secondary wastewater (SW) and second trial with dischargeable treated wastewater (TW). This study involves the monitoring of six different poplar and willows genotypes during the initial months of growth. Biomass production was evaluated, differentiating each fraction, and relevant relations such as root:shoot ratio and tolerance index were determined. While differences among genotypes were observed in both trials, treatment differences were only found for the SW in relation to the control, but not in the TW trial. No genotype-treatment interactions were observed in any of the trials. The average reduction in above-ground woody biomass was 17% with TW, and 33% with SW, with the exception of the *Salix* genotype 'Levante' that showed only a 17% reduction with SW and even a 28% increase with TW, suggesting a potential fertilizing effect. In addition, the nutritional status and physiological variables were also evaluated, with particular focus on total nitrogen (N) concentration due to its importance in this type of wastewater.

The reuse and regeneration of industrial wastewater while producing a key feedstock is a crucial nature-based solution for water-constrained short-rotation plantations.

Influence of Green Manure on the Initial Performance of Forest Species Implanted in an Experimental Forest Landscape Restoration Plot in Paraguay

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Green manure plays an important role in protecting seedlings against extreme weather conditions, as well as providing nutrients to the soil and other benefits. Therefore, this study aimed to compare the influence of green manure on the initial performance of implanted species in terms of Diameter at Collar Height (DCH), Height (H), and Crown Area.The research was conducted in an experimental plot for Forest Landscape Restoration at Itaipu Binacional, located in the district of Hernandarias, Alto Paraná Department, Paraguay. The experiment consisted of 2 treatments and 5 blocks. The treatments were planted in strips, including a conservation strip and a production strip. The production species were native species with energy purposes. The treatments differed in the planting of green manure (Cajanus cajan L. Mills) in the inter-row of the plantation.After 12 months of planting, the experiment was evaluated considering the variables of height, crown area, and DCH of the 21 forest species.The results show a greater crown area in species planted without green manure, with an average of 1.1767 m2, as well as a higher DCH without green manure, with an average of 22.2037 mm. However, regarding height, the plantation with green manure had an average of 98.3180 cm, while the plantation without green manure had an average of 98.7262 cm.In conclusion, green manure influences the growth of different variables, particularly benefiting height.

Phytotechnologies at Stillmeadow Community PeacePark Forest

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Forests in cities contribute to critical biophysical and socio-cultural ecosystem services, and provide outdoor classrooms for unique educational experiences. Threats from invasive plants, deer browse, and introduced pests and disease often prevent native forest regeneration, particularly when coupled with existing anthropogenic impacts. Fast-growing trees present an opportunity to establish canopy cover and enhance soil organic matter in challenging site conditions where keystone native species (e.g., *Quercus* and *Carya* spp) struggle to establish. The USDA Forest Service (USFS) is implementing this approach in an 'urban silviculture' experiment in partnership with Stillmeadow Community Projects, a non-profit organization based in Baltimore, Maryland, USA. Stillmeadow Church owns 4 hectares of forested land known as the PeacePark. The Church and PeacePark are located in a community comprised of predominantly African American households that have been historically underserved, and are vulnerable to flooding and heatwaves. The PeacePark forest was ecologically degraded due to intense deer browse, invasive understory plants, poor soil quality, and extensive mortality of ash (*Fraxinus* spp) canopy trees due to the invasive Emerald Ash Borer. As a result, USFS scientists partnered with Stillmeadow to install phytotechnologies designed to foster 'anthropogenic succession.' Six poplar and six willow genotypes were planted in experimental plots throughout the forest, and a wood chip ground cover treatment was incorporated to suppress invasive plants. The trees were planted as hardwood cuttings and as potted saplings, testing the effectiveness of these approaches in rapid establishment of forest canopy cover as well as their success as community planting techniques. Planting and maintenance of the experiment has been led by the Stillmeadow community, providing educational experiences and workforce training opportunities. Early results indicate that both species planted from one-gallon containers are capable of high survival rates and vigorous growth in the first years after planting, but cuttings planted directly in the ground suffer much higher mortality in these site conditions. However, community-led planting was very successful, as was the community nursery established to grow potted poplar and willow trees. Phytotechnologies are a viable nature-based solution that may be applied to other urban forest or vacant land sites throughout Baltimore City and beyond.

Potential of short rotation willow systems for water treatment

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Increasing resource consumption and growing impact of climate change necessitate resource reuse and development of resilient systems. Collection and treatment of domestic wastewater in rural areas and effective management of stormwater in urban areas pose significant challenges globally, leading to extensive research and implementation of resilient nature-based solutions (NBS).

Municipal wastewater is characterized by a continuous flow of organic matter, nutrients, and water, while stormwater is sporadic and depends on rainfall, resulting in variable loads and volumes. NBS incorporating fast-growing trees are effective for addressing both water sources. While these systems are widely used in Northern Europe, their application in sub-Mediterranean climate with higher and more intense rainfall requires specific adaptations. This paper addresses the design and performance of short-rotation willow systems for the treatment of (a) municipal wastewater and (b) stormwater runoff applied in Slovenia.

The wastewater treatment system (a) comprises a watertight, soil-filled basin planted with fast-growing clones 'V 160' (*Salix alba* L.), 'V 052' (*Salix alba* var. *calva* x *S. alba*), and 'V 093' ((*Salix alba* x *S. alba* var. *vitellina*) x *S. alba*). A clay layer is incorporated near the soil surface, and drainage pipes are installed to prevent rainwater from entering the system. Mechanically pre-treated water is pumped into the system and used for plant growth and evapotranspiration. As a zero-discharge system, it is suitable for environmentally sensitive areas with strict discharge requirements or for areas where infiltration of treated water is not possible. Among the clones, 'V 052' has shown the highest conversion rate of wastewater to woody biomass (8.5±0.6 kg per m^3 of wastewater) and was therefore selected for the stormwater treatment system (b). This system functions as a flow-through system for 10- and 60-minute rainfall with a 10-year return period. Stormwater is introduced at the top and is treated as it vertically passes through the media and willow root system.

Both systems described represent the first application of NBS using fast-growing trees in this European region. Therefore, it is crucial to present their performance and co-benefits for the environment and people, such as biomass production, habitat function, microclimate improvement and esthetic value.

Potential to increase the availability of a hybrid poplar resource for Engineered Wood Products based on Agroforestry production systems

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: The agricultural sector is often disconnected from the forestry wood chain especially with regard to green building. Innovative agroforestry systems create potential for the agricultural sector to diversify and increase incomes. However, there is a need to develop specific road maps towards green building. Hybrid poplars are a main component for this strategy. Alongside the more general introduction of this fast-growing trees suitable for engineered wood products, the advantages for the agricultural, forestry and construction sectors are very relevant. For the agricultural sector this is mainly related to climate change impact and environmental aspects and for the forestry and construction sector this will clearly contribute to the need for extra wood resource to enable bio-based building materials to be used more generally. Integrating these sectors is a timely challenge that needs advancements in research and innovation. There is a clear need to bring together experts and also to communicate on current research and results obtained in the near future on a national and international level. Networking in a multi-, inter and transdisciplinary way, experts from agricultural, forestry and bio-based building related industry will create not only a platform for exchange of research outcomes but also have a major impact on socio-economics in a pan-European context. This AGROPOPTECH network as part of the FAO structure IPC (International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment) creates a unique opportunity to build communities and pursue new ideas to impact the wide range of countries to get involved in agroforestry based on fast growing tree/wood species like hybrid poplar.

Selected references

Response of Four Tree Species to Fertilizer, Watering and Weeding Regimes in the Sub-Humid Conditions of West Oromia, Ethiopia

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Abstract

Post plantation seedling management activities are the most important factors that determine survival rate and growth performance of tree seedlings. The objective of this study was to investigate and compare growth performance of four tree species (*Cordia africana, Croton macrostachyus, Acacia abyssinica* and *Grevillea robusta)* with and without applying different management regimes (weeding, watering and fertilizer application). Half of the seedlings were fertilized with 138 gram of Phosphorus and 123 gram of Nitrogen per plant. Moreover, half of the seedlings were also weeded and irrigated with 15 liter per seedling per week for twenty months. Accordingly, split-split-split plot design with three replications having sixteen seedlings each was planted at four meter spacing. Plant height, root collar diameter and survival rate were collected starting from one month after plantation for twenty months. As no initial data (at planting) were taken, the data collected one month after plantation were used as covariate. This is because; there were significant effects in some treatments one month after plantation. The collected data were subjected to multivariate analysis of variance. Analyzing both height and diameter at twenty months after planting with one month as a covariate indicated that no interactions were significant, while, fertilizer and weeding had clear main effects. The twenty months survival rate was unaffected by main effects or interactions. Gravilia robusta was the most sensitive to weed competion compared to others explained by higher plant height when weeded than not. Similarly, *Cordia africana* and *Croton macrostachyus* revealed higher sensitivity to fertilizer application. The no response in growth performance of seedlings to the supplementation of water during the dry season could signify that moisture was not a growth limiting factor in the area during the growing season. Application of different management regimes, particularly fertilization and weeding was essential in improving growth performance of tree species in the area. Hence, treatment effects on survival rate might have been expressed indirectly through improving growth performance of the species. In general, further studies should be conducted to obtain optimum water and fertilizer requirements of the different tree species.

Key words: *Fertilizer, watering, weeding, plantation*

The implications of fast-growing broadleaved trees for lichen diversity in northern Europe

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Sweden aims to achieve a 70% reduction in greenhouse gas emissions by 2030, and reach net zero from 2045. Bioenergy will be an indispensable piece of the puzzle for achieving both energy and climate policy goals. Currently, bioenergy supplies approximately 25% of energy in Sweden, most of which is sourced from the forest sector. However, this sector is dominated in Sweden by conifer forestry, an increasing proportion of which is experiencing problems with abiotic and biotic disturbance. This has spurred calls for a more diversified forestry, to help ensure that the future of forest biomass provision is sustainable and resilient to the risks and uncertainties of anthropogenic climate change. One prominent path to diversification is the wide-spread adoption of fast-growing broadleaved tree species (FGB), which include silver birch, poplar, aspen, and hybrid aspen. However, the use of such intensive forestry will have important but potentially complex implications for biodiversity. FGB combines the use of intensive even-aged disturbance regimes, with either native broadleaf tree species, or broadleaves of hybrid or introduced origin, with potentially adverse biodiversity outcomes due to the simplified forest systems that result. In contrast, the increased use of fast-growing broadleaves is consistent with attempts to diversify the uniformity of Sweden's conifer-dominated production lands, and their adoption could benefit at least some aspects of Sweden's diverse broadleaf dependent flora and fauna. Due to the counteracting drivers involved, the potential implications of fast-growing broadleaves for biodiversity remains unclear for many broadleaf associated taxa. Lichens are a key component of this diversity in forest systems, are directly coupled to the tree species grown and forest management intensity, and are overly represented on the Swedish red-list. Here we provide results from lichen surveys conducted in FGB stands as part of the Trees For Me project. We highlight differences in the diversity and prevalence of lichen species found, and link these patterns to the species of FGB planted, stand characteristics, landscape context, and management regimes employed. By providing targeted knowledge regarding the biodiversity implications of FGB, landowners and society can better make evidence-based decisions regarding the advantages and disadvantages of the choices available.

Transcriptome and metabolism reveal different mechanisms of cadmium absorption, accumulation, and resistance between female and male Salix viminalis

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: *Salix viminalis* is a typical dioecious and fast-growing shrub willow, which has been widely used in phytoremediation for heavy metal-contaminated soil due to its characteristics of fast growth rate, deep root system, and resistance. It has been reported that dioecious plants present sex-specific responses when exposed to biotic and abiotic stress. However, sex-specific response mechanisms to cadmium stress of male and female *S. viminalis* remain undefined. In this study, the growth, cadmium absorption and distribution, root physiology, transcriptome, and metabolism of male and female *S. viminalis* under cadmium stress (200 μM) were investigated to identify sexual differences. The results showed that female *S. viminalis* suffered more severe impairment than males. The cadmium net influx rate of males (139.67 $pmol \cdot cm^{-2} \cdot s^{-1}$) was significantly faster than that of females (76.64 $pmol \cdot cm^{-2} \cdot s^{-1}$). Furthermore, the abilities of cadmium transportation and enrichment of males were much stronger than those of females. Transcriptome and metabolism analysis showed that both male and female *S. viminalis* up-regulated *ZIP2*, *AtbZIP6,* and *ZIP11* to activate transmembrane transporter activities. Male clones of *S. viminalis* synthesized more phenolic acids, lipids, and organic acids, and up-regulated *ZIP1* and *ATNRAMP6* to improve cadmium absorption. Female clones up-regulated more ABC transporter family genes (*ABCA3* and *ABCC3*) and stress-related genes such as *PCR2*, *GSTU7*, and *ATMT-1*, which were involved in the mitigation of cadmium toxicity, and synthesized more flavonoids such as myricetin, quercitrin, and alfalfa 5-*O*-glucosides, and amino acids such as glutamate and L-threonine for antioxidant defense against cadmium impairment. In conclusion, this study revealed the physiological and molecular mechanisms in cadmium resistance between male and female *S. viminalis*, providing strong evidence for the phytoremediation application of dioecious fast-growing trees on heavy metal-contaminated soil.

Urban phytotechnologies for forests in cities: using hybrid willow and poplar in urban afforestation and forest restoration projects

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: Phytotechnologies lend themselves to the challenges (e.g. disturbed sites and contaminated soils) and management priorities of greening efforts in cities (e.g. stormwater and heat island mitigation). In urban natural areas, early-successional, fast-growing trees such as hybrid willow and poplar may support management efforts to create new forests (i.e. urban afforestation) and restore existing forest ecosystems in cities. For example, these trees may both tolerate urban site conditions and provide rapid greening that accelerates succession, controls invasive plant establishment, and facilitates the establishment and growth of later-successional trees that are desired by municipal forest managers. These trees are relatively easy to propagate and can be used as part of a cost-effective strategy that supports the broad goals of municipal forestry divisions.

Here we present two studies that test strategies using hybrid willows and poplars in natural land settings in Philadelphia, PA, USA. The Parkwood Afforestation study was installed in 2022 in a disturbed landscape, characterized by compacted and anthropogenic soil, with the goal of establishing a new forest stand. The study compares the tolerance (i.e. survival and growth) of native Populus and Salix species to hybrid Populus and Salix, as well as the potential for hybrid willow and poplar to act as nurse trees and facilitate the establishment of mid-successional tree species. The Three Springs Canopy Gap study is located in canopy gaps within a mature oak-tulip forest, where the goal is to establish advance regeneration of native mast tree species via direct planting. In this study, we compare traditional pre- and post-planting treatments, including mechanical removal of invasive plants and vines, herbicide application, and co-planting hybrid willow and poplar with mast trees in order to provide rapid canopy closure to suppress invasive plants and facilitate mast tree establishment (ie nurse tree strategy). We present preliminary findings and how phytotechnologies have been adopted by a municipality with the goal of scaling-up operations and integrating fast-growing trees across management practices.

Using shrub willows and soil amendments for biomass production and site remediation on reclaimed mine lands and marginal agricultural lands

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: The Mid-Atlantic region of the U.S. has over 10 million acres of mined and marginal agricultural lands that can be reclaimed and used to produce biomass crops without occupying or competing with food crops for existing cultivated areas. Both reclaimed mine sites and marginal agricultural lands present challenges to growing biomass crops. Soil physical and chemical characteristics often limit productivity and reduce ecosystem services provided. We explored the use of shrub willow biomass crops on six sites in the Mid-Atlantic region (3 reclaimed mine sites and 3 marginal agriculture sites) to assess the potential for biomass production and overall site reclamation. To overcome site limitations, soil amendments consisting of nitrogen fertilization and biochar additions were imposed. After 3 growing seasons, growth and survival were substantially greater on the agricultural areas. Despite intensive establishment efforts, the site conditions on the mine sites presented significant problems to willow establishment. The effects of the amendment treatments on both site types will be discussed in the content of biomass production and changes in plant and soil health.

Using specialized trees and biochar to remediate and stabilize mining waste for the Keweenaw Bay Indian Community (KBIC)

T2.8 Fast-Growing Trees for a Greener Future: Global Applications of Nature-Based Solutions

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Abstract: The Keweenaw Bay Indian Community (KBIC) is a federally recognized Indian Tribe consisting of the L'Anse and Ontonagon Bands of the Chippewa Indians, and is located along the shores of Lake Superior in the Upper Peninsula of Michigan, USA. Lands surrounding the KBIC are abundant in mineral resources that historically have been exploited by industrial mining activities. During the 20th century, a nearby copper ore stamp mill (Mass Mill) processed and dumped over six billion pounds of copper ore processing waste, known as stamp sands, into the Keweenaw Bay less than five miles north of the KBIC. These stamp sands have been redeposited by lake currents at Sand Point, an area of significant cultural, recreational, and subsistence value to the KBIC. Elevated levels of heavy metals in the stamp sands, as well as their erosion-prone nature, together pose risks to human health and the wetlands, meadows, wild rice beds, and pine forests that border Sand Point. To date, restoration activities at the site have involved soil capping of stamp sands, placement of mounds and boulders to provide protection from the wind, and annual plantings of trees, shrubs, and herbaceous native plants. Despite these efforts, the stamp sands continue to impair many of the beneficial uses of Sand Point. Therefore, researchers at the USDA Forest Service and University of Missouri have partnered with the KBIC to design and deploy an adaptive silvicultural system that combines specialized, fast-growing trees with biochar soil amendments to enhance stamp sands phytoremediation and phytostabilization. Poplars and willows are ideal fast-growing trees for meeting the restoration objectives of Sand Point due to their rapid growth, extensive rooting, and ease of propagation. Multiple greenhouse cycles of phyto-recurrent selection will be employed to select superior varieties for outplanting in a demonstration system at Sand Point. We will present updates on field establishment of the demonstration site, including results on establishment success. We also will discuss the engagement and outreach activities we conduct with the KBIC that promote knowledge exchange among community members and researchers and enhance the dissemination of information to guide management decisions for stamp sands affected lands.

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

Benefits of biochar in sustainable agricultural operations

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

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Abstract: Forest restoration and fuel reduction treatments are often used to reduce wood volume in overstocked forested lands in an effort to reduce wildfire risk and the incidence of insect and disease outbreaks. However, these forest treatments produce large quantities of woody residues. If no use or consumer is identified for the woody residues, they are often disposed of by on-site burning. As a management adaptation, woody residues can be converted to biochar and either used on-site or moved to local agricultural producers to improve soil conditions. Biochar can be used to enhance soil organic matter levels and can provide a variety of benefits. For example, biochar can store more plant available water, reduce nutrient leaching, reduce soil bulk density, raise soil pH, and sequester large quantities of carbon to mitigate climate change. In short, biochar's unique chemical and physical properties improve microbial activity, minimize offsite movement of pesticides, facilitate C storage in the soil, and can increase plant growth and yields. The largest yield improvements on biochar-amended soils tend to be on nutrient-poor or coarse-textured soils that benefit from additional soil organic matter. Biochar created from forest operations offers a way of restoring forest ecosystems and degraded soils by redistributing excess organic matter from forest sites into soils that lack organic matter.

Exploring Biochar Production from Residual Biomass in Colombia: Potentials, Prospects, and Barriers

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

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Abstract: Biochar is recognized as a land-based net-negative emissions technology (NET) that plays a crucial role in supporting the targets of the Paris Agreement. It has significant potential for climate change mitigation and offers opportunities for co-benefits such as soil quality maintenance and facilitating the growth of new products. By converting residual biomass into biochar, the release of CO2 emissions into the atmosphere can be mitigated, providing an alternative to the decomposition of residual biomass in open fields. Biochar derived from residual biomass can be utilized for various applications, including soil amendment, remediation of contaminated soils, water treatment, and as an additive in construction materials, among others. While biochar production and usage can be adopted worldwide, tropical countries possess an advantage due to their abundant year-round availability of residual biomass.

This study presents the results of an investigation into the potential for biochar production from diverse residual biomass sources, using Colombia as a case study. The research involved conducting interviews with experts, an expert elicitation on agricultural residual biomass, and an estimation of agricultural residues for biochar production. The examination of potential biomass sources revealed that invasive plant species could be of interest for biochar conversion and subsequent soil incorporation. The valuable insights obtained from literature and expert interviews were analysed using a Policy, Environmental, Social, Technological, Economic, and Legal (PESTEL) approach. The findings indicate that approximately 10% of the residual biomass derived from key agricultural products (such as sugarcane, plantain, potato, rice, banana, cassava, oil palm, corn, pineapple, tomato, and coffee) could be transformed into biochar and reintegrated into the soil. Our conclusions present prospects and barriers of biochar production in the Colombian context. Our findings can be used internationally for navigating the biochar production and barriers of biochar production, and devising deployment strategies.

Phenotypic variability of fruits among provenances of Moringa oleifera Lam. in Kibwezi, Kenya

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

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Abstract: ABSTRACT

Phenotypic characterization of plant species is the basis for selection, conservation as well as improvement. *Moringa oleifera* Lam. belongs to the monogeneric family, Moringaceae. In Kenya, *M. oleifera* occurs in different agro-ecological zones, and is grown for its multiple uses that include medicinal, vegetable and as food supplements. The leaves and young pods are a rich source of minerals and vitamins; cooking oil can be extracted from the seed; and the back and roots can be used as medicine. This study reports on the evaluation of intraspecific phenotypic variations among eight Kenyan *M. oleifera* provenances (namely, Kibwezi, Ramogi, Kitui, Msambweni, Mbololo, Kilifi, Mtongwe and Gede) in a three-year old progeny trial established in Kibwezi. Our results indicate significant statistical differences ($p<0.05$) in quantitative fruit traits. The trait range was: pod length (Ramogi, 30.92 to Kibwezi, 35.95 cm), pod diameter (Msambweni, 1.50 cm to Kitui, 1.71 cm), weight of 100 seed (Msambweni, 16. 9 g to Mtongwe, 24.5 g) number of seeds per pod (Ramogi, 14.5 to Kibwezi 18.2) and number of locules per pod (Msambweni, 15.6 to Kibwezi 18.2) among families and provenances. **Pearson** correlation (r) results at $p=0.05$ revealed that the seed weight had a significant, positive correlation with pod length ($r=0.38$), pod diameter ($r=0.46$), and number of seed ($r=0.59$). The number of seed per pod was positively correlated to pod length ($r=0.39$) and pod diameter ($r=0.06$). There was a negative correlation between pod length and pod diameter ($r=-0.02$). Significant and positive correlations among traits of fruits show potential of simultaneous and direct selection for farmers' desired traits. The present results provide insights into the diversity of *M. oleifera* genotypes for fruit productivity and calls for further improvement in the species to suit various eco-climatic conditions found in Kenya.

Keywords: *Moringa oleifera*, phenotypic variation, morphometric, cluster analysis, characterization.

Potential of rice husk biochar as a forest soil amendment in Asia

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

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Abstract: Biochar is any biological residue from any organic-based materials including forestry by-product, manures or agriculture waste which were produced through gasification or pyrolysis at 300-600 degree Celsius under the exclusion of oxygen. Many studies show that biochar is one of the best options for agriculture and forestry sectors to use as a soil amendment to increase soil fertility. Besides that, biochar also enhances soil carbon sequestration.

About 600–800 million tons of rice straw is produced every year in Asia, while globally about 800–1000 million tons of rice straw is produced. Furthermore, the world annual production of rice husk and rice bran are 120 tonnes and 76 million tons respectively. The rice husk is partially used as fuel in rice mills to generate heat to dry paddy and burning of rice residue.

Some farmers burn rice residue because it is a cheaper and easier option to manage rice residue and contribute to soil nutrient cycling. There is also a belief among rice farmers that it will contribute to soil nutrient cycling. However, prolong burning of rice waste contributes to air pollution and increases greenhouse gas emissions. Thus, not only a sustainable approach to rice production is needed, but also in rice residue management. Converting rice husk into biochar has the potential to address both of these issues.

Rice husk biochar has high silica content which increases its adsorptive capability, enhanced nutrient retention, plant turgidity and structure. In forestry plantations especially in Malaysia, biochar is not used as soil amendment, as compared to the usage of rice husk biochar on agricultural farms. This work objective is to explore the benefits of using rice husk biochar to fertilize forest soil, thus, reducing the application of chemical fertilizer.

Properties of self-binding particleboard made of sweet corn stalk (Zea mays L.) and citric acid for furniture purposes

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

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Abstract: Particleboard fabrication faces challenges in utilising conventional adhesive and the shortage of wood particles as the main component. Agricultural by-products have the potency to substitute wood chips as raw material for particleboard due to their lignocellulosic components. Corn stalks are agricultural by-products that are abundant globally and widely available. Citric acid is reported as a cross-linking agent that can improve particleboard properties. This research investigated the physical-mechanical properties of particleboard made of sweet corn stalks (*Zea mays* L.). One-layer particleboards were fabricated with dimensions 28.2 x 20.8 x 1.2 cm with the targeted density of 0.5 and 0.7 g/cm^3. Citric acid with a solid content of 59% was added with three different percentages, i.e. 0, 10%, 15% and 25%. The pressing temperature was 200°C, ten minutes, and the pressure was 2.4 MPa. Properties were determined for their physical and mechanical properties according to JIS A 5908-2003. The chemical composition of the corn stalks was investigated using Fourier-transform infrared (FTIR) and Pyrolisys-GCMS (Py-GCMS). The result shows that the higher the particleboard's density, the better the mechanical properties of the particleboard. The bending strength of particleboard with 0.5 g/cm^3 density was 3.2-3.8 MPa. The bending strength for 0.7 g/cm3 particleboard was between 6.02-7.47 MPa. The bending strength value from 0.7 g/cm^3 is imminent to the standard. The internal bonding (IB) and screw-holding power (SHP) results in line with the bending strength results. The higher the board density, the higher IB and SHP value. On the other hand, the particleboards' water absorption (WA) and thickness swelling (TS) properties showed better results in lower-density particleboard. The WA and TS values of 0.5 g/cm3 particleboard were found to be 77.82-88.84% and 3.13-5.48% consecutively. For 0.7 g/cm^3 particleboard, the WA and TS values were 49.95-62.39% and 8.70-19.90%. The TS value for 0.5 g/cm^3 particleboard met the base particleboard standard. FTIR characterisation shows that corn stalk has noticeable peaks at 3300, 2900, 1700, 1200 and 600 cm^{-1} wavenumbers. Py-GCMS analysis results show that cellulose/carbohydrate has the highest percentage of pyrolysis products with 67.88%, followed by lignin at 24.16% and extractives at 7.33%.

Restoring degraded peatlands for food, biomass, and energy: Challenges and Opportunities in South Sumatera, Indonesia

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

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Abstract: Indonesia is the home of the largest tropical peatland in the world with a total area of 13,43 million hectares which provides multiple ecosystem services essential for climate and water regulation, home to flora and fauna biodiversity, and livelihoods of local communities. However, Indonesian peatland has undergone land use transformation from forest to other land use systems, especially, agricultural systems. Further, peatland mismanagement has led to an increase in emissions, fires occurrence, and soil subsidence that cause environmental and economic problems and health issues. Indonesia pledged to restore nearly 2,5 million hectares of degraded peatland through three approaches: Rewetting, Revegetation, and Revitalization (3R). This study aims to present the potential of agrosilvofishery as a climate-smart peatland management model, to improve ecosystem services and livelihoods from degraded peatlands. Early findings from a 3 hectares trial plot of agrosilvofishery model in Perigi, Ogan Komering Ilir, South Sumatera province, show that potential accumulative avoided emission from fire and revegetation is about 217 $tCO2e^{-ha}$ in 30 years. Additional direct economic benefits are from food crops and fish, such as paddy, pineapple, and medicine plants. However, the model requires capital and technical support to overcome capacity constraints. Uncertain climate leading to drought and flooding significantly affects tree growth and food crop production. In addition, the pest is also a challenge to fish and food production if the practice only locates in small areas. Expansion of large-scale agricultural plantations is indicated leading to changes in water conditions in agrosilvofishery areas which affect tree growth and food production as well. Adopting agrosilvofishery for climate and livelihoods improvement, therefore, requires investment support from the government or private sectors as well as collaboration among stakeholders on the landscapes.

Significance of forest in maintaining ecosystem services of bees in croplands in Kangsabati South Forest Division, Purulia, India

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

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Abstract: Ecosystem service is a concept of any positive benefits that wildlife or ecosystem provide to human beings. Ecosystem services can be categorized into four different categories; crop pollination belongs to sub categories of supporting category. Ecological intensification enhances crop production with supporting and regulating ecosystem services management in agriculture practices. Agroforestry provide foraging, nesting and mating sites for all bees and also provide diverse floral resources throughout bees' active period. In croplands, bees and other pollinators are essential for improvement of crop quality or quantity, genetic diversity which will enhance the crop production and food security. Crop pollination by bees is a valuable ecosystem services in many mixed agricultural landscape and natural habitats.

The experiment conducted in agro forestry ecosystem which supports a huge habitat and food preference for bees. The studied area Kangsabati South Forest Division in Purulia, is characterized by undulating topography with hilly terrain in the western and southern parts which are continuations of the Chotanagpur Plateau. Mixed cropping system is practiced dominantly in the studied area. The experimental study was conducted in various farm lands from March – April 2022. The aim of the study was to find out the comparison of diverse bee population between croplands adjacent and distant to forest areas.

The study was conducted in seven plots for each crop (sunflower, cucumber, sesame) and fourteen forest areas in peak flowering period. Observation study performed at three time hour i.e. - 8.30-9.30hr., 11.30-12.30hr., 15.30-16.30hr., transect walk and focal observation followed to record bee abundance and species richness. GPS location of survey plots were also recorded. The abundance of *Apis* bee species were prominently observed in the crops fields nearby human habitat than crop fields surrounded by natural vegetations. Diverse wild bees population noticed in croplands adjacent to forest edges. Wild bees are more effective pollinators than honey bees. Alternation of nesting and resources site affect bee population composition and dynamics. The correlation between ecosystem service of bees and natural habitat can be utilized for conservation and restoration.

Keywords: Ecosystem services; Crops pollination; bees; agroforestry

Sustainability impacts of firewood and charcoal production and consumption in Tanzania analyzed using a new bio-economic model

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

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Abstract: Forest degradation and land rehabilitation are major concerns in Tanzania. The wood harvested for charcoal, firewood and poles constitutes more than 90% of the country's estimated total forest harvest. This study evaluate forest sustainability impacts of the future production and consumption of firewood, charcoal and poles by developing and utilizing a dynamic forest sector model for mainland Tanzania. The model integrates detailed forest data from 32,773 sample plots in Tanzania's National Forest Inventory (NFI) with data on production costs, transport costs and demand for wood products. The developed model (TanzFor) is an intertemporal dynamic, spatial partial equilibrium model and links in an economic consistent framework the spatial supply and demand for fuelwood, poles and charcoal. The study is the first in Africa applying this type of a model with data from a detailed NFI and newly developed forest growth functions as basis for future wood supply. The study results shows alarming negative impacts on forest growing stocks by the steadily increasing consumption of firewood and charcoal in Tanzania, mainly caused by high population growth, high urbanization rates, low efficiencies in both charcoal production and consumption, and free access to common pool resource land. Future promising research tasks include further use of the NFI data, provision of more accurate data on the present and future consumption of charcoal and firewood, analyses of property regimes' effect on wood supply, improvement of TanzFor and its application in policy analysis related to land use and forest climate change mitigation and adaptation.

The economics of producing biochar from forest biomass to meet demand in agriculture

T2.9 Forest to Food: Developing synergies across forest restoration, the bioeconomy and sustainable agriculture

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Abstract: Biochar is an anthropogenic charcoal used as a soil amendment. It can be made from forest biomass using a wide range of methods, from wooden ricks and simple kilns to large-scale industrial pyrolysis systems that produce heat, power and sometimes liquid fuels and chemicals as co-products. This presentation is focused on understanding the potential costs and benefits of using woody biomass from forest management to produce biochar used as a soil amendment in agriculture. The authors synthesize the results of multiple published studies and ongoing field research cutting across both investment-oriented financial analysis and broad economic analysis that includes non-market benefits and ecosystem services. Technoeconomic analysis is presented for a variety of biochar production pathways at mobile, modular and centralized scales. The agricultural end uses considered are soil amendment for row crops, orchards and vineyards, and biochar use as an adsorbent in bedding material in dairy and cattle operations. Results show that the benefits of biochar systems linking forestry and agriculture are likely to be undervalued when calculated strictly on a financial basis. For example, under the standard practice of disposing of slash through pile-burning, the net present value (NPV) of fuel treatment thinning to reduce wildfire risk on 138,034 ha over 20 years is -$275 million. If the biomass is used for energy at market value, NPV improves to -$178 million without consideration of nonmarket benefits. However, NPV of the same forest management regime improves to -$25 million (with 27.7% of outcomes having positive NPV), if nonmarket benefits associated with better forest health, lower wildfire likelihood, expanded renewable energy, and better air quality are included. Project NPV improves significantly further into positive outcomes (>$10 million over 20 years) if carbon offsets are generated from biochar application in agricultural settings under existing incentives and carbon offset protocols, depending on price. Biochar production for agriculture provides an opportunity to efficiently use a variety of forest biomass feedstocks that are otherwise treated as waste biomass, and the authors provide recommendations to improve the financial viability and economic value of biochar supply chains that link the forest and agricultural sectors.

T2.10 Forest-based Bio-economy Prospects in Africa

Assessing the ambiguity in socioeconomic outcomes of plantation forest companies: reconciling decades of contrasting evidence from Sub-Saharan Africa

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: Forest plantation companies have been recognized as leading providers of socio-economic development and investments in rural communities in sub-Saharan Africa (SSA). Yet, negative consequences of their associated socio-economic impacts have been flagged, begging for insights on their potential to drive sustainable bioeconomy transitions. This study aims to understand the socio-economic outcomes of large-scale forest plantation companies in SSA as a proxy for deriving further research avenues toward promoting their positive contributions while mitigating the negative ones.

A review of the literature is complemented by two independent case studies portraying the roles of large-scale plantation forest companies in a) advancing socio-economic development in rural communities in Sierra Leone; and b) developing farmers' silvicultural capacity through an out-grower scheme in Uganda. Semi-structured interviews were conducted in Sierra Leone (n=125) and Uganda (n= 80), complemented by key informant interviews of five officials from the plantation forest companies in both countries.

The forest plantation company in Sierra Leone contributed to providing income diversification opportunities through salary and land lease payments, supplying fuelwood, generating employment, and providing on-the-job training for the workers. The employment contribution was ranked as the most important, followed by income, fuelwood, and capacity building. The findings from Uganda demonstrated that the training provided by the plantation forestry company significantly benefited the smallholders in the out-grower scheme in developing their capacity to engage in sustainable tree management practices. The farmers also acknowledged the program to enhance their access to high-quality planting materials and farm credits.

Therefore, to contribute to the empirical evidence of how forest plantation companies can further build resilience in rural areas, we derived further research agenda regarding the trade-offs between land allocation for large-scale plantation forestry and other alternative land uses, the effectiveness of benefit-sharing mechanisms and land tenure security issues and how these shape the potential for large-scale plantation forestry companies to deliver societal-desired socio-economic outcomes in rural areas. Our results suggest the need to leverage the potential contribution of plantation forest companies as key players in the global forest-based bioeconomy agenda to balance social, ecological, and economic demands.

Building Communities Resilience to Climate Change Through Sustainable Green Businesses in Semi-Arid Regions of Kenya

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: Arid and Semi-Arid Lands (ASALs) occupy 80% of Kenya's lands area and home to 70% of the total livestock population and 90% of wildlife. These regions have been impacted by periodic cycles of devastating droughts over the years impacting on local communities' main source of livelihood which is livestock keeping. The abundance of resins and gums producing tree species in these regions presents untapped green business opportunities for local communities to tap into. The Kenya Forestry Research Institute through the TWENDE (Towards Ending Drought Emergencies) is supporting local communities dealing in gums and resins to upscale sustainable trade by providing climate resilient investment in value chain. To ensure sustainable production and consumption of gums and resins the project designed a sustainable green business model with five key interventions targeting various nodes of the gums and resins value chain activities. This paper presents key findings and observations from rapid appraisal surveys undertaken on 689 beneficiaries from six local community groups and 1 cooperative in Sabarwawa and Mid tana Landscapes covering five arid Counties of Marsabit, Samburu, Isiolo, Garissa and Tana River. Key bottlenecks in the value chain observed include; low productivity linked to drought cycles, limited value addition due to lack of basic equipment and requisite knowledge, low market prices due to exploitation and information asymmetry among actors where middlemen have more information than the collectors, high transportation costs, limited market for some products. To address the value chain challenges the project has rolled several interventions including training on sustainable production of gums and resins, harvesting/collection and post-harvest handling and processing, sustainable harvesting, and compliance procedures. To support market development a web based and mobile system for linking producers and buyers of gums and resins to markets is being developed. To ensure sustainability of the interventions past the project period a local a Value chain technical assistance plan will be defined for the gums and resins producing Counties to mainstreamed within their County Integrated Development Plans (CIDPs)

Economic value of selected Non Timber Forest Products towards household food security and income in Niassa Special Reserve, Mozambique

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: An assessment on the economic value of selected Non Timber Forest Products (NTFPs) towards household food security and income was done on the selected households in selected villages in Mecula-Marrupa corridor in Niassa Special Reserve (NSR). The sampling framework was the households from selected villages, local leaders, traditional healers, and officials managing NSR. The study utilized household survey method and market survey in collection of data. Once the NTFPs collected and produced in the study were identified, household surveys were conducted to attach value on the different NTFPs, locate the main area where each household collects NTFPs, the amount collected per year, and what income they generate from the sales. During market survey, information on market price, how prices change across seasons, market capacity and quantities of different NTFPs that reach the market was collected. Types, prices, and amounts of NTFPs supplied and sold to the market were recorded. Total sales per year were also determined to obtain the total income. The economic value of each NTFP was obtained basing on Shackleton and Shackleton model. It was established that the mean annual value of the identified NTFPs ranged from 600.00MZN/$6.68 to 6.000.00MZN/$96.77 which meant that the community attached much economic value to firewood, mushrooms, medicinal plants, and honey which was statistically and economically true. It was thus learnt that collection, production and selling of NTFPs have a positive and significant influence on rural livelihoods. Such practices pose a great potential to conserve forests in the area since they always fight to ensure that their source of income and food is never interrupted. These can be important practices in addressing concerns of food insecurity, unemployment, and poverty alleviation in Mecula-Marrupa corridor, NSR of Mozambique and other parts of Sub-Saharan Africa. The study recommended that domestication of indigenous tree species should be encouraged for the reduction of poverty and for balance to be maintained in the ecosystem. The government should also encourage the cultivation of edible and medicinal tree species around homes incorporated with honey production. This will reduce encroachment into the forest for tree species exploitation for economic and medicinal reasons.

Enabling policy and private investments as requisites to improved non-timber forest products' contribution to people's income and national economies

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: Recent estimates (2022) show that about 677 million African households use NTFPs for subsistence and income. However, many of them still face food insecurity and high poverty rates, partly due to under-exploitation of the opportunities offered by NTFPs. Indeed, despite the globally recognized potential of NTFPs, the sector faces many challenges of which, the lack of, or poor policy frameworks is critical. This paper synthesizes evidence to drive interest of policymakers in strengthening an environment conducive for NTFPs value chain development. Literature review and field case studies are used to document the contribution of NTFP to household livelihoods and economies for communities and countries in Africa. Results show that NTFPs are crucial to household subsistence and income of rural African people, in particular women and indigenous people. Case studies, for instance, in DR Congo, Ethiopia, Benin and Burkina Faso show that NTFPs contribution to households' income can be as high as 32 - 45%. Income from NTFPs has also an equalising effect on income inequality. NTFPs are recognised as safety nets for communities whose agricultural activities are impacted by climate change; yet how NTFPs themselves are affected by climate is not enough studied. However, due to informalities, there is limited evidence on the contribution of NTFPs to GDP; about 5% is reported for Burkina Faso and Mali; in Sudan, gum Arabic alone contribute about 4% of the GDP. These statistics are of course underestimated. In many countries, the NTFP sector remains informal and mostly serves only local markets; there is urgent need for private investment to develop NTFPs-based industries with added value such as employment and taxes. This potential NTFP development pathway is constrained by the fact that NTFP are not duly addressed in sectoral policies aiming at socio-economic development. Areas that still need attention to provide more evidence to policymakers include: how to effectively monitor and improve the contribution of NTFPs to national economies? This will require an improved understanding of the dynamics of the resource base (extent and quality) in the changing land uses and climate, and related impact on livelihood and income, access and benefit sharing mechanisms.

Lessons Learnt from Forest and Landscape Restoration of Arid and Semi-Arid Lands (ASAL) of Kenya through Bio-Enterprise Development

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract:
The Food and Agriculture Organization of the United Nations in collaboration with the Kenya Forestry Research Institute and other partners implemented a project in Mount Kulal Biosphere Reserve in Marsabit County and Mukugodo forest landscape in Laikipia County. These two landscapes are degraded and vulnerable to climate change. An integrated approach was adopted to address deforestation, land degradation and biodiversity loss, targeting policy and institutional capacity while supporting community-led forest and landscape restoration (FLR) and the development of alternative sources of livelihoods. The national and county level policy and regulatory frameworks were strengthened to support FLR in the two counties and the country at large. At the national level, a forest and landscape restoration implementaion plan (FOLAREP), forest regulations on benefit sharing and a strategy on non-timber forest products and services (NTFPs) are in place. Total economic valuation for the two ecosystems was carried out and estimated at US$ 85million /year for Mukogodo and US$ 187.97 million/year for Mt. Kulal. Participatory forest management plans and forest management agreements for the two forests have been signed, launched and operaionalised. So far, a total of 1165 ha and 193,931 ha of land have been directly and indirectly restored, respectively, using various options identified during ROAM assessment. Gums and resins, aloe, honey and ecotourism were identified as key bio-enterprises with great potential for development and income generation. 40,913 beneficiaries (21,766M, 19,147F) from 8,182 households had their capacity strengthened in FLR and bio-enterprise development. The project developed 17 bankable projects, several knowledge products and established a knowledge management portal for sharing the generated information. Some of the key lessons learnt include: sensitization of local communities on protection of worked sites; prioritization of land tenure in ASALS; long and extended dry spells and pandemics (COVID-19, Desert Locust) may affect FLR results; development of bio-enterprises as low ly-ing fruits for FLR is critical; public-private sector partnership in bio enterprise development is crucial; knowledge products to be uploaded to the Knowledge Management portal for ease of access; synergies and complementarities critical for greater impact and that domestication of the developed FOLAREP in counties is essential and urgent.

Net Zero Bamboo Pulp Production – A Forest Based BioEconomy for Africa

T2.10 Forest-based Bio-economy Prospects in Africa
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Abstract: Africa's growing populations present a unique opportunity for a sustainable forest-based bioeconomy. In 2021 South Africa imported \$187M of toilet & tissue paper, and \$133M of wood pulp. Ghana imported \$64M of toilet & tissue paper, and \$20M of wood pulp. Even the tiny nation of Rwanda imported \$5.88M of toilet & tissue paper and \$1.2M of wood pulp. These imports represent a significant loss of export dollars for these African economies. The opportunity for domestic forest based industries to replace imports for consumer pulp and paper products is high. Yet this transition does not require the traditional focus on monoculture plantations for fast growing timber, and its subsequent conversion in antiquated chemical based kraft pulping.

In contrast, bamboo provides an opportunity for a holistic framework for African nations to leapfrog technology and develop reforestation strategies, hand in hand with next generation, net zero biorefineries for the production of a truly green climate-friendly pulp.

Since 2012 EcoPlanet Bamboo has been working towards the development of such a forest-based bio-economy in these three countries – Ghana, South Africa and Rwanda - through a multi-phase approach. Phase I restores degraded lands integrating select species of bamboo with remnant forest patches to create biodiverse permanent forested ecosystems that have the potential to produce a long-term, deforestation-free source of wood while utilizing a fraction of the land area of traditional plantations. Phase II utilizes harvested bamboo in a biorefinery for the production of a high quality pulp, and a lignin by-product. This patented next generation technology is net zero, while also being energy and water neutral, relying on bioenergy from a portion of the bamboo harvest, and the water content of the fiber itself.

With just over 22,000 hectares undergoing such restoration to date on the African continent, these forest based operations are creating more than 1,500 generational job opportunities, sequestering >8M tons of CO_2, creating microclimates that provide mitigation and adaptation benefits, reduce pressure on degrading landscapes, and have the long term potential to create scaleable and replicable forest-based bio-economies that can meet the growing demand for toilet and tissue paper products.

Non-Timber Forest Products (NTFPs)-based Bioeconomy transition for community livelihoods in Cameroon: A gendered perspective

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: Cameroon is endowed with over 710 non-timber forest products (NTFPs), with 16 of the commonly exploited NTFPs generating a total annual income of USD 64.7 million. The NTFPs resource base in Cameroon is enormous making an NTFPs-based bioeconomy transition very feasible. The wide array of NTFPs are already playing a vital role in community livelihoods particularly in the forested regions of Cameroon. Despite the important role being played by NTFPs, little is known about the role an NTFPs-based bioeconomy transition can play in community livelihoods especially along gender lines. The objective of this study is to bridge this knowledge gap by assessing the contribution of an NTFP-based bioeconomy transition to community livelihoods with emphasis on gender. Three NTFPs (Bamboo, Rattan and Bush Mango) are selected for the study. Data were collected from 563 randomly selected households across Cameroon using a structured survey. Findings reveal that women and men in the target communities obtain different unprocessed and processed products from Bamboo, Rattan and Bush Mango which support their livelihoods. Unlike Bush Mango harvesting, processing and trading where 80% of the harvesters, processors and traders are women; most (95%) of the harvesters, processors and traders of Bamboo and Rattan are men. Unprocessed and processed Bush Mango generates a total annual income of USD 45,730,000 and USD 7,080,000 with women accounting for USD 36,584,000 and USD 5,664,000, respectively. For Bamboo, unprocessed and processed products generate a total annual income of USD 354,000 and USD 12,434,400 with women accounting for USD 17,700 and USD 621,720, respectively. For Rattan, unprocessed and processed products generate a total annual income of USD 876,000 and USD 24,606,000 with women accounting for USD 43,800 and USD 1,230,300, respectively. From the foregoing, it can be deduced that, while Bush Mango contributes more to the livelihoods of women, Bamboo and Rattan contribute more to the livelihoods of men. An NTFP-based bioeconomy transition geared towards enhancing community livelihoods in Cameroon therefore needs to factor in the gender dimension of NTFP harvesting, processing and trading for a more balanced and robust transition.

Key Words: Non-timber forest products; Bioeconomy; Livelihoods; Gender; Cameroon

Preserving Gardenia erubescens: Unveiling its Value and Ensuring Resilience in Burkina Faso amidst Climate Change

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: The conservation of local fruit trees and their contributions to food security, biodiversity, and ecosystem services are increasingly recognized. This study explicitly examines *Gardenia erubescens* Stapf & Hutch.—a plant species classified as least concern (LC) by the International Union for Conservation of Nature (IUCN). However, the species along with 59 others isthreatened in Burkina Faso due to excessive harvesting, The main goal of this study is to create a scientific database that will help in the development and conservation of the species in the context of climate change. Specifically, it aims to (i) evaluate the use value and factors influencing G. erubescens' utilization in Burkina Faso, and (ii) assess the impact of climate change on its distribution and conservation.

A semi-structured survey was conducted with 514 informants from 15 villages bordering three community forest areas. Ethnobotanical indices were computed to assess G. erubescens' use and cultural importance, considering variables such as gender, ethnicity, age groups, and geographic location. Geostatistical and species distribution modeling techniques were used to evaluate the vulnerability of *G. erubescens* to climate change and project its future distribution under two climatic scenarios (optimistic RCP 4.5 and pes- simistic RCP 8.5).

The results indicate that *G. erubescens* has multiple uses, with its various organs involved in over thirty different applications. The study identified eleven socio-cultural groups, with the Gourounsi (29.77%), Gourmantché (23.54%), and Mossi (13.04%) being the most prominent. The modelling results suggest that climate change will adversely affect the distribution of *G. erubescens* in Burkina Faso by 2070. Under the RCPs 4.5 and 8.5 scenarios, habitats currently favourable to the species are projected to decrease by 18% to 53%. These findings underscore the potential for integrating these species into production systems in Burkina Faso and highlight their significance in implementing ecosystem-based approaches for climate change adaptation.

Status and opportunities for value addition of Non-Timber Forest Products (NTFPs) in Africa

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: Inadequate value addition of NTFPs in Africa affects their trade and, thus, negatively impacts on sustainable forest management and livelihoods. The process of value addition entails three processing aspects, namely: primary (harvest and post-harvest handling), secondary and product formulation. Considering the diverse types of NTFPs that exist, only four categories will be used for illustration: gums and resins, bee products, indigenous fruits, and herbal products.

Considering gums and resins, primary processing has progressed substantially, due to awareness and training programmes that have been carried out in the region since the 2000s. Nowadays commodities entering the market meet the quality requirements in most countries, as improved equipment has been developed enhancing the quality and quantity of the produce. However, secondary processing and product formulation remain a big challenge resulting in exports of raw form, and hence generally low prices.

Similarly, considering bee products, Africa has great potential, yet trading is so far mainly based on raw products such as raw honey, wax, and propolis, due to lack of knowledge and skills for production of more advanced products, that could boost farmer income.

With regard to indigenous fruits, value addition activities on all levels have only been more professionally advanced for selected species across the African continent. One such example is the baobab tree (*Adansonia digitata* L.), for which adequate harvesting and storage practices, supply chain management and quality control mechanisms, processing technology as well as novel product development have been realized. However, the potential for many other species has not been realized.

Finally, Africa can also tap into the global demand for chemicals and products derived from herbal plants, e.g. for affordable healthcare, creating entrepreneurial opportunities. However, progress in this front is minimal, due to lack of appropriate technologies and agronomic practices, among others.

This paper will be based on extensive review of literature and case studies where applicable. A broad scope for each category and level will be covered to reflect regional experiences in regard to existing technologies and best practices. Opportunities for scaling up relevant and suitable technologies will be explored, and recommendations made.

Sustainable industrial process-heat from African forests: Kenya's tea industry and implications for bio-economy prospects in Africa

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: Industrial energy needs in Africa are increasing. To fuel a bio-economy, energy sourcing needs to be climate-conscious. Forest based bioenergy can be particularly beneficial in rural areas by creating and sustaining green jobs. However, bioenergy is a major risk to existing tree cover in Africa. Forest based bio-economies in Africa must acknowledge that risk while tapping into its potential – particularly for industrial process-heat where often no alternative exists to, frequently imported, fossil fuels. We present on an enduring and large industry in Africa: Kenya is the world's largest exporter of black tea. Tea contributes around one third to Kenya's GDP, and is the country's largest employer (>10% of Kenyans depend on tea for income). Over the past century, fuelwood has provided process-heat required for drying tea at Kenya's ~100 tea tea factories. Fuelwood quality, supply security, sustainability and price are major concerns to the tea industry. Energy expenses are the second highest cost category after labor costs.

A key to a sustainable bio-economy in this context is to identify drivers of heat energy cost and specify performance and spread of two thirds of Kenya's tea factories. Research objectives were design an analytical framework covering i) fuelwood and ii) alternative biomass fuels supply chains, iii) onsite fuel logistics, and iv) boiler operations; followed by field surveys, data analysis, factory ranking, and information gap identification.

We surveyed 65 tea factories and collected data on over 50 variables for fuelwood supply, plantation data, alternative biomass fuel use, and boiler performance, respectively. We also explored the impact and risk of sourcing fuelwood from the open market as well as from dedicated fuelwood plantations.

The industrial process-heat sector is responsible for over 25% of Kenyan oil consumption; impacting Kenya's climate footprint and trade deficit. We demonstrate that bioenergy based industrial-scale process-heat is cost effective and scalable for an entire industry. Switching from oil or coal to wood heat can reduce costs by over 20%. Efficient and sustainable bioenergy systems can therefore allow for further growth and 'greening' of industries in need of process heat, such as the regional beverage, food-processing, and cement industry.

The contribution of indigenous knowledge in advancing domestication of Non-Timber Forest Products species in Africa

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: Domestication of indigenous plant species for producing non-timber forest products (NTFP) in agricultural landscapes is promoted to sustain their access and use while conserving their natural resources. In Africa, the decentralized participatory domestication approach has been adopted, which provides opportunity for communities' engagement and the use of traditional knowledge (TK) in shaping locally accessible technologies that address context-specific challenges hindering NTFP species management and cultivation. The paper focuses through literature review and case studies on key progress achieved in the domestication of NTFP-based species. It highlights the contribution of TK systems in advancing the process. So far, more than 59 candidate species for domestication have been documented on a wide range of topics from their ethnobotanical use and management, including resource and socioeconomic assessments to set priority among targeted species to the adoption, uptake and impacts of newly developed cultivars, skills, techniques and strategies capturing the benefits associated with production and marketing of NTFPs in human-managed landscapes.

The first step in the domestication process is the identification and characterization of existing diversity within and among populations based on end-users preferred traits and guided by TK. In all African subregions, morphological, biochemical, and genetic descriptors have been applied to selected priority species. However, the mapped "ideotypes" still poorly contribute to cultivars' development through breeding and improvement.

Low-technology and low-cost propagation techniques have been co-developed and applied to produce and distribute improved planting materials. However, intensive cultivation of NTFPs species in agricultural landscapes is challenged by the lack of capacity and skills to scale up the technologies to other species and contexts. Hence, many of them are still being sourced exclusively from the wild. TK on farmer-managed natural regeneration is contributing to preserving locally valued species in natural and agricultural landscapes.

Emerging trends in NTFP' species domestication are focusing on the impact of climate change on their distribution and conservation through niches modelling based on climatic scenarios and communities-led resources mapping, as well as exploring entrepreneurship opportunities and technologically efficient value addition processes for a better contribution to the development of NTFP-based bioeconomy.

The economic potentials of wood offcuts; an entry point to forest-based bio-economy in Ghana

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: The versatility of timber makes it a unique raw material that can be processed into various products with enormous benefits. As a flexible raw material depending on the targeted end-use, off-cuts are generated along the production value chain. In the forest, only the merchantable parts of harvested trees (timber) are conveyed to the mill leaving the branches, buttresses, etc. behind notwithstanding the multiple arrays of benefits that could be accrued from these parts by other wood users, reducing the economic net value of the wood. This study aimed to unravel the economic potential of other products derived from offcuts both at the forest floor and mills to improve recovery toward sustainable forest management.

The study used random and purposive sampling techniques for selecting respondents from bush managers, lumber processing firms, domestic wood market dealers, and tertiary wood dealers. Additionally, the views of respondents were sought through semi-structured questionnaires and interviews conducted with key informants in Ghana's wood industry and regulators.

The result indicates that approximately 28.7% of the harvested trees were left on the forest floor as waste whilst 71.3% were conveyed for further processing. It was also revealed that, a lot of economic viable and useful products can be generated from the logging offcuts to diversify income and businesses along the timber production value chain. Lastly, through the study, we find out that efficient use of harvested tree can contribute to sustainable forest management by reducing the number of trees that could otherwise have been harvested

Owing to the economic benefit coupled with the secured wood source to the small-scale wood user, a call for review of the Manual of Procedures (MoPs) governing Timber Resource Management and Legality Licensing Regulations, 2017 (L.I. 2254) is timely. Thus, the allocation of timber to factor in leftover tree parts to serve as the legal wood source for carvers and other small-diameter machinery processors. Securing legal wood sources could help meet the heightened demand for the domestic market as well as serve as a tool to curtail illegal chain saws.

The Wood Solution–An integrated industrial system in which wood buildings drive large-scale restoration & sustainable development across the tropics

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: The demand for housing will skyrocket throughout the century. Building in wood is broadly considered a climate-positive solution, but it is hotly debated whether increasing demand for wood would lead to positive or negative outcomes for forests and biodiversity. Within the current tropical timber industry, increasing harvests from natural tropical forests would almost inevitably degrade the remaining primary forests; and increasing tree plantations would likely come at the loss of natural tropical forests. To be maintained across the landscape, natural tropical forests must generate substantial value to compete with other land uses. Including them in this emerging new market for wood buildings can drive this value generation. We advocate for looking at the mechanisms that lead to positive or negative outcomes and create a system that promotes wholly positive outcomes for people and nature.

We propose a new and integrated industrial system in which cities, forests, and industry are directly linked. “The Wood Solution” enables an enormous shift in the tropical timber industry. Instead of degrading pristine forests through selective logging, degraded natural forests can be restored through active management that includes logging. The key to making this work is adapting timber processing systems and markets to utilize small- and medium-sized trees of diverse species. A variety of engineered wood products will be needed, and knowing these products in advance will enable efficient and high-value use of the wood.

Our analysis shows that restoring the 1.2 billion ha of non-primary forests could sequester over 34 PgC without any change in land use. More importantly, this system improves profitability at each step of the value chain, especially close to the forest resources. Forests could gain 10 times their value; and operating margins in the local sawmills can increase nearly 28 times with an optimal mix of products and markets. Mass timber building is completely possible in tropical environments. Tapping into the \$US10 trillion year^{-1} construction and engineering industry[87] could serve as a massive market driver for large-scale forest restoration and management and the creation of a new, regenerative industry.

Valorization of the nutritional and functional properties of Non Timber Forest Products (NTFP) in the district of Bignona , Senegal

T2.10 Forest-based Bio-economy Prospects in Africa

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Abstract: In the Ziguinchor Region, forests provide a range of valuable products for the population, especially in rural areas. Among these products, non-timber forest products (NTFPs) play an important role in improving livelihoods. Despite its importance, the nutritional and functional contribution of NTFPs is not well known by stakeholders. For this reason, this research aimed to study the nutritional and functional value of NTFPs for better valorization. To do this, surveys and quality analyses were conducted. The NTFPs most consumed by households in the study area were *Saba* senegalensis A. DC. Pichon (90.5%), *Landolphia heudelotii* P. Beauv (67.55%), Detarium senegalense J.F. Gmel (51.19%), Sesbania sesban L. Merrill (40.63%) and Adansonia digitata L. (32.98%). The three most traded NTFPs were Saba senegalensis, Detarium senegalense and Landolphia heudelotii. The results of quality analysis of the NTFPs showed that the nutritional elements of the processed forest fruits differed significantly ($p < 0.05$) among the products. For Saba senegalensis, jams were richer in protein (0.1%) and phosphorus (20 mg) than syrups. As for *Detarium senegalense*, the marmalade contained more protein (0.43%), phosphorus (20 mg) and iron (61 mg) than the syrup. However, syrup has higher carbohydrate content than jam and marmalade. There is a variation in nutritional properties between the raw and processed products. The raw products contained significantly higher protein, phosphorus, lipid and vitamin C content than processed products. While, processed products were richer in carbohydrates. NTFPs were rich in nutrients but processing reduced the nutritional value.

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

Adaptation, mitigation or sequestration? An analysis of storylines reiterated in the public discourse in the sustainability transformation

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Context: The main aim of the European Commission's new EU Forest Strategy for 2030 is to ensure that European forests are resilient and multi-functional ecosystems. In the short-term they need to provide society with products to replace fossil-based materials and energy flows. In the long-term, they need to be climate-smart and adapted to increasing forest disturbances. Simultaneously, forests need to provide a merit of other forest functions, such as sequestering carbon, controlling temperature and safeguarding biodiversity. All these efforts need to be streamlined with different EU programs, such as the EU Bioeconomy strategy or the EU Biodiversity strategy.

Such interconnected but diverging goals present a complex challenge of adaptation, mitigation and sequestration, which could lead to trade-offs. For instance, simply storing carbon in forest ecosystems could increase risk in the event of natural disturbances, and disregards the need to decarbonise the global economy. In contrast, overusing forests might compromise carbon sequestration, water (in)filtration, temperature control and biodiversity goals.

Specific topic of the study: As many different players take interest in a forest, different opinions on which function to prioritise exist. It is necessary to increase knowledge on climate-smart, multifunctional forestry to foster synergies, minimise trade-offs and derive lessons for operational guidance towards enhancing climate resilience in European forests.

Methods: In this study, we combine a print media analysis with data on forest disturbances and forest-based sector market reports in Austria over the last 20 years to get a better picture of the different storylines reiterated in the public discourse. In this regard, print media is seen as a means to represent the public opinion and policy agenda, particularly on issues that might lead to conflicts.

Preliminary results: From our preliminary analysis, we can derive that reporting on forest disturbances and adaptation of forest management have increased over the last 20 years and align with major disturbance trends. Following discussions about biodiversity loss and climate change, sequestration storylines have become more prominent. Lastly, discussions on how to optimally use wood and mitigate climate change are intensifying. At the time of the IUFRO Stockholm 2024, we will present the final results.

Balancing of assembly lines in industrial house building

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: The production of prefabricated houses enables the continuous use of wood and is an important part of the supply chain in this sector. It is characterised by a high degree of standardisation. Wall panels are manufactured in the factory, transported to the site and assembled. Our focus is on the factory process and the production of prefabricated elements, including external and internal walls and ceilings, on a mixed model assembly line.

Although many of these production processes still require large numbers of workers, companies are considering automating the production lines. The question is what these lines should look like and how the potential of digitalisation can be used in the best possible way.

We are developing a model for balancing a multiple, mixed-model assembly line that takes into account the requirements of variable work processes, workers and material consumption. Our goal is to maximise production output for a given number of workers. An optimisation model is built and solved exactly, as well as heuristic approaches are developed.

Our approach combines this optimisation model (based on average production values) with a simulation model for concrete situations (taking into account specific order situations and variable processing times). We use discrete event simulation, which allows us to look in detail at processes, sequences and production possibilities for wall elements (such as number of windows, doors and installations).

Our simulation model is validated using real-time data from our industry partner's enterprise resource planning system. It is planned to use the optimisation model continuously to evaluate different configurations until we reach a predefined output limit.

In our work, we compare the optimal configuration of production lines - for example, a single line, multiple lines, production cells, or even alternative or duplicate stations. The robustness of the determined optimal configuration is then evaluated using the simulation model.

Our results show that our approach is suitable for determining the optimal configuration of production cells and lines for wall elements in industrial prefabricated house building.

Can planted and natural forests be distinguished in forest area development assessing different drivers?

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Global forest area dynamics can be represented as a function of drivers using the concepts of the Environmental Kuznets Curve for deforestation (EKCd) and the Forest Transition Hypothesis (FTH). Several studies have already analyzed the determinants of these concepts but a widely accepted consensus is still lacking. Based on a systematic literature review, we analyze the selection and significance level of socio-economic variables used in studies estimating EKCd and FTH. For this purpose, we extract independent variables used in 85 heterogenous estimation models. Across these studies, we identify 150 different drivers and assign them to 12 main categories according to their type (e.g., income factors or institutional factors). Our results reveal that the main drivers of forest area development are income, demographic, and trade factors. We also observe variations in the identified drivers when the choice of geographical scope and respective data selection, dependent variable, and the EKCd and FTH concepts are considered. We find that the latter influence the significance level of independent variables in relation to forest area development. We also find differences in the identified drivers across various continental studies, e.g., the forest area of Latin America is more strongly influenced by income variables when compared to forest areas in Asia or Africa. A closer analysis of the EKCd and FTH concepts, in our scrutinized studies, reveals unsolved challenges related to their application in developed countries. In particular, the afforestation component of the FTH has not yet been thoroughly explained. Thus, in a subsequent step, we develop the FTH concept further and split the curve shape of the FTH into two sigmoid functions. We then re-estimate the econometric model with significant economic drivers while differentiating the forest area types based on natural forests and planted forests and plantations. Our approach isolates individual drivers of forest area change and enhances the analysis and projection of forest area development thus contributing with a deeper understanding of global forest area dynamics.

Carbon pricing policies in the forestry sector: Possible leakage effects when accounting for intra- and inter-sectoral dynamics

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Forest-based measures for climate change mitigation are acknowledged to hold the global temperature target of the Paris Agreement in reach. To foster carbon sequestration in forests and in forest products, carbon pricing policies appear to be promising approaches. Forest sector models are established instruments to assess the impacts of carbon pricing policies on forestry and wood product markets as well as on forest-based mitigation potentials.
Modelling researches reveal that leakage effects might undermine the climate change mitigation potential of carbon pricing policies in the forest sector. Limited by the system boundaries of forest sector models, past assessments are mainly focused on intra-sectoral dynamics. Especially the spatial displacement of economic activities between regions pursuing a carbon pricing policy and foreign regions is analysed. However, the forest sector is embedded in the overall economy and increases in forest-based carbon sequestration might be offset by economic dynamics in other sectors. Therefore, the consideration of inter-sectoral implications seems important for quantifying leakage effects.

In this study, the Global Forest Products Model (GFPM) is linked to DART-BIO, a computable general equilibrium (CGE) model, to complement modelling approaches of leakage effects related to carbon pricing policies in the forest sector. Through the linkage, inter- and intra-sectoral dynamics are analysed simultaneously when carbon sequestration in the forest sector is valued. For this analysis, varying carbon tax and subsidy policies are integrated into the GFPM to value carbon fluxes. The sensitivity of inter- and intra-sectoral leakage effects is analysed over a range of carbon prices and through changes in valued carbon pools.

The results show a need to evaluate climate change mitigation policies involving forest-based measures from an overall perspective to achieve effective GHG reductions at the global level.

Could forest biodiversity and carbon sequestration be enhanced without harming forest industry and rural development?

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: It is of global importance to manage boreal forests sustainably as it is one of the most extensive biomes and the largest area of coniferous forest in the planet. The forest sector contributes significantly to the rural economy of Nordic countries where even-aged management with clearcutting is the dominant silvicultural regime. In this context, policies seeking to increase carbon sequestration and preserve biodiversity need to recognize its potential impacts on the forest industry. In this study, we assessed the impacts of biodiversity and carbon policies on the Norwegian forest industry competitiveness and employment, applying a simulation-optimization framework. First, we simulated stand growth dynamics and yields for common management practices in Norwegian forests using the tree-level simulator *TreeSim*. Second, we applied the partial equilibrium model *NorFor* to project national and regional levels of harvest, industrial production, trade and labor. We compared three scenarios of high policy relevance that combine carbon and biodiversity against a baseline BAU: (a) BioDiv scenario restricts harvests of old forests and deciduous forests important for habitats; (b) Carbon scenario aims to enhance net carbon sequestration through a tax and subsidy scheme and (c) BioDivCarbon scenario combines the BioDiv and Carbon policies. Impacts on the rural economy employment were assessed through combining data of industry localization, degree of rurality and employer multipliers with industrial output. Contrasted to the baseline scenario, all policy scenarios led to reduced timber harvest with the impacts being most marked in the BioDivCarbon scenario, which led to long-term reduction of 20% compared to the BAU level of 15 million m^3. In the Carbon scenario, long-term timber harvests declined by up to 15%, contrasted to 5% in the BioDiv. Pulp and paper and sawn wood industries were considerably harder impacted by the policies than boards and bioenergy industries, with the carbon policy having larger effects than the biodiversity policy. Long-term reductions amount to 12% for the pulp and paper industry and 20% for the sawn wood industry. In overall, we see that forest industry outputs have larger trade-offs with forest carbon sequestration than with forest biodiversity preservation.

Effects of the reform of state-owned forest areas on the common prosperity of state-owned forest industry enterprises: A quasi-natural experiment

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts
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Abstract: Common prosperity is an essential requirement of socialism with Chinese characteristics and an important feature of China's modernization. As a characteristic economic and social organization located in the key state-owned forest areas in China, state-owned forest industry enterprises are of great significance to the realization of the goal of common prosperity in China, but few studies focus on this issue. Especially in the policy background of the reform of state-owned forest areas, the policy impact on the common prosperity of state-owned forest industry enterprises is more worth exploring. Based on the panel data of 87 state-owned forest industry enterprises in key state-owned forest areas in 2012-2020, this study measures the common prosperity of state-owned forest industry enterprises from the dual perspective of internal and external income gap between enterprises, and further analyzes the policy effect of the reform of state-owned forest areas on the common prosperity of state-owned forest industry enterprises. Our results indicate that: a) the internal income gap of state-owned forest industry enterprises shows an overall decline, while the external income gap of enterprises rises; b) the reform of state-owned forest areas can significantly reduce the internal income gap of enterprises, and the impact on the income gap between labor and capital income is significantly higher than that on the income gap between managers' and ordinary workers' income; c) the reform of state-owned forest areas has a negative influence on the external income gap of enterprises, which is mainly reflected in the income gap between 87 state-owned forest enterprises.

Forest management strategies to address climate roadmap 2045 strategy in Swedish context

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Sweden's climate policy aims at to have zero net GHG emissions by 2045 and continue as negative emission nation thereafter. There is a growing concern that urgent action is needed to reduce atmospheric carbon. Land forest cover is seen as one of the best solutions to mitigate climate change because of its pivotal role in binding and storing carbon. For this reason, forest policies are expected have a major impact on society in the near future. However, the effects of instruments such as conserving forests for increasing carbon stocks or of managing forests for climate mitigation are still not fully understood. Using a forest sector model (SWEFOR), we investigate the implementation of a carbon mitigation payment system. Alternative policies such as lengthening rotation age, increasing conservation area and promoting biodiversity will affect forest owners and thereby payment is a mechanism to compensate forest owners for positive externalities and forest management opportunity costs.

This study aims at evaluating the consequences of forest management decisions for carbon mitigation payments. By implementation and simulating using the forest sector model SWEFOR, we describe the effects of innovative forest policies for optimal payment levels, potential mitigation measures, payment mechanisms, and transactions in the system. Further, we analyze the implementation of strategies such as variable set aside areas, and the costs to implement such strategy, gains in terms of nature conservation and carbon storage. Our study will provide new insights regarding pathways to carbon neutrality through the instrument of payments to forest owners.

SWEFOR model is equipped with national forest inventory data, process-based model, forest planning model, product flow and carbon balance models and economic models integrated for the analysis. Our preliminary results show that the various projected prices for carbon for the payment services would help to increase carbon sink in the forest, but it will also affect forest industry and product markets and consumer's demand in the economy. Evaluation of model results show that payment contracts could support achieving negative emission goals also after having achieved carbon neutrality.

Key words: Forest sector model, SWEFOR, national policy, carbon credits, LULUCF, transaction costs, ecosystem services.

Geospatial Decision Support Systems for Sustainable Management of Dry Forest Land and Ecosystem Services: A review of approaches and methods

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Dry forests, on which millions of the world's poorest and most marginalized people depend, are among the most threatened and neglected ecosystems globally. Nevertheless, the demands for their land and ecosystem services are increasing with increasing conflict with each other. While addressing some demands such as reducing CO_2 emissions require conservation, other demands such as meeting domestic energy needs require utilization of different forest products and services. Making decisions to meet these conflicting demands while addressing the problems of deforestation/forest degradation and subsequent loss of important ecosystem services is very complex. The implementation of forest policies at multiple levels (global, national, and local) extends the complexity of the problem. Consequently, there is a growing demand for tools that enable decisions related to sustainable management of forest land and resources given the complexity of the above-mentioned problems. There has been a significant increase in the development and implementation of Geospatial Decision Support Systems (S-DDS) over the last decade. However, efforts to use such tools for forest planning and management in dryland countries have been limited due to, among other things, the lack of S-DDS development guidelines that are accustomed to the given country's forest types and socio-economic context. The objective of this study is therefore to review approaches and methods in S-DSS and select a combination of approaches and methods for developing S-DSS that enable ex-ante assessments of policies, management measures, resource use plans, and technologies that minimize trade-offs and maximize synergies between different forest ecosystem services and between global, national, and local objectives. We reviewed the approaches and methods of 25 widely used S-DSS in forest planning and management. Accordingly, we proposed a framework for developing a S-DSS for sustainable management of dry forest land and ecosystem services in East African countries, where dry forests are the dominant vegetation types. The framework and thus S-DSS will also enable to assess the forest sector's potential in contributing to sustainability.

Greener homes: Factors underpinning Europeans' intention to live in multi-storey wooden buildings

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Climate policies aimed at curbing greenhouse gas emissions embodied in the built environment support the wider implementation of multi-storey wooden buildings. A body of research on public perceptions toward wood as a structural building material is emerging, but close examination of behavioral factors underpinning prospective dwelling is scarce. We used contextualized constructs from the theory of planned behavior to quantify and compare the roles of attitudes, subjective norms, and perceived behavioral control on intentions to dwell in multi-storey wooden buildings. Structural equation models were fitted to survey data from seven European countries (Austria, Denmark, Germany, Finland, Norway, Sweden, United Kingdom; *n*=7,056). We found that attitudes consistently explain intention to dwell in multi-storey wooden buildings. We also found a varied pattern of relationships between factors underpinning intention across countries. An implication of our results is that national-level policies aimed at promoting social acceptability of dwelling in multi-storey wooden buildings should universally address attitudes towards such novel buildings. But in some countries policies might in addition be tailored to emphasize citizens' subjective norms or perceived behavioral controls.

Keywords: Multi-storey wooden buildings, wooden construction, theory of planned behavior, structural equation model, Europe.

Harvest and Its Impacts on Climate Mitigation Policies in the Forestry Sector

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Parties to the Paris Agreement seek ways and alternatives to reach their carbon neutrality targets. For carbon neutrality, the GHG emissions must be balanced with the removals. Harvest and the use of wood products have a substantial influence on the forestry sector carbon removals. On the other hand, the wood products industry has increasing raw material demands in developing economies, and every increased harvest may harm the biogenic removals. An opposite scenario is also possible. Low harvest rates may reduce the increment if the forests are not appropriately managed and stands start to age. Therefore, the balance between the increment rate and harvest has to be established for a significant and sustainable removal rate. The wood production in Türkiye increased from 18.7 to 31.9 Mm3/yr during the 2011-2021 period, reaching 69.8 percent of the increment. The standing stock stabilized at 121-123 m3/ha for the period indicating a slowdown in growth. To project the 2053 net zero target, we used harvest rate scenarios and their effects on biogenic removals. Based on the increment and harvest relationship on the national scale, the 15 Mm3/yr has been determined as a threshold for supporting increment. Harvests over this value will reduce the removals from forests. We presented the projection results and discussed the consequences and possible policy alternatives to increase forest carbon stocks sustainably.

How do increased reuse of wood affect the forest sector and the overall economy?

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Climate change mitigation is urgent, and the forest sector plays an important role when aiming for net zero emissions. The EU Waste Framework Directive requires all member countries, including Norway, to gradually increase the reuse rate of materials to 65 percent by 2035. The European Waste Hierarchy provides guiding principles suggesting that the reuse of wood takes precedence over energy recovery. In practice it also involves implementing a cascading strategy where wood products are systematically retained in the loop on the highest possible level of quality.

Shortages of timber in the world market are already restricting sustainable development. At the same time, the forest sector is facing a need for major transition with focus on increased resource efficiency and a value chain for reuse. Relevant analysis must rest on capable understanding of forest product markets and the end-user markets will evolve over time.

To analyze sectoral impacts of increased reuse of wood, we apply a partial forest sector model covering the Nordic countries and Baltic countries on a regional level. Various scenario analyses are conducted to assess uncertain political and technological implications towards 2040.

The results show how increased reuse rates of wood affect the consumption of harvested wood products, regional production, harvest decisions, and trade patterns. The trade-offs between persecuting a cascading strategy and utilizing discarded wood for energy recovery is also analyzed. Wood cascading and reuse follow the logic of basic sustainability principles and provide important environmental benefits. Policymakers should nevertheless carefully consider trade-offs and consequences, before executing policy measures.

Impact of raising protection targets on the future EU forest-based bioeconomy

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: The EU Biodiversity Strategy (EUBDS) for 2030 aims to protect 30% of EU land. That includes to strictly protect at least 10% of it (including all primary and old-growth forests) and to manage the remaining area (at least 20%) with Closer-to-Nature management. Currently, 23% of EU forests are protected and 5% are strictly protected. The ambitious target is expected to further strengthen the conservation of Europe's biodiversity. In this study, we investigate how different approaches to distribute the protection targets among member states and habitats may affect the future EU forest-based bioeconomy, with a focus on woody biomass harvest volumes, forest products trade and spatial allocation of harvested areas. The analysis is based on the global spatially explicit forest sector model GLOBIOM-forest. We show that the impact of the EUBDS depends on how the protection is allocated among member states and habitats. If the "Closer-to-Nature" management – interpreted in our modelling as harvesting maximum 50% of merchantable woody biomass potential – is to be applied on 20% of the forest area, the EUBDS would lead to a 7-12% long term (by year 2100) reduction in EU forest biomass harvest volume compared to a baseline. This 7% reduction represents the implementation of the target at EU scale, while the higher reductions represent implementation at country (9%), or finer spatial scale as a green infrastructure (12%). All scenarios lead to lower harvest levels and thus lower net exports of EU forest products, affecting the EU forest bioeconomy, which may lead to leakage effects to other regions (mainly boreal) and sectors. If considering set aside to be applied in the whole protected area (30%), the EU harvest level decreases by 22%, and the EU could become forest products net importer after 2050. The general conclusion of the analysis is that EU forests can preserve forest-based bioeconomy if the spatial allocation of new protected areas is shared across the EU regions and protection

managements also allow for wood procurement. However, even if spreading the protection target across EU, biodiversity cannot be claimed to be preserved as it will not represent the diversity of EU habitats.

Investigating Forest Growth-to-Drain Ratio and Its Affecting Factors at County-Level in Arkansas, USA

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: The forest growth-to-drain ratio (FGDR) is an indicator of forest sustainability. Forest managers tend to keep FGDR close to one to balance the forest growth and removals. A few past research shows FGDR has changed in the southern United States. However, the recent state-level ratio is not available for Arkansas. The study attempted to fill the gap by collecting the data for ten years from various sources and employing the mix-effects models. Results found that Arkansas has 1.6 FGDR suggesting that the forest growth rate was higher than the removal rate. Also, the ratio was higher in hardwood as compared to softwood because the demand for softwood was higher and most of the mills were utilizing the softwood in the state. The study further found that South Central Plains (SCP) has the lowest FGDR among the four ecoregions. The reasons were that the SCP region has dominated by pine forests and most of the forest products industries were located in the region. The study founds that the number of consulting foresters and the area of forestland showed negative statistical significance to the FGDR whereas income from forestry showed positive statistical significance. The study concluded by suggesting that surplus forest products should be utilized by establishing the forest product industries and expanding the existing industry in order to reduce the possibility of wildfires, diseases, pests, and insects. Also, outreach programs should be developed and conducted to increase public acceptance of wood utilization.

Structure and dynamics of the roundwood trade from a network analysis perspective: Increasing tensions over wood resources.

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Sustainability and climate change concerns have led to a greater integration of wood products in construction and energy transition policies, which is reflected in an increase in international timber trade. However, this poses a potential problem as international demand for wood products significantly contributes to global deforestation.

While the literature provides comprehensive studies on international timber trade, few consider the physical structure of the trade network in their analyses. This study adopts a network-theoretic approach to deepen our understanding of the wood product trade. We analyze the structure and dynamics of the international roundwood trade network between 1983 to 2022, and use machine learning techniques to forecast future network structures. Over the historical study period, the trade network experienced an increase in value while maintaining a relative stable size. Moreover, it became more interconnected, indicating growing interdependencies among participating countries. Furthermore, we observed an increasing concentration in the global network, particularly highlighting the growing market power of China and its dominance over roundwood trade in the first half of the 21st century. We attribute temporal changes in network structure to three main categories of events: economic disruptions, political events, and natural disasters. By 2050, we expect the trade network to tend toward a monopsony of China.

The implications of our findings extend to forest policy, as local or regional shocks can cascade throughout the global trade market. Moreover, growing polarization centered around key trading partners can exacerbate trade tensions in the forest-based sector. Understanding the dynamics of the roundwood trade network are necessary for policymakers and stakeholders in the forest-based sector to develop efficient strategies that promote sustainability and mitigate risks associated with global trade.

The potential of forest resource as a chemical source: in the contexts of Japan and World

T2.11 Forest-based sector in sustainability transformation: opportunities and sectoral impacts

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Abstract: Woody biomass can be used not only as an energy source but also as a source of chemicals. Material for chemicals such as plastics accounts for 12% of the world's petroleum demand and is expected to increase in the future. Their reduction is important for the sustainability transition. Although the modern energy use of wood biomass is expanding, chemical applications that can store hydrocarbons in society may be advantageous in terms of carbon balance. The conversion technology of woody biomass has been studied abundantly, but there are few studies from the viewpoint of forest science. We examine the potential use of wood biomass for chemicals in two contexts: in the world with a growing population, and in Japan, where forests are underutilized.

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

Agricultural residues from Western Africa to produce biocomposite panels for building applications.

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: This work is part of the BIO4AFRICA project (H2020-Nº 101000762) which aims to diversify incomes in rural areas of Africa through sustainable and locally replicable solutions. The project focuses on developing technologies adapted to the environment and improving traditional techniques in African rural contexts with the local biomass available to develop bio-sourced materials for habitat. In this context, three agricultural residues issued from Côte d'Ivoire and Senegal were selected to produce composite panels for building applications as non-load-bearing materials. The selected biomasses are oil palm empty fruit bunch, rice husk, and cocoa pods. All the listed biomasses have no nutritional value and their use in such applications is beneficial, first economically and second to reduce waste and solve the induced health and environmental problems; they are left on plantation sites, which is the main cause of many diseases in the Western Africa area. They are available in large quantities, seasonal, and present different inherent properties.

Firstly, the biomasses are pre-treated using dry fractionation process. The resulting lignocellulosic fillers are chemically, biologically, physically, and thermally characterized in order to study their effect on the panel production and properties. For this, biocomposite formulations are prepared using a conventional binder (melamine urea-formaldehyde). Many parameters can affect the final properties of the panels such as the inherent properties of the biomass (chemical composition, size, density, porosity…), the type of the binder, and the ratio between biomass and binder. Our aim is to obtain particle panels with interesting mechanical, insulating acoustic, and thermal properties, fire resistance, and durability regarding the international standards; while taking into consideration the climate of Western Africa where the panels are destined to be applied. The tropical climate is known for its high temperature and humidity levels which are two major factors that can affect the service life of biocomposites. Therefore, it is necessary to develop durable and resistant panels in these conditions.

Characterization of the properties of pulpwood chips based on near-infrared spectroscopy

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: In China, the supply of high-quality wood is insufficient, and the raw material for chemi-mechanical pulping is mainly woodchips from fast-growing trees, the quality of which fluctuates greatly. To ensure stable pulp quality, the mills generally suffer from high drug consumption and high electricity consumption. The research on the characterization of pulpwood chips based on near-infrared(NIR) spectroscopy is expected to enable timely adjustment of pulping and papermaking process parameters through real-time monitoring of pulpwood chips properties and to achieve energy saving and consumption reduction.

Through the NIR dynamic monitoring of moisture desorption of water-saturated woodchips, the variation of the NIR spectrum with the moisture content of woodchips was revealed. The second-order derivative spectrum of water-saturated woodchips were used to build the basic density prediction model of woodchips, and the external parameter orthogonalization(EPO) algorithm was used for spectral moisture correction, which effectively eliminated the spectral variability caused by moisture variation and improved the anti-interference ability of the model. The model was used to predict the basic density of woodchips with different moisture contents with the root mean square error of prediction(RMSEP) as low as 22.66 kg/m³ and the residual prediction deviation(RPD) value of 2.10.

For the problem of overlapping and redundant wavelengths of NIR spectral signals, which affects the prediction of chemical components of woodchips, the competitive adaptive reweighted sampling(CARS) algorithm was used to screen the lignin-related wavelengths, and the RMSEP of the lignin content model was 0.76% and the RPD reached 3.49. The successive projections algorithm(SPA) was applied to optimize the relevant wavelengths of the holocellulose prediction model, the RMSEP of the model was 0.91% and the RPD reached 3.43.

The experimental spectrometer and industrial spectrometer were used to establish models for the analysis of woodchips properties. The modeling results were compared, and suitable model transfer techniques were selected to enhance the industrial application of the models according to the characteristics of the woodchips properties. Based on the results of this study, an intelligent analysis system for woodchips properties was developed, which can be initially applied to the control of raw material quality and the production process of chemi-mechanical pulp.

Concentration of Ash-Forming Elements in Poplar Biomass from Second Rotation Plantation

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: The utilization of forest biomass in thermochemical conversion processes as an alternative to fossil fuels can alleviate the climate change crisis. Sustainable use of those biomass feedstocks can be assured just if efficient biorefining and bioenergy production methods are developed. Determination of the chemical composition of biomass is a step towards the development of efficient biorefinery processes. Among other factors, the concentration of ash-forming elements can affect combustion, gasification, and pyrolysis processes by producing ash-related operational problems such as slagging and fouling. In the present work, concentrations of ash-forming elements in different tissues of hybrid poplar, a fast-growing tree and a promising feedstock for biofuel production, were determined. Biomass samples were collected from a second rotation poplar plantation located in southern Sweden (age 18 years – 10 years after thinning treatment). Samples were classified based on the thinning treatment as untreated (6000 stems per ha), light thinning (3000 stems per ha), medium thinning (1100 stems per ha), and heavy thinning (550 stems per ha). In each treatment samples of stem wood, bark and branches of trees with different diameters (7, 15, and 25 cm) were collected and analyzed for different ash-forming elements including Ca, Mg, Na, K, Al, Fe, Si, S, P and Cl. Almost in all tissues, the highest concentrations were detected for Ca and K, followed by Mg and P. The results showed significant differences in elemental concentrations between different tissue types. When compared to wood tissue, bark and branches had higher amounts of different ash-forming elements. The results of this work can be used for the evaluation of the potential ash-related problems in different thermochemical processes for the production of bioenergy from poplar biomass.

Decision support system for optimized value chains in bioeconomy

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: In the large ongoing transition towards a low-carbon society, bioenergy is an essential part of the new emerging bioeconomy needed to meet several of the sustainable development goals. In this transition, the bioenergy sector has the potential to produces, among other things, heat, electricity, biochar, and other biomass products using sustainable and renewable resources or feedstocks from biomass, such as wood residues, agricultural crops, forest residues, and organic waste. Managing the supply chain for these feedstocks involves multiple activities including biomass sourcing, transportation, processing, production, and distribution. This give rise to complex challenges in evaluating profitability, increasing performance, and managing integrated planning. The challenges include handling processes, coordination of multiple assortments and different value chains, for example, forest and agriculture. The supply chains are also difficult to integrate due to the difference in assortment attributes, conversions, and processes.

Woodflow is a decision support system that considers factors such as distance, mode of transport, storage, processes, and handling requirements to determine the most efficient and cost-effective transport and logistics solutions. One key element of Woodflow is an integrated distance calculator which based on local road network information calculates accurate distances with very high resolution and efficiency. The system is flexible and efficient in using optimization for modeling the supply chain. It enables Woodflow to meet the needs and challenges of the bioenergy supply chain, including the essential steps for bioenergy utilization.

Woodflow ensures the efficiency of the supply chain by integrating all stages, feedstocks with business decisions, and thus, reducing costs, increasing profitability, and ensuring due diligence. The results also offer a reduction in waste, better supply balancing and improvement of the sustainability using multiple different biomass feedstocks at a lower cost. Combining forest, agro and waste streams in a more integrated approach to help deliver the right biomass, in the right form, to the right customer at the right time is important when assessing future smart and efficient biomass mobilization and logistics. Woodflow is therefore utilized for developing the future bioeconomy, bioenergy production, creating input data for policy decisions and supporting the development of biomass-based industries.

Effect of pre-hydrolysis on the hardwood pulp dissolution in ionic liquid

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: Cellulose is the most abundant and sustainable bio-resource generated on earth. Cellulose and its derivatives have been utilized for various purposes in our daily life. Due to the crystalline structure of cellulose, it is extremely difficult to dissolve in common solvents. The cellulose is derivatized to dissolve it, such process is called the viscose process. Viscose is produced from dissolving pulp, which is produced by the pre-hydrolysis kraft process. Pre-hydrolysis is carried out prior to pulping to remove hemicellulose from the lignocellulosic, which creates problems in viscose processing. Ionic liquids (ILs) are potentially alternative solvents for cellulose dissolution. It is interesting to gather knowledge on, how hemicellulose affects pulp dissolution in ionic liquid and the regeneration process.

In this investigation, hardwood pulps were produced by kraft (KP) and pre-hydrolysis kraft (PHKP) processes. The α-cellulose and residual pentosan contents were 95.6% and 4.2% in PHKP and 84.3% and 9.9% in KP, respectively. Both pulps were dissolved in 1-Butyl-3-methylimidazolium chloride $[C_4mim]Cl$, 1-Butyl-3-methylimidazolium acetate $[C_4mim]CH_3CO_2$ and their double salt at the ratio of 6:4 ($[C_4mim](CH_3CO_2)_{0.6}Cl_{0.4}$) at 90°C. It was observed that PHKP had slightly higher solubility in both ILs and double salt. The dissolved pulps were regenerated by water and characterized by FTIR, TGA, X-ray diffraction, and viscosity. All pulps and regenerated pulps showed cellulose I structure, and the crystallinity index of regenerated cellulose decreased. As observed in FTIR, the regenerated cellulose showed a stronger absorption band at 1647 cm^{-1} corresponding to the C–O stretching vibration of C–O–H. The viscosity of regenerated KP was higher than PHKP, which affected the strength of produced cellulose film.

Forests barking: How to obtain value-added compounds from forestry side-streams – case studies across the supply-chain

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: Polyphenolic stilbenes and tannins are abundant in the fresh bark of Norway spruce (*Picea abies* [L.] Karst.) trees. Bark extracts could be industrially utilized due to their antioxidative, and antimicrobial properties [1]. The postharvesting conditions, especially industrial debarking, influence the chemical properties of bark. Inherent variation in high-value compounds of bark is assumed to be offset by modifications within bark supply chain; essential quantitative information is still rare but needed for optimizing the bark supply chains for biorefinery purposes. We have elucidated the magnitude of variation in the stilbenoid and tannin content and composition of Norway spruce bark due to (1) geographical origin of Norway spruce seeds, (2) geographical location of the growing site, (3) within-tree variability, (4) storage time and type; and (5) industrial handling and pilot-scale extraction and fractioning processes. The inherent variation in stilbenoid content was large: the total average stilbenoid content of inner bark varied from 70 to 110 mg/g of dry weight [2]. Sampling position in the stem and growing site explained over 50% of the total variance in stilbenoid content. Trees with a northern origin of seeds had a different compositional ratio of stilbene glucosides than the trees with a southern origin of seeds, regardless of their growing site. Industrial bark from sawmills showed a significantly higher total stilbenoid content in winter than in summer. Stilbenes rapidly degraded during storage, but tannins were more stable: 5–7% of the original stilbene amount and 30–50% of the original amount of condensed tannins were found after 24-week-storage [3]. Summer conditions led to the faster modification of bark chemistry than winter conditions. Changes in antioxidative activity were less pronounced than those of analyzed chemical compounds. Inner bark preserved its activities longer than outer bark - intact bark attached to timber is expected to maintain its activities longer than debarked one. To ensure prolonged quality, no debarking before storage is suggested, sampling of northern forests and short handling times in supply chain are recommended. To increase economic feasibility, cascade processing of bark is discussed [4,5].

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Fuel composition and thermophysical properties of poplar from second rotation plantation

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: Biomass is one of the few resources that has the potential to meet the challenges of sustainable and green energy systems. Fast-growing broadleaved (FGB) trees are very suitable for energy production as these tree species are economically viable, has higher growth rate, and can be harvested at much shorter intervals. The production of chemicals and energy from FGB trees can be achieved by coupling efficient conversion processes and technologies. Tree species, forest management, and consequent growth rates have a significant effect on the feedstock properties and fuel conversion characteristics. Efficient thermal conversion processes for FGB trees can be developed by understanding these effects.

This study presents how the forest management methods affect fuel and material characteristics of various assortments of feedstock. Physical, structural, and chemical compositions of biomass feedstock will be analyzed in detail, for example, macromolecular composition, particle density, and thermophysical parameters.

Second rotation poplar trees of 18-10 years of age after thinning treatments (untreated (6000 stems per ha), retention of biggest sprouts (1100 stems per ha), retention of biggest sprouts and removal of every second tree row (550 stems per ha), removal of every second tree row (3000 stems per ha)) were collected from Sturup, Southern Sweden. Stem wood, bark, and branches of trees with different diameters (9, 16, 26, and 35 cm) were selected from each thinning treatment.

As a result of these studies, we are going to present how the above-mentioned thinning treatments and stem diameters of second rotation poplar trees affect the feedstock composition which include elemental composition (organic elements), macromolecular composition (cellulose, hemicellulose, lignin types, extractives), fuel composition (volatile matter, fixed carbon, ash content), structural parameters (density, cell wall thickness, and pore size distributions), and thermophysical parameter (specific heat, conductivity, etc.). In addition, we will present how such properties will affect the pyrolysis behaviour, for biochar and bio-oil production. We will also discuss the suitability of biomass properties for various future biorefinery value chain.

Further development of the measurement and quality determination of raw wood to include future needs and requirements of the wood industry

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: Central elements of the raw wood supply are the measurement and the quality determination of the raw wood. The framework agreement for the raw wood trade has provided the basis for this in Germany since 2014. Based on intensive discussions and negotiations, the framework has undergone numerous changes since its creation in order to adapt it to the needs and requirements of the market partners.

Various industry trends and influencing factors have been significant for these adjustment processes: These include, among others, the changing wood quality requirements of the different industries due to new developments in the processing of the wood, the pressure for rationalization on both the supplier and the customer side, as well as the situation of the raw wood markets influencing the availiability of raw wood. In addition, the (expected) distribution of revenues in the value chain, silvicultural trends towards a higher portion of hardwood instead of conifers, technological and legal developments - such as the approval of devices for photo-optical stack measurement -, as well as the possibilities of the market partners to include these new technologies in the wood logistics chain play a decisive role. These influencing factors and industry trends will be discussed and analyzed with regard to their significance for the future development of the measurement and quality determination of raw wood in Germany and Europe and the related consequences for an economic supply of raw wood for traditional wood industries as well as future biorefineries.

Potential of Calophyllum inophyllum for bioenergy and landscape restoration

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: Land degradation is acute in tropical countries, such as Indonesia which has ~14 million ha of degraded land. In 2018, the Government of Indonesia launched an initiative to restore degraded land by 2030 to achieve national goals in climate and landscape resilience, including bioenergy production. The restoration target includes 12 million and 2 million hectares of degraded mineral soil and peatlands, respectively. The Government also committed to provide energy to all its population through the National Energy Policy, which highlights the importance of diversification, environmental sustainability and enhanced deployment of domestic energy resources. The contribution of new and renewable energy (NRE) to the nation's energy supply is mandated to reach 23% by 2025, of which biofuel is an important NRE alternative. If developed appropriately at landscape scale, bioenergy plantings have the potential to restore degraded land and support biodiversity and multiple ecosystem services. Our study assessed the potential of *Calophyllum inophyllum*, a biofuel species known by various local names in Indonesia and herein called 'Tamanu', for land restoration and production of biofuel, using climate-smart agroforestry approaches. We demonstrated that seed can be harvested for up to 50 years, maintaining high levels of kernel oil and providing high volumes of non-edible oil. In natural forests, *C. inophyllum* seeds produce Tamanu Crude Oil (TCO), refined TCO and Tamanu Biodiesel, ranging 37–58%, 36–53.8% and 17–33%, respectively. Through breeding programs and improved oil pressing methods, the TCO can reach 64–67% (mechanical method) and 72–85% (solvent method), making it ideal for biofuel production. Apart from biodiesel, tamanu oil also has the potential to produce bio-aviation fuel and the waste from biodiesel production process as by-products can be used as raw material in pharmaceuticals and cosmetic industries and as compost for soil enrichment. Our study also demonstrated that various cash crops (rice, maize, cassava, peanuts, soybeans, fodder grass) can grow with *C. inophyllum* in climate-smart agroforestry systems to spread risk and provide income to farmers, thus creating added value. The species can grow in a wide range of environmental conditions and has proven to be a good candidate for landscape restoration.

Supply chain determines the quality of forest biomass for biorefining

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: Forestry value chains produce lignocellulosic biomass from both harvesting and processing residues, which have the potential to be used in a cascade manner in biorefineries. Currently, the side streams like tree bark are almost solely utilised for combustion and energy production. New technologies for fractionation of the recalcitrant biomass enable the production of high value-added products derived from carbohydrates, lignin and especially extractives like resins and phenolics. In order to control the raw material quality for biorefineries, it is crucial to know how various processes affect the biomass properties along the harvesting, transport and storage value chain. This presentation gives a brief review about the chemical, physical and biological processes that influence the extractive content and composition in wood and bark. Potential ways to limit the degradation and losses of extractives prior to processing are discussed.

Wood press water as a sawmill side-stream can boost the production of biotechnologically relevant enzymes in filamentous fungi

T2.12 Future biorefineries: forest biomass and side streams supporting circular economy

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Abstract: The mechanical drying of wood chips with a roll press is an innovative method that improves the heating value of sawmill by-products in a cost-effective and energy-efficient continuous process. The moisture that comes out of the wood chips as press water (PW) contains a variety of dissolved and undissolved organic substances. The disposal as wastewater would generate additional costs offsetting the benefits associated with the reduced energy demand. On the other hand, the high levels of wood-derived compounds make this side-stream very interesting for applications using lignocellulolytic filamentous fungi. Hence, the aim of this study was to examine the potential of PW as a novel substrate or media supplement, respectively, for enzyme production by the industrially used fungus *Trichoderma reesei* RUT-C30.

Our results demonstrate that the addition of PW from Douglas fir (*Pseudotsuga menziesii*) to the cultivation medium can significantly boost the production of cellulase and hemicellulase enzymes, while allowing to replace salts and trace elements of the conventionally used media, such as Ca^{2+}, Mg^{+}, K^{+}, Fe^{2+}, Zn^{2+}, and Mn^{2+}, as well as an equal volume of fresh water. Further experiments demonstrated that this effect occurs mostly by genetic induction of the cellulolytic response and not by improving fungal biomass generation during submerged fermentation. On the other hand, supplementation with PW was found to enhance the growth rates of several wood-degrading basidiomycete fungi, and their mycelial networks were able to bio-clarify the PW by filtering out the suspended particles.

Finding innovative use cases for problematic side-streams from the sawmill industry by fungal biotechnology supports their transformation towards modern, resource-efficient biorefineries with broadened and value-adding product portfolios.

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

Challenges of realizing ambitious reforestation goals in Hawaiʻi

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: There are ambitious goals for reforestation in Hawaiʻi to both restore native ecosystems and to expand commercial plantings for sustainable timber harvest. As outlined by reforestation leaders, there are many challenges to the reforestation pipeline. Perhaps these challenges are most poignant in the context of one of the most isolated island archipelagos. Hawaiʻi lies within the tropics, with the main islands between 18° and 22° north formed from volcanoes erupting from an undersea hot spot. Hawaiʻi is comprised of 27 of the 38 Holdridge life zones and home to a large range of forest types from warm wet, to dry scrub, and sub-alpine. Hawaiʻi is also commonly referred to as both invasive species and extinction capitals. The microcosm of ecological variety and threats to endemic biodiversity add heightened importance and complication to reforestation efforts. Several prominent land stewards have acquired funds to plant hundreds of thousands of trees, but reaching that capacity is proving difficult. Identified pressing difficulties include nursery capacity on island, diverse seed availability, and recruiting a resilient workforce. There are several examples of programs being limited due to infrastructure and reforestation resources in Hawaiʻi to consider, learn from, and support. Embracing Indigenous Hawaiian perspectives and protocols can help build reforestation capacity. In doing so, there is great potential in Hawaiʻi to address these challenges and meet profound reforestation goals.

Development of Growth and Yield Curves for Melia volkensii Tree Species used in Afforestation and reforestation Programs in the Drylands of Kenya

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: Predicting tree growth, timber volume and biomass accumulation in any given site can be important for decision- making in forest management practice and planning. It is determined using species-specific site index models that take into account climatic and edaphic factors. *Melia volkensii* (Guerke) is a fast growing indigenous multipurpose tree species in the family Meliacease and is endemic to the drylands of eastern Africa. In Kenya, the species has been over-exploited because of its high quality timber and non-timber products. Melia is currently being promoted for growing by smallholders and private companies for timber production and carbon credit. The species has a relatively shorter short rotation period of 12–18 years. Although Melia trees have been planted actively in recent years, there is little information on the growth and yield of Melia to guide future afforestation and reforestation programs. The purpose of this study was to prepare a comprehensive Melia growth and tree volume yield model for Melia plantation that can be used to predict growth and yield and support forest planning and decision-making. Tree height, diameter at breast height and bole height data was collected from 109 temporary sample plots of 9 trees each spaced at 4m x 4m from plantations ranging in age from 3 to 20 years. There were 19, 51, 28 and 11 plots in Kiambere, Kitui, Kibwezi and Nyangoro respectively. The highest site index was for Kiambere.>Kitui>Kibwezi and lowest for Nyangoro. The results showed that there was difference in height growth ($p=0.01$), tree basal area ($p=0.03$), tree volume ($p=0.02$) and above ground biomass ($p= 0.02$) which did not corresponded to annual rainfall of site. Diameter growth of the low tree density was larger than that of the high tree density and great in the case of high site index. Apart from climatic factors, additional site variables such as edaphic factors are recommended to be taken into account in future when developing the Melia growth curves. The developed Melia growth curve were useful in determining Melia plantation productivity and guiding investment in commercial Melia growing and planning forest restoration programs.

Forest restoration and management on Indigenous landscapes

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: Recent initiatives and targets have pushed reforestation and forest restoration agendas to the forefront of land management efforts. Action to this regard, however, needs critical planning and resources to be successful. While stitching together and ramping up the pieces of the "reforestation pipeline" might seem straight forward, is important to keep in mind the end goals of ecosystem and cultural services these restored landscapes will ultimately provide. This requires acknowledging and considering Indigenous ties to the landscape. Plants and Indigenous people have had a long rich history and connection to the land. Plants provided all the necessities for survival, and the cultures that relied on them developed appropriate knowledge systems and science to understand them. Fast forward to now, and we see land use has changed and landscapes are being damaged or degraded by altered ecosystem disturbances, all of which create unique challenges for land management. When one layers cultural plant use into this equation, land management becomes even more challenging. Currently, indigenous people are managing forests and reservation areas for contemporary multiple uses, but non-indigenous management systems have frequently conflicted with traditional values and knowledge systems. At the same time, science and theoretical concepts for land management have also largely ignored traditional knowledge for indigenous land management practices. This often creates friction when trying to integrate traditional knowledge with western science. New ways to synthesize the two valid systems are needed, especially within the reforestation pipeline. Fortunately, a conceptual model exists for producing target seedlings for indigenous people that integrates Traditional Ecological Knowledge with modern land management tactics. This presentation will cover a brief history of this approach and include some ongoing examples of successful integration of the topic.

GERMAN-UKRAINIAN EFFORTS TOWARDS BUILDING CLIMATE-RESILIENT FORESTS IN WESTERN UKRAINE

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: Forestry in Ukraine is still very much oriented in clearcuts and the management of pure stands. Alternative silvicultural systems such as long-term natural regeneration or other cutting systems are though well-known but not implemented in practical forestry. In the project 'Resilpine' the focus was laid on the conversion of the Scots pine dominated forest in Western Ukraine into mixed continuous-cover forests, by implementation and analysis of experimental and demonstration plots as well as further education and training.

The specific goals and measures to achieve this were to develop the state forest enterprise Lviv and Stradch Educational and Production Forest Enterprise as model forest enterprises for a near-natural and multifunctional and climate change adapted forest enterprise, to implement and analyze permanent observation plots on forest conversion (alternatives to clearcutting) and fire management, including the establishment of two marteloscopes and their integration into the international network ‚Integrate+', and to establish demonstration plots for training purposes.

The tree species and silvicultural systems analyzed were Scots pine (*Pinus sylvestris*) with shelterwood and group selection cutting, pedunculate oak (*Quercus robur*) with shelterwood cutting and European beech (*Fagus sylvatica*) with shelterwood cutting. Moreover, five demonstration plots for different thinning variants in Scots pine were implemented.
It could be shown, among other things, that Scots pine is the most abundant species in all the felling systems, with on average more than 100 k plants per ha on relatively poor soils. Other admixed tree species only occur with small shares. Natural regeneration, especially of Scots pine, was less abundant on comparatively rich soils and in shelterwood, compared to small clearcut. After the young plants have established, their abundance slightly declined in the second and third year, due to competing herbaceous plants and thick litter.

Key words: alternative silvicultural systems, close-to-nature forest management, Scots pine, Ukraine

Long-term dynamics of grasslands and livestock in Norwegian cultural landscapes: implications for a sustainable transition of rural livelihoods

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: The abandonment of cultural landscapes in Norway has had a notable impact on grasslands and domestic livestock that depend on them. The rate and direction of these changes vary across different geographical settings. Using two contrasting regions, representing inland (Hedmark) and coastal (Sogn og Fjordane), landscapes, respectively, we analysed the temporal dynamics of grassland and livestock from 1918 to 1999 in a total of 40 municipalities in the two regions. The results showed a 66% and 20% decrease in grassland areas in Hedmark and Sogn og Fjordane, respectively. However, in Sogn og Fjordane, the cultivated grassland used for mowing increased over the years. In contrast, in Hedmark, the cultivated grassland used for mowing decreased by 70% from 1949 to 1979. This reduction coincides with the period when cultural landscapes were abandoned, and spontaneous reforestation occurred in the region. The domestic livestock, which depends on grassland for sustenance, showed differences between the two regions. In inland Hedmark, livestock experienced a huge decline, especially from 1959 when the population dropped by 35%. This decline continued in the subsequent years. On the other hand, in coastal Sogn og Fjordane, the livestock population experienced a clear drop of 18% in 1949 and then stabilized. Finally, we advocate that regional planners have to consider the historical trajectories of changes within cultural landscapes to ensure ecological services by conserving and maintaining these landscapes' valuable habitats.

Mechanical Site Preparation Across Space and Time: A Trans-Atlantic Perspective on Successful Regeneration of Boreal Forests

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: Successful forest regeneration is crucial for sustainable forest management. In boreal contexts, plantation forestry is notably used when natural regeneration is insufficient after harvesting or wildfires, but planted seedlings face various stresses on harvested sites, jeopardizing their survival and growth. Limited access to water, nutrients and light, plus exposure to pests, and diseases contribute to these stresses. Mechanical site preparation, disturbing the organic layer and upper mineral soil through techniques such as discing, mounding or inverting, is commonly used to mitigate post-planting stress. However, climate change, social interest in forest management, and the need to procure diverse ecosystem services require precise silviculture practices tailored to regional and local objectives. Our empirical research in boreal ecosystems of North America and Scandinavia reveals intricate interactions affecting seedling establishment after reforestation. For instance, in boreal Quebec, Canada, successful conifer seedling establishment depends on regional precipitation, temperature, and interactions with soil characteristics and microsite conditions. In Sweden, planting position within scarified sites significantly influences conifer seedling survival, but effects vary with soil moisture. Long-term silviculture studies also demonstrate the importance of early treatments for stand productivity. For example, mechanical site preparation significantly enhances seedling growth and survival, impacting sapling growth even after 18 years in boreal Quebec. We have observed that seedlings planted in scarified plots show improved water use efficiency compared to control plots. Also, we have shown that site preparation effects on standing volume and density persist for at least 30 years in Sweden. In conclusion, our empirical studies with *Pinus* and *Picea* species across multiple sites in Canada and Sweden highlight the absence of a universal solution for regeneration success in boreal ecosystems. Forest managers and decision-makers must recognize these complex interactions and support further international research collaborations. The success of large-scale forest landscape restoration and reforestation programs depends on implementing regionally tailored silviculture prescriptions based on an understanding of the mechanisms driving seedling responses.

Pine reforestation programs in Mexico

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: Mexico is one of the six megadiverse countries in the world, with around half of the world´s pine species. *Pinus* is one of the most economically and ecologically important forest genera in Mexico. However, in accordance to some authors, deforestation rates in México are about 370,000 ha/year. This threatens the richness of forest genetic resources in México, causing the disappearance of locally adapted populations and rare and endangered pine species. Reforestation programs in Mexico have been used to respond to deforestation problem since many years ago. In addition, these programs can be used as an important strategy for rehabilitating ecosystem structure and function in degraded lands. Restoration of ecosystems is a long process that involves reforestation as a main element. For sites where conditions present several adverse factors for seedling establishment the challenge to recover degraded areas is bigger. One of these programs was located in the central part of Hidalgo State in Mexico. People from Community El Porvenir, Hidalgo have been planting pine trees since 25 years ago trying to recover degraded lands. Several studies regarding performance of these plantations were done during last two decades. Evaluation includes species adaptation, seedling survival and development, richness and abundance of species of shrubs and herbaceous plants in the plantations, etc. We also interviewed people from the community involved in reforestation process to obtain information about the practices applied before, during plant establishment and maintenance after planting. Results show that degraded lands have been slowly recovered. Two promising species were *Pinus greggii* var *australis* and *Pinus cembroides*. Results indicated that survival, growth, and adaptation of these two species is good. One of the studies found a total of 44 species of vascular plants in the understory distributed among 42 genera and 34 families, with 90% native species. People involved in tree plantations consider three main factors for reforestation success: species selection, site preparation, and participation of most people of the community in the establishment and maintenance of the reforested areas. This evaluation demonstrates that rehabilitation of degraded lands through reforestation is possible and lead to an increase in biomass accumulation and diversity

PostCont – the technological system for the containerization of bare-rooted planting stock of trees and shrubs

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: The poster will provide information about a semi-automatic device capable of encapsulating the roots of bare-rooted planting stock into paper pots and a growth medium based on peat (PostCont stands for post-containerization). The PostCont device does not require the purchase of containers. The production of paper pots is a part of the containerization process. Secondary raw materials (e.g., old paper, cardboard, moulded pulp) and water are used to create the pots. The paper pots are made from the feedstock in a so-called "wet process". The tested PostCont machine can recycle the surplus water extracted from the pots and the substrate when the plants are containerized. Immediately after containerization, the planting stock can be handled with some care. The PostCont plants represent a compromise between bare-rooted and standard container technology. According to our initial results, the roots of plants grow freely through the walls of the paper pots and do not show deformities. The containerization of originally bare-rooted plants by the PostCont technology has the potential to support the resistance of the planting stock to stresses during transportation and after planting on harsh forest sites (drought, unfavourable soil environment, etc.). In this respect, PostCont plants are, to a certain extent, close to the standard container stock that often shows a higher survival rate than the bare-rooted stock. However, PostCont technology demands less irrigation water, fertilizers and pesticides than container technology. This is because in the PostCont technology, the planting stock is grown on mineral outdoor nursery beds, and the containerization is completed after the plants are grown. Semi-automatic root encapsulation is faster than manual transplanting to containers. The developed PostCont device can be easily transported and utilized wherever there is a water source and a connection to the electricity grid. The PostCont technology is designed primarily for smaller mineral nurseries focusing on bare-rooted planting stock. It will allow them to containerize some part of their planting stock so that the containerized seedlings can be used on harsh sites or in less favourable planting conditions.

Potential of bamboo for forest landscape restoration following degradation by artisanal mining activities

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: Artisanal mining activities in southern Ghana entail methods that result in significant environmental damage, including forest degradation, air pollution and pollution of water bodies in the mining communities. Bamboo is abundant in Ghana and is known to be useful for soil erosion control, etc; but its use for restoration of degraded land has yet to be fully explored in the country. This study therefore sought to explore the potential of bamboo for reclaiming degraded mined sites and to identify suitable bamboo species for this purpose. Plots measuring 825 m^2 were demarcated on randomly selected un-mined, reclaimed mined and un-reclaimed mined sites. Seedlings of seven bamboo species were planted at 2 m x 2 m on each plot and the seedlings were assessed for survival rate, shoot production rate, height growth and qualitative phenotypic characteristics. The results indicated 97% survival of seedlings of all the species on all plots and 70% of seedlings developed new shoots on the un-mined and reclaimed sites one month after planting; with 50% on the un-reclaimed site. After three months, mean shoot production for reclaimed-, un-mined-, and un-reclaimed mined sites were 3.0, 2.0 and 1.0 shoots per clump, respectively, with corresponding mean height growth of approximately 173 cm, 113 cm and 63 cm. By the tenth month, the bamboo had formed an impenetrable barricade on the reclaimed and un-mined sites. We conclude that *Bambusa vulgaris*, being the most common in Ghana, is suitable vegetation cover for rapid reclamation of degraded mined lands in southern Ghana. In addition to curbing air pollution and improving ecosystem functioning and livelihoods of local communities in the mined sites, it would contribute significantly to Ghana's commitments to the Bonn Challenge, AFR100 and other restoration initiatives, and to Targets 3, 4 and 5 of SDG 15.

REGENERATION OF FORESTS WITH SILVER BIRCH (BETULA PENDULA ROTH): THE PERFORMANCE OF CONTAINERIZED BIRCH SEEDLINGS IN THE FIELD

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: Conifer species are dominating in the forests of the boreal and nemoboreal zone. Due to climate changes, more frequent damage has occurred in recent years, especially in Norway spruce *(Picea abies* (L.) Karst.*)* stands, which is a drought-sensitive species. This concern, as well as the energy sector's transformation from using fossil fuels towards biofuels, prompted the idea of increasing the amount of fast-growing broadleaved tree species. For this goal, the Trees For Me excellence centre was created to develop the potential of Silver birch (*Betula pendula* Roth) as a complementary tree species. Artificial regeneration is a crucial step in forest management to reach the goal of highly productive birch stands. Therefore, studying containerized birch seedlings' performance in the field is of interest. At four research stations across Sweden, two different sizes of containerized seedlings were planted in 2023 and will be repeated each year until autumn 2027. Seedlings will be planted during spring, summer, and autumn. Additionally, three different site preparation methods will be tested: disc trenching, inversion, and no soil preparation. Also, fertilisation with arginine will be applied to one-third of the seedlings on each plot. Height, root-collar diameter and damage will be registered after each growing season. The data obtained from this study will allow for a comparison of growth and survival in two sizes of containerized birch seedlings using different site preparation methods and dates of planting during the year. The study will enable to distinguish favourable conditions for establishing future birch forests and optimize artificial birch regeneration.

Restoring Atlantic Forest's contributions to people

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: Forest landscape restoration has been promoted globally as a means to achieve multiple socio-ecological benefits, yet little is known about the relative contribution of different tree growing approaches for ecosystem services and human wellbeing. In the Brazilian Atlantic Forest, an ambitions restoration target of 15 million hectares has been promoted since 2009 by the Atlantic Forest Restoration Pact, but stakeholders' engagement has been constrained by the lack of evidence of the benefits people may get from restoring tree cover in deforested landscapes. Here, we explored how nature contributions to people are recovered by different tree growing approaches. We collected data in 700 30 x 30 m plots, using a standardized protocol focused on multiple ecosystem attributes and functions (e.g., forest inventory, soil measures, water infiltration), distributed across the Atlantic Forest in southeastern Brazil and seven types of tree cover (second-growth forests, restoration plantations, agroforests, active monocultures, unmanaged monocultures, degraded remnants, and conserved remnants). We used the IPBES framework to estimate nature contributions to people based on the ecosystem attributes and functions measured in the field. We found a broad range of variation of tree growing approaches in providing nature contributions to people and evaluated the influence of environmental factors in this process. Our results highlight the need for matching tree growing approaches with stakeholders' demands and the local socio-ecological context, as well to consider critical trade-offs when deciding why, where, and how to restore tropical forests.

Tree planting machines for effective reforestation: examining seedling supply systems that facilitate mechanized tree planting

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: In parts of the world, some reforestation is performed mechanically. To be cost-effective, all tree planting machines are dependent on efficient seedling/cutting handling and logistics (seedling supply systems). Today, seedling handling is a bottleneck that costs time and money when reloading the machines' planting devices. In our study, we present some historical attempts to develop seedling supply systems that facilitate mechanized tree planting. Some have been put into operation, while others have only been tested in development projects or as theoretical concepts.

From the nursery, seedlings can be delivered in: cultivation trays; trays with round/square plastic cultivation tubes; crates; or in cardboard boxes. With trays, the tray design can be made compatible with the planting device’s seedling feeding system. Also, the seedlings’ positions can be defined, and the seedlings can be fed automatically on the planting machine either by pushing them out or by individually grabbing and lifting them out of the tray cavities/ plastic tubes. Cohesive root plugs (or root plugs supported by e.g. paper pots) aid seedling handling and feeding; however, such solutions might add costs, require additional nursery investments, and/or deform roots. Overall, trays are robust and protect the root plug, but seedlings in cultivation trays are prone to desiccation and cannot be frozen-stored cost-efficiently.

Cardboard boxes, in which seedlings are packed either with the stems intertwined or standing up, is the second most common seedling packaging system. In boxes, seedlings can be packed densely, which is especially important if the transport distance from nursery to the reforestation site is long. However, before seedlings can be transferred to the tree planting machine's planting dibble, boxes require either manual handling or that the seedlings have defined positions in the boxes (or be band-mounted. e.g. the EcoBandPak concept) if they are to be picked automatically.

With increasing labour shortages, additional technical development, standardization, and joint research initiatives, we predict that previously failed solutions for seedling supply might become cost-efficient in the future. Nevertheless, because the international reforestation context varies widely, we conclude that there is no single global solution for seedling supply systems of mechanized tree planting.

What factors enhance survival and growth of planted saplings in clumps on sandy soils?

T2.13 Improving the flow of the reforestation pipeline to support regeneration and ecosystem function for the future

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Abstract: In the context of afforestation and forest conversion, planting saplings is a frequent avenue to rapidly boost species richness. Planting saplings in groups of 20 to 40 trees, so-called clumps, is a management strategy with the intention of creating mixed forests. The establishment of young trees however remains a challenge - and with increasing shortages of seeds and planting material and rising costs - it is crucial that we use our available forest reproductive material efficiently. The first years after planting are generally hard as young trees coming from nurseries are exposed to difficult surviving and growing conditions. Challenges include climate change related disturbances (drought and heat stress), soil degradation (acidification, compaction, …) and high herbivory pressure from game. The addition of amendments in the planting pit and protection against game can alleviate some of these constraints. Here, we focus on species poor forests on degraded sandy soils (Pleistocene deposits of the West-European sand belt) in Southern Netherlands and Northern Belgium, where all of the above challenges are widespread and hinder successful conversion of pine monoculture to mixed forest. In this large scale observational study monitoring up to 50 000 trees planted in 3403 clumps between 2014 and 2021, we evaluated the success and growth of young trees per tree species and soil type, the effect of soil amendments (fertilizer, rock dust and/or hydrogels) in the planting pit, and the type of game protection measures. Our results indicated that water availability is the prime limiting factor for survival and growth of young trees, however most results are context dependent. The effect of amendments is variable (depending on tree species and soil type) and should therefore not be adopted as a blanket treatment. The type of wildlife protection is determinant for survival and growth of young trees: the individual, complete protection options such as tubes seem to be the most effective. The findings of this research can be taken into account by the forest manager when planting the (mixed) forests of the future.

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

20 years of forest sector innovation in Europe

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: The European forestry and forest-based sector plays a crucial role in addressing global challenges related to climate change, biodiversity preservation, and the provision of forest ecosystem services. As markets evolve and consumer behaviours change, and as European policies increasingly aim to foster the development of a circular bioeconomy, understanding the role of innovation becomes increasingly important.

This presentation offers a comprehensive overview and analysis of innovation activities within the European forestry and forest-based sector over the past 20 years, with a specific focus on the key drivers and barriers that influence the development and adoption of innovations. The research methodology adopted ensures a robust and evidence-based analysis. By conducting a systematic literature review, analysing data from recent EU projects and patent database and empirical data collected through surveys conducted across EU countries and expert interviews, this presentation will provide insights into the practical challenges faced by innovators and stakeholders in the sector. The findings will contribute to a deeper understanding of the innovation dynamics within the European forestry and forest-based sector. By identifying the key factors that influence the development and uptake of innovations, policymakers, industry players, researchers, and other stakeholders can better comprehend the current innovation ecosystem. These insights can inform the formulation of effective strategies and policies to foster innovation, drive sustainability, and address emerging challenges, thereby helping forestry position itself better in the bioeconomy. By leveraging these findings, the forestry sector can seize opportunities, optimize resource utilization, and contribute significantly to the growing field of bio-based products and services.

An integrated modeling and analytical framework of machine learning and life cycle assessment in forest biomass utilization for bioproducts

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: The utilization of forest biomass for value-added bioproducts can contribute to sustainable forest supply chain management and mitigation of climate change. The diverse biomass conversion pathways and process conditions make conducting comprehensive environmental impact assessments difficult. To bridge this research gap, we developed an integrated life cycle assessment (LCA) and machine learning (ML) analytical framework to evaluate forest logging residues' life-cycle energy consumption and environmental impacts under various conversion technologies and processing conditions. A “cradle-to-gate” LCA is used to quantify the environmental impacts of feedstock harvesting, transportation, storage, preprocessing, and conversion components. ML models trained from experimental data are used to predict the yield and properties of bioproducts produced from logging residues through different thermochemical conversion pathways. The outcomes of the ML predictive modeling are subsequently incorporated as input parameters within the integrated analytical framework in conjunction with LCA. This modeling and analytical framework is applied in the eastern United States, where abundant forest biomass resources show great potential for the industrial development of bioproducts. Our results indicate that the LCA models, coupled with results derived from ML models can help minimize the environmental impacts of forest biomass utilization. The application of this integrated modeling framework can further enhance the environmental sustainability of the industrial development of forest biomass for bioenergy and bioproducts.

Bioeconomy, forest and digitalisation - developing sustainable business models

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Forests in the Nordic countries have been a source of food, products and welfare for both local communities and nations for as long as there has been settlement. More recently, the way in which forests support the climate has become more pronounced. But people are now facing major challenges due to climate change as well as societal and environmental challenges. Fundamental changes are needed to ensure future prosperity in the face of growing resource depletion, climate change and environmental degradation.

Forests are crucial for the development of a sustainable bioeconomy in forest-based countries to replace fossil fuel-based materials and energy. Forest biomass has a great potential for developing new bio-based products. However, bioeconomy and circular economy transformation depend on both technological and social innovations together with societies adapting to a bio-based sustainable future, which emphasizes the ecological, economic and social functions of forests.

This presentation discusses opportunities and challenges for the digitalization of the Swedish forestry value chain in a circular bioeconomy. The vision of project was to create digital solutions for a sustainable and efficient forest/based bioeconomy; the mission is to explore and create enablers for realizing a digital forestry value chain. The forest sector is challenged by level of digital maturity, establishment of digital ecosystems, increase in level of service innovation, and increase in digital competence. Individually these challenges are developed, however, the major challenge is to bring them together and linking business models with the digital ecosystems available and eveloped. The level of digital maturity in the Swedish forestry sector is reportedly low –both among large companies and smaller forest owners. While researchers have contributed to an increase in service innovation in the Swedish forestry sector, there remains the need to build digital ecosystems that enable an increase in digital competence across the entire value chain. This presentation discusses advancements, pending tasks, and lessons bring them together with business models togehter with the concept of Industry 5.0 –a stage in which technologies are used with a perspective that accounts for humans' fears towards digitalization— may be what Sweden needs to pursue a full-scope digital transformation.

Comparative factor analysis on consumers' preferences of wood utilization in Asian countries

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Wood demand is continuously growing in most of the Asian countries owing to increasing population and rapid economic growth. In 2021, we conducted web-based questionnaire surveys in Japan, China, Vietnam, Thailand, Indonesia, and India to understand the citizens' preferences and knowledge about forests and wood utilization. The number of valid responses counted 500 in Japan, 312 in China, 450 in Thailand, 389 in Vietnam, 216 in Indonesia, and 41 in India. Based on the collected data, we conducted multiple linear regression analysis to determine factors that influenced the preferences of wooden products including interiors and furniture, and wooden house. Regarding wooden products, explanatory variables such as 'degree to consider cutting-down forests as deforestation and destruction of nature', 'degree to be fond of entering forests', and 'frequency to enter forests' significantly influenced the degree of wooden product utilization. For instance, citizens who responded more negatively to cut down forests had significantly lower degree of wood product utilization in Vietnam, while the opposite was true in China. Considering the frequency to enter forests, citizens in Japan who frequently entered forests had significantly higher levels of wood product utilization, while citizens in China, Thailand, and Vietnam were unaffected by this factor. More than 30% of citizens in Japan, Thailand, and India indicated that they would like to live in a wooden house in the future, while more than half of the citizens in other three countries rejected the idea. In Japan, Vietnam, and Indonesia, a factor 'degree to be fond of entering forests' showed positive influence. In these countries, advertising wooden house with positive image of forests might be effective to expand wooden house market. Considering a negative influencing factor, citizens who answered 'like to feel the surface of wood by hand' had a negative opinion to live in wooden house in China, Vietnam, and India, while Japanese citizens had a positive opinion. For wood exporting countries, effective export strategies would be established for Asian market based on these science-based findings.

Do wooden buildings improve consumer perceptions of corporate sustainability?

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: With an increasing focus on climate change and negative environmental effects caused by humans, we see increasing concern among consumers, followed by behavioural changes. Environmental considerations are increasingly important in consumer decision making. We are surrounded by corporate buildings, we pass them when traveling, we visit them, and we see them in the media. Some companies use their corporate headquarters as part of their marketing strategy, by, for example, creating iconic structures that bolster their brand. Corporate buildings are frequently strategically depicted in company homepages. Despite the attention and investment by industry, research has largely neglected the relationship between corporate building appearance, brand associations. An especially relevant question today is, to what extent do environmentally friendly corporate buildings and the materials used in those buildings affect companies' credibility when it comes to being environmentally sustainable.

We study how building materials (wood vs steel/concrete) used in corporate buildings influence perceptions of company image related to sustainability. Our theory is that building materials influence how sustainable a firm is perceived to be, but that the effect depends on perceptions of the sustainability of wood.

We therefore hypothesize that firms that use wooden (vs concrete) buildings are perceived as more sustainable by consumers, and consumers have a more positive brand attitude towards such firms. We also hypothesize that the effect of wooden buildings on perceived sustainability and brand attitude is positively moderated by beliefs about environmental attributes of wood.

We test the hypotheses using an online survey-based experiment (n=1200, UK and US-based respondents) where we manipulate the building materials of corporate headquarters (wood or steel/concrete, four different fictional companies) using realistic images and text. The analyses and results and implications will be presented.

Estimating the sustainable availability of unused woody materials for energy from planted forests in Japan

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: This study estimated the sustainable availability of unused materials for woody biomass power generation plants under operation with FIT at the end of June 2020 as the supply potential considering reforestation costs of the planted forests, about 10 million ha in Japan. As a result, supply potentials of used and unused materials were estimated at 65,413,601 m^3/year and 13,082,720 m^3/year, respectively whereas those techno-economic availabilities were estimated at 54,202,304 m^3/year and 10,840,481 m^3/year respectively. Therefore, the rate of the availabilities to the supply potentials was 82.9%. Furthermore, the rate of the availabilities to the demands was 124.8%. With woody biomass power generation plants registered in FIT at the end of June 2020, the rate of the availabilities to the demands was 98.5%. Considering the subsidy rate of 100% to secure the reforestations, the availabilities met the current demands in Japan as a whole.

Examining the paradoxical tensions of intersecting market-shaping strategies in Nordic forests

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Despite decades of scientific research and international agreements, it is evident that current global efforts to address sustainability challenges such as climate change and biodiversity loss are neither substantial nor fast enough. The reason behind this relative inaction is not the lack of informative natural sciences research or policymakers' ambitions. Rather, we posit that one of the main reasons behind the slow progress is that sustainability efforts have viewed and used one of the most pervasive and potentially efficient mechanisms for allocating resources in contemporary societies – markets – in a much too narrow sense. Importantly, there is more to markets than the objective price allocation mechanism often depicted as an 'invisible hand'. Markets are complex social systems that enable exchange and value creation within open, democratic societies. Within such market systems, actors regularly engage in market shaping—reactive or proactive actions to either change or maintain the way markets work. In this study, we look at how multiple market-shaping efforts intersect and interact in the ongoing sustainability transition of contemporary society, focusing on the Nordic forestry sector. Forests are viewed as key resources in the transition towards more sustainable futures, providing vital goods and ecosystem services. At the same time, the established and industrialized forest-related markets may also be part of the problem via their emphasis on mass production and the associated forest management practices. Our initial findings suggest that some of the parallel market-shaping efforts are mutually reinforcing while others are mutually opposing. Furthermore, there appears to be no simple relation between the way such market-shaping efforts intersect and the sustainability outcomes they generate. To investigate these complex dynamics, we apply paradox theory and particularly the difference between paradoxical tensions in the epistemological realm (i.e., actors' perception of tensions) and paradoxical tensions in the ontological realm (i.e., the systemic reality underlying the tensions). As an outcome, we develop a typology of the included paradoxical tensions and elaborate how this typology can be used both to 1) improve the sustainability outcomes of multiple intersecting market-shaping efforts in the forestry context and to 2) limit the repercussions of their unintended consequences.

Gate-Gate Life Cycle Assessment of industrial metabolism of wood plastic composite to achieve circular economy

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Wood Plastic Composite (WPC), known for its excellent durability, dimensional stability, high rigidity, and relatively low density, is one of the largest forest bio-economic industries. WPC, as a product, are environmentally sustainable, but since it is an unorganized market, being unable to prioritize the social aspects and industrial production hinders the nation from achieving Sustainable Development Goals (SDG) 2030. Therefore, it is essential to assess the industrial metabolism of WPC to re-invent and re-introduce this market using Life Cycle Assessment (LCA) to achieve a circular economy.

The study aimed at a less attempted gate-gate LCA of WPC industries, which analyses the burdens posed on the environment at a microscopic level and corrects the faults in the industrial units such as fibre selection, route planning for internal transportation, technological and processing faults, labour resources, human safety and storage units. Evaluation and correction in these units reduce energy consumption and other costs while ensuring the safety of labour and the environment. The energy and carbon model for the next 50 years of the improved industrial hubs showed a steady decline in plastic waste and carbon footprint and an increase in economy from the green industries.

The rise of the WPC industries demands sustainable life cycle assessment (LCSA) and restoration of industrial metabolism to ensure a livable environment. These results would help to formulate better industrial designs and bio-economic policies to thrive internationally.

Keywords: Wood Plastic Composite, Life Cycle Assessment, Industrial Metabolism, Circular Economy

Housing developers' intention of reuse wood materials in building projects

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: The construction industry is a significant cause of greenhouse gas emissions, resource consumption and waste generation. Among other things, the industry has a large potential for increased material circularity. Therefore, the interest in circular strategies associated with reuse, repair, renovation, recycling and recovery have received increasing attention in recent years. However, a complex set of factors will affect the decision to the reuse of wood materials in the construction industry, and there exist several barriers that slow down circular development. This study investigates behavioral and institutional factors that impact the intention of housing developers to implement the reuse of wood materials in residential and leisure buildings in Norway. A quantitative cross-sectional survey was conducted in the fall of 2022 on housing development companies (N = 138) in southern Norway. A conceptual model based on the Theory of Planned Behavior and Institutional Theory was developed and tested on the data that included questions related to the research models main constructs. To test the hypotheses, Partial Least Square Structural Equation Modelling was utilized. Furthermore, a bootstrapping test was used to inspect potential mediating effects. The conceptual model explains a large proportion of the housing developers' intentions to reuse wood materials. The results indicate that previous reuse behavior, behavioral attitude, perceived behavioral control, and regulatory and market factors are positively associated with intentions to reuse, while subjective norms have no significant effect on the intention variable. To enhance the intention to reuse, this study suggests focusing on digitizing and systematizing access to materials and information, sharing knowledge through holistic collaboration, educating professionals in circular economy practices, and adapting laws, regulations, policies, and economic incentives towards more reuse and circular building activities. This requires a holistic attitude shift among individuals, governments, and businesses.

Incorporating Circular Bioeconomy Principles into Strategic Biomass Planning

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Forests in the United States (U.S.) Pacific Southwest Region generally support an overabundance of biomass supply with inadequate demand and facilities to make use of the materials. U.S. Forest Service Biomass Program activities here have helped to retain 21 commercial biomass energy facilities using over 46 million board feet of timber per year, support biomass uses at over 25 other wood processing facilities and contribute toward research and development of other value-added uses for small woody materials. However, forest managers and industry often struggle to match supply with demand for a variety of reasons including high costs to extract and deliver material, unpredictable supplies, challenges from environmental groups, a dearth of skilled forestry workers/equipment, subsidized or less expensive renewable energy sources competing in the public market, and a lack of newer production facilities that can make higher value products from small wood. Applying circular bioeconomy concepts to this biomass supply and demand imbalance may lead to solutions by designing and applying technological and/or biological solutions that ultimately remove waste and pollution from the system. Some important considerations for supporting sustainable biomass components in a circular bioeconomy include:

- Assessing and developing pathways to provide consistent supplies.
- Optimizing specifications in contracts/agreements to balance economic and ecological goals.
- Investing in timely research, development, and innovation with diffusion of that technology.
- Collaborating with state, industry, partners and interest groups to promote shared stewardship.
- Facilitating education and technical expertise with a range of collaborators and stakeholders.
- Maintaining and growing partnerships that sustain wood processing infrastructure and jobs.

Developing a shared vision and strategic pathway for sustainable, effective biomass utilization is the first step toward a blueprint that could guide forest managers, stakeholders, and industry plans. To maintain and restore healthy, resilient forests and associated ecosystem services while also providing for socioeconomic prosperity, six priority strategic elements are suggested as a basis for actions: 1) address supply availability and sustainability; 2) increase collaboration on research, development & innovation; 3) integrate natural capital accounting; 4) identify sustainable funding commitments; 5) promote education programs; 6) advance positive narratives for public support.

Innovations in climate life cycle assessments for forest products: coupling forest management with wood product analysis, and policy applications.

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Greenhouse gas life cycle assessments (GHG LCA) play a key role in identifying promising forest management and forest product alternatives for a circular bio-economy. These GHG LCA's consist of several steps along a forest-to-disposal path: considering forest management and wood product utilization. Focusing on key components of advanced forest product GHG LCAs, we will present examples of recently published studies. Key components include i) assessment boundaries; ii) baseline and alternative future forest management assumptions as new wood product supply chains, including bioenergy, come online; iii) uncertainty analysis including stochastic events affecting forest carbon stocks (wildfire, pests, climate change, etc.); iv) wood product substitution benefits including dynamic baseline assumptions for alternative energy generation (e.g., sliding grid electricity emission profiles); v) inclusion of a wider range of climate-relevant impact metrics (different GHGs, albedo effects, etc.); vi) temporal considerations including dynamic accounting that considers GHG specific half-lifes; and vii) GHG emission discounting to explore near-term GHG benefits.

These components can be accommodated in a host of GHG LCA accounting frameworks for attributional or consequential in forest management or (forest) product centered life cycle assessments (e.g., Buchholz et al., 2015; Buchholz, Kifalu, et al., 2017; Buchholz & Nepal, 2023). Applications can range from jurisdictional climate action plans (e.g., Maritato et al., 2021), state-wide (forest management) strategies for nature-based climate solutions, to product specific LCAs such as wood-based high-rise buildings. We will further pull from previous research into state-level forest sector analytics (e.g., Canham et al., 2013; Gunn & Buchholz, 2018) and scenario specific assessments (e.g., Gunn et al., 2020; Timmons et al., 2016) as well as integrating risk and sensitivity analysis into these LCAs (e.g. Buchholz et al., 2022;) and extensive management scenario analysis (e.g., Gunn & Buchholz, 2018).

To identify key levers for decision makers, accounting elements need to be reported separately to disaggregate carbon impacts and associated uncertainties by category (stocks, products in use, post use, energy, substitution energy, substitution products) and allocate uncertainty factors separately by accounting element.

This presentation provides the audience with an overview on state-of-the-art GHG LCA analysis and how to translate results into actionable climate policies.

Innovative investment, ownership concentration and corporate financial performance – evidence from the Chinese forest products firms

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Forestry product firms shoulder the dual missions of economic development and ecological protection. Therefore, analyzing firms' performance is conducive to improving firm-level operations and country-level green development. This paper uses the fixed-effect model with panel data for 102 listed forest product firms from 2014 to 2020 in China to explore the relationship between innovative corporate investment, ownership concentration, and performance. In addition, further analysis was conducted based on different industrial segments (pulp and paper, wood-based panels, and other forest products firms) and ownership property (state-owned and non-state-owned). The results are drawn as follows: (1) There is a positive relationship between innovative investment and corporate performance of forest product firms but a negative relationship between ownership concentration and performance. (2) Ownership concentration negatively moderates the relationship between innovative investment and corporate performance. (3) Innovative investment has a more considerable impact on the performance of pulp and paper than wood-based panel firms; similarly, ownership concentration has a severe impact on the performance of pulp and paper and other forest products firms than wood-based panel firms. (4) Innovative investment has a more significant impact on the performance of state-owned firms than non-state-owned firms. However, ownership concentration only significantly impacts the performance of non-state-owned firms. Therefore, this paper concludes that forest product firms should enhance the awareness of innovation, increase innovative investment and moderately adjust the ownership structure to establish an effective ownership balance mechanism. Moreover, the government should provide stable and supportive policies and regulations to encourage innovative corporate operations.

Interdisciplinary life cycle assessment model for ecosystem services evaluation to achieve resilient, circular economy

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Life cycle assessment (LCA) has proven to be beneficial for economic development and reduced climate burden, and in the last few decades, it has significantly addressed social and technological issues. However, the current analytical LCA approaches are still not able to assess the impacts of anthropogenic metabolism on the ecosystem and its services. The lack of knowledge and data obstruct the interlinkage of the different disciplines to facilitate a more tailored approach to address the complex issues of quantifying ecosystem services and learning the microscopic units of the ecological system to mitigate climate change impacts. It hinders the transition of the Global South from an anthropocentric approach to a greener, more resilient circular economy.

The use of an interdisciplinary model of life cycle assessment (LCA) could advance the analysis of ecosystem services (ES) delivered by nature-based solutions (NBS). This paper highlights the plethora of models and guidelines for selecting suitable models, structures, and frameworks concerning spatio-temporal changes and biological systems. It views LCA beyond the human visual system and calls attention to a dynamic and viable system model for resilient landscapes. It includes additional functions like data, structure for controlled and autonomous systems, critical systems of acoustic and visual systems, perception, and depth. It has evolved from a model to an interdisciplinary integration framework addressing knowledge and socio-technical gaps.

The research stresses the significance of the flow of material and energy, sustainable management rules, and environmental consequences that don’t exceed marginal benefits, but also talks about governance and social aspects. It goes beyond the assumption of fixed coefficients in production and gives rise to a solution for the knife-edge problems of sustainable and resilient forest-based economies.

Nature-based solutions as innovations to enhance sustainability change in the built environment – A literature review

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Bio-based circular economy has been presented as a solution to manage global human-induced problems related to climate change and decline in ecosystem carrying capacity. Nature biodiversity provide well-being benefits for humankind through ecosystem services. Abreast with ecosystem services acquired directly in natural environments (e.g., recreation, collection of berries and mushrooms), ecosystem services may also bring benefits in the built infrastructures through innovations in nature-based solutions. For example, as innovations they may substitute the existing technologies in cooling of buildings or purification of air.

Yet, so far, according to a preliminary literature review on the topic, the interconnections between ecosystem services as sources for nature-based solutions in the built environment and business development in the bio-based circular economy have not gained much of attention in academic research. By employing literature on ecosystem services, innovations and business models as an analytical framework, the overall purpose of this study is to provide information on the existing nature-based solutions, which as innovations may substitute the existing technologies and enhance sustainability change in the built environment. The material of the study is based on peer-reviewed studies, which are collected with systematic review approach and snowball methodology. As methods of analysis, qualitative approaches (e.g., thematization) is being used.

To fill in the void in the existing academic knowledge on the theme, the first aim of the study is to provide information on the current knowledge on the nature-based solutions to enhance sustainability change in the built environment. The second aim of the study is to identify the availability of different types of nature-based solutions in the markets. The third aim of the study is to assess the potential of different types of nature-based solutions in the built environment to create sustainable value for different societal stakeholders (e.g., their potential to substitute the existing technologies). The results of the study will provide new insights on the potential and barriers of nature-based solutions to become established product-service offerings in the markets, which could bring sustainable value for multiple societal stakeholders in the built environment.

Promoting forest-based circular bioeconomy business on marginal lands: Climate impacts and financial profitability

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Forest-based bioeconomy actors are urged to respond to challenges that require climate change mitigation, biodiversity conservation, and the overarching need to understand and promote the overall sustainability of operations. A transition to a more sustainable forest-based bioeconomy necessitates the exploration of resilient and socially just solutions that can simultaneously address these challenges, ensuring environmental integrity, equitable outcomes, and long-term viability for all stakeholders involved. This calls for initiatives that address both climate and financial goals while promoting sustainable rural development.

We present an integrated model for circular bioeconomy business focusing on utilization of marginal land area in Finland. The integrated model comprises short rotation cultivation, wood-based biochar production, and a greenhouse, with integration achieved following circular bioeconomy principles. By leveraging wood and by-product utilization among these actors, we seek to maximize resource efficiency and create a synergistic relationship within the system. To evaluate the integrated model from multiple perspectives, we employ a combination of life cycle assessment and financial analysis, allowing us to gain insights into the design of an integrated circular bioeconomy model that enhances both financial viability and climate change mitigation.

Our model is assessed based on climate impact and financial profitability, comparing the impacts to a non-integrated business-as-usual (BAU) model. The impacts will be addressed from the perspective of each actor separately to understand the equitability of the outcomes too. As such, our research emphasizes the need for more holistic approaches that not only deliver financial viability but also foster social and environmental resilience. This multi-method approach not only contributes to circular bioeconomy strategies for policymakers and offers a scalable case study for practitioners but also generates valuable insights for researchers seeking to explore the potential of other integrated models in the bioeconomy sector.

Regional wood-based construction policy networks: a case of Joensuu, Finland

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Previous literature suggests that wood-based construction (WBC) policy networks confronts inadequate alignment and cooperation at a different level. Even though WBC is prominent for climate change mitigation and achieving global sustainability goals, there is limited understanding of the regional WBC policy network, which are however critical for adopting circular forest-based bioeconomy policies in Finland. This study represents an exploratory case on one frontrunner city in terms of carbon neutrality goal by 2025, Joensuu's regarding WBC, underpinning the policy network analysis theory. Since wooden structures in Joensuu are rapidly ascending, the current study aims to examine and better comprehend the characteristics of policy networks. This study accumulated data utilizing online survey from 2021 and used quantitative Social Network Analysis to investigate the policy network. Our results show that the WBC policy network of Joensuu is moderately dense and mainly consists of research, business, and government organizations. Some of the most commonly mentioned organizations are considered the most influential actors based on different centrality measures. Interestingly, a local hub Business Joensuu, although being a non-profit business and regional development organization, holds a central position in the network. Three groups—government and research, business and industry, and a mixed one—predominantly emerged as a result of the higher frequency of communication in the network. Scientific information and knowledge are the most common resources distributed among policy actors, indicating the network is primarily in the research and innovation phase. Considering the range of policy goal preferences, network actors are most concerned with the pressing issue of climate change mitigation measured by reducing carbon emissions from construction material flow. Future research could progress with comparative case analysis with other municipalities utilizing qualitative approach for value networks and their consequences on policy outcomes, and public procurement for securing circular bioeconomy, and forest-based business sustainability transitions.

Seeds of Transformative Forestry? An Exploration of Innovative Business Models Supporting Fast-Growing Broadleaf Forestry Value Chains

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Forests are the focus of heated debates surrounding sustainability transitions in Sweden. Several streams of research on biodiversity and biomass production point to potential benefits for the Swedish bioeconomy through increasing the amount of fast-growing broadleaf species (FGBs) within the landscape. Efforts to transition this social-ecological system towards greater sustainability and resilience entails a complex interaction of anticipation and action by a diverse array of stakeholders. Such a process includes the development of new values, technologies, and networks to produce bio-based goods and services. Innovation and sustainable business models in the forest sector are crucial to this process, but how do actors come to see FBGs as a source of value for their business and what techniques make the realization of these values possible?

In this project, we interact with fifteen innovative firms across the forest sector, from forest owners to producers of value-added goods, in order to gain insight into how economic, social, and ecological values are ascribed to and produced in FGBs and how these are transmitted through the value chain. Through a series of semi-structured interviews, we conduct an analysis based on sustainable business model archetypes to describe rationales and motivations of innovators' selection of FGBs as a source for sustainable business practices. We discuss how these are operationalized into processes of economic production and how they are translated and transformed through network relationships along the value chain.

Our approach builds on theoretical assumptions about change processes within socio-technical systems from a multi-level perspective. We contribute a novel methodology for engaging with systems transitions from an actor perspective that implements qualitative analysis of business models as a means of exploring the complex processes of social learning within emerging niche-networks and gives insight into innovation diffusion and niche accumulation as driving forces for system transitions.

Seizing new business opportunities? Financial competitiveness and value creation in wood construction element value-chain

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: The outlook of wood construction is widely regarded positive. This is largely reasoned with the various bioeconomy strategies that target to increase the use of wood in construction. Also, regardless of the materials used, industrialization of building processes in an urbanized society has long been considered a requirement for enabling better construction efficiency and competitiveness of construction industry businesses.

However, despite the positive outlook, the use of wood construction components has remained as a promising niche that has not met its full potential. Especially with the strong industrial ties between concrete industry and construction sector, wood construction element (WCE) value-chain needs competitive businesses to enable innovations, implementation of new solutions and to gain larger market share in a strongly competed construction sector. For wood product companies, the shift toward construction sector supply chains has resulted in product and process innovations together with business model development.

To assess the financial competitiveness and value creation in Finnish WCE value-chain, this study uses quantitative methods to analyse and compare annual financial reports of identified wood element manufacturers and sawmills over years 2012-2021. The two industries present important parts of wood construction and therefore their financial status gives indication about competitiveness of the value-chain. The companies in this study are mostly small and medium sized enterprises which were selected to present their corresponding industry. Therefore, for example sawmills with major secondary production were dismissed. This ensures that the companies truly present their part in the value-chain also enabling industry comparison.

The preliminary results suggest that although the financial competitiveness between the industries have been on similar levels, the development over ten-year period has had clear differences. Especially, the solvency and liquidity of sawmills have developed to a more favourable direction compared with WCE manufacturers. On the other hand, value creation reveals clear differences in the industries asset structures. More precisely, the WCE industry is more labour oriented, therefore requiring more employers leading to weaker labour productivity. However, the opposite is true when looking at the value-added by capital employed.

Sustainability as a market opportunity for the cross-laminated timber (CLT) – A literature review on multi-dimensional life-cycle impacts in building

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Market diffusion of the wooden multi-storey construction (WMC) through utilization of engineered wood products (EWPs) brings opportunities to enhance transition towards sustainable circular bioeconomy. Especially the technological properties of the cross-laminated timber (CLT) make it a prominent alternative to concrete and steel used in traditional multi-storey building processes. Building with CLT may induce economic, environmental, social and technological (i.e., multi-dimensional) life-cycle benefits for several stakeholders. For instance, society may benefit from increase in carbon sequestration, businesses from industrialization of building processes, and citizens from more pleasant living environments.

The first objective of this study is to identify relevant information and gaps on understanding the multi-dimensional life-cycle sustainability of building with the CLT. The second aim is to compose a framework to evaluate and communicating the sustainability impacts for different stakeholders. The material of the study is composed of peer-reviewed articles published in international academic journals gathered and analyzed with a systematic literature review approach.

The preliminary results show building with the CLT to offer several benefits contributing to the transition towards sustainable circular bioeconomy. However, the existing research information is neither balanced from the perspective multi-dimensional sustainability assessments, nor in relation to different life-cycle phases of building with the CLT. For example, the existing information mostly addresses economic, environmental, and technological impacts of early life-cycle phases (i.e., material manufacturing and building processes), while information on social impacts and later life-cycle phases (i.e., usage of buildings and re-use, recycling, or disposal) is much scarcer. Yet, to develop new circular business models and create new value with customers by building with the CLT, more comprehensive life-cycle sustainability information would be required.

Key words: forest bioeconomy, circular economy, wooden multi-storey construction, innovations, business renewal

Sustainable value creation in the forest-based sector: a literature review

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Sustainability transitions such as the transition to circular bioeconomy challenges traditional forest-based sector and the way it operates. Specially, companies within the sector should contribute to climate change mitigation, biodiversity loss and societies' well-being while providing income to the shareholders. So far, the traditional forest-based sector has been considered path-dependent and locked-in to specific technologies which could hamper its ability to renew. Similarly, the sustainability of the sector is increasingly contested in science and public discussions despite the efforts to sustainability reporting and compliance with certifications. Hence, there is a need for new sustainable business models and value creation within the forest-based sector through which companies could increase the well-being of both ecological and social systems by sustaining business activities. So far there is a great amount of research regarding the sector's value creation, and a thorough picture is needed. Thus, the aim of this systematic literature review is to provide profound information on how sustainable value creation is considered in the diverse literature regarding forest-based sector. Our data consists of 73 peer-reviewed articles, book chapters and conference papers. The preliminary results indicate the economic dimension in value creation has dominated the literature whereas environmental and social dimensions have started to emerge within the past ten years. Three-dimensional perspective on sustainable value creation has been studied most in the past five years. The social dimension has been studied the least. Value creation is especially measured and monitored on monetary terms and the value of environmental and social dimensions are considered more on conceptual level. Based on our categorisation, business model, servitization and value chain are the three most used theoretical perspectives to consider value creation. Overall, more empirical research is needed to understand sustainable value creation and realisation of environmental and social values. Hence, a systemic perspective on value creation which includes aspects of social and environmental dimensions should be emphasized in future research. Furthermore, there is a need for inter-disciplinary approach in studying and assessing sustainable value creation and here several different theories, methods and tools could be applied to enhance the sector's contribution to sustainability transitions.

The Industrial Development of Forest Biomass Utilization for Bioenergy to Advance a Circular Forest Bio-economy: A Holistic Analysis Framework

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Forest biomass utilization for bioenergy has been a critical part of the development of the circular forest bio-economy. A holistic analysis framework including forest-biomass facility siting, forest biomass supply chain optimization, techno-economic analysis and life cycle assessment of forest biomass utilization for bioenergy, was developed to aid in the industrial development of forest biomass utilization for bioenergy over the eastern United States. The results indicated that, 30 industrial sites were identified as the top priority sites for forest biomass-based bioenergy industry development in the high-suitable areas which accounted for 24.26% of the total area of the eastern U.S. The delivered cost of forest biomass to these identified sites ranges from $41.90 to $50.17 per dry Mg with an average of $44.77 per dry Mg, while the stumpage, harvesting, storage, preprocessing, and transportation accounted for 34.66%, 45.54%, 0.0004%, 5.58%, and 14.21% of the total delivered cost, respectively. Furthermore, for the forest biomass utilization for four alternative value-added bioenergy products in the eastern US, the minimum selling price is $177.82/Mg for pellet fuel, $110.24/MWh for biopower, $1059.4/Mg for biochar, and $4.98/Gallon for aviation fuel. The life-cycle Greenhouse Gas emissions are 149.80 kg CO_2 eq./Mg pellet fuel, 52.22 kg CO_2 eq./MWh biopower, 792.12 kg CO_2 eq./Mg biochar, and 2.13 kg CO_2 eq./Gallon aviation fuel, respectively. Considering the uncertainties, the 95% confidence intervals of minimum selling prices range from $164.77 to $190.97 /Mg for pellet fuel with an 81.85% probability to be profitable, from $100.20 to $120.21 /MWh for biopower with a 49.38% probability to be profitable, from $1000.91 to $1109.25/Mg for biochar with a 79.51% probability to be profitable, from $4.86 to $5.54/Gallon for aviation fuel with an 0.03% probability to be profitable. The minimum selling prices of pellet fuel and biochar are much less affected by market changes than those of biopower and aviation fuel. However, the production of biopower and aviation fuel has lower carbon intensities than that of pellet fuel and biochar. This study could comprehensively inform the decision-makers regarding the industrial development of forest biomass utilization for bioenergy to advance a circular forest bio-economy in the eastern U.S.

Tracking environmental performance using life-cycle assessment of hardwood product production

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: In recent years, life cycle assessment (LCA) has become one of the most effective tools available for assessing and reducing the environmental impacts of products. This study used LCA to track the environmental performance of hardwood products produced in the U.S. The hardwood product sector in the United States has undergone major changes in the last two decades. These changes have negatively and positively affected the utilization of hardwoods. U.S. hardwood production has declined substantially because of both imported finished wood and nonwood products along with the cost competitiveness of domestic softwood species as replacement for industrial products like pallets. Contrarily, technology changes for hardwood product manufacturing have mostly improved the environmental footprint of these products. These environmental improvements have been quantified and tracked for two hardwood products (plane dried lumber and industry average pallets) using LCA. For cradle-to-gate production of planed dry hardwood lumber in the northeastern/north central and southeastern U.S., thermal energy consumption decreased from 5,800 to 3,876 and from 4,678 to 2,733 MJ/m^3, respectively while global warming (GW) impact decreased from 187 to 166 but unexpectedly increased from 134 to 209 kg CO_2e/m^3, respectively. For wood pallets, cradle-to-grave GW impact for new pallet production was 4.88 kg CO_2e per industry-average pallet compared to the value of 0.355 kg CO_2e for an industry-average repaired/remanufactured pallet. The reduction of GW impact for repairing wood pallets underlies a huge reduction of embodied carbon emissions which in part comes from lower requirements of raw materials such as roundwood while keeping current wood in circulation to the best extent possible.

Wooden elements for beauty, utility, and low carbon building stock – Co-creating sustainable innovation with four case municipalities of Finland

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Solutions nurturing low carbon building stock are urgently needed in the municipalities. Novel innovations emerge with wooden prefabricated elements, which offer new opportunities for a versatile, nature-based municipality landscapes to both new wooden multistory construction and retrofitting the existing multistory buildings. These new solutions with wood and with their high ambition level can have synergies with both saving natural resources and circular economy.

To co-create such transformative low carbon solutions, four case municipalities in Finland were involved in development processes. These included a municipality workshop series with altogether seven municipality workshops organized between 2021-2023. Simultaneously, this workshop process was enriched by expert suburban walks in which the local actors provided practical and contextual knowledge on developments made and planned with wooden elements. Research method is based on service design approach, innovation studies and a dash of futures studies. The study builds on innovation theories and human-centered, transformative service-design theories. The multi-actor co-design process involves researchers, practitioners and other stakeholders for a dual suburban/rural approach and seeks for holistic, feasible and acceptable carbon-wise housing solutions in case municipalities. The data consists of workshops and interrelated city walk discussions, i.e., documented in transcribes, posters, notes, and photos as well as background materials, such as consumer interviews, diaries, and municipality strategies.

Preliminary results indicate that instead of creating a wide pool of new service ideas, the process leads the way for ideas and solutions to intertwine supporting the systemic innovation uptake. When bringing the experimentations to practice, few pathways were favored. Some municipalities envisioned pathways relating to the reasonable retrofitting practices, which have synergies with novel innovations with wooden retrofits. One case municipality was keen on promoting intertwined information actor networks pathway and took steps to linking municipality land use zoning actors. Results can be used for more in-depth service development to foster sustainability among municipalities in Finland and beyond.

Woodshed Mapping: Assessing Feedstock Availability, Economic and Environmental Impacts, and Attracting Investment and Identifying Locations

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Managers and decision makers are often tasked with accomplishing large landscape level goals with limited resources. While policy mechanisms like tax incentives and cost-sharing can accomplish landscape scale goals, it is also important for managers, decision makers, and the landowners themselves to understand market coverage and competitiveness for the harvested wood products available on the landscape. This is simply because they don't create revenue to help offset total project costs. The woodshed maps demonstrate where market 'hotspots' occur, highlights areas best suited to invest in, from both an industry, forestry professional, and policy perspective, and which wood products industries are most likely to succeed. It focuses on wood products and categorizes them into three main types: sawlogs, pulpwood, and biomass, and can be used for feedstock assessment, evaluating economic and environmental impacts, and optimizing the supply chain to support decision-making for management, investment, and policy formulation. Woodshed allows users to generate maps for different aspects of the market. A demonstration of the woodshed mapping tool and various applications will be highlighted. Current research application of woodshed maps includes feedstock assessment and economic impacts of increased biopower, biochar, and mass timber production in the Great Lake States. This approach also estimates the available wood in each logger's basket (service area), assesses competition and analyzes the logging sector. Finally, this approach will also be used to evaluate interstate forest product dependency and carbon leakage with varying policies between the adjoining states.

"Living with nature as the nearest neighbor" – Values related to nature in Finnish citizens' housing expectations

T2.14 Innovations and new business models towards more sustainable circular forest bio-economy, especially including life-cycle and techno-economic assessments

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Abstract: Human-nature connections in the built environment have multiple benefits related to physical health and mental well-being, and proximity to nature has started to become more important also in defining citizens' housing preferences. People value nature in diverse ways, and in forest rich and scarcely populated Finland, nature has also always been a significant part of the citizens' national identity. Yet, there is still limited information on the values Finnish citizens attach to nature in relation to other housing attributes. This study investigates the conceptualization and the role of nature in citizens' housing expectations in Finland. The data were collected in 2022 with an online questionnaire sent to randomly sampled 10,000 people aged 18–80 living in Finland. In this study, an open-ended question related to sub-section of data on citizens' wishes and hopes for housing with 382 responses was utilized and analyzed with qualitative methods (e.g., thematization, content analysis).

The preliminary results show that having a home near nature is important to half of the respondents. They especially emphasize living near forests, lakes, and the coast. Furthermore, citizens attach different values to nature in their housing expectations, including intrinsic, instrumental, and relational values. Also, other types of values (e.g., emotional, social) are recognized. The results provide new information on the meaning of nature in Finnish citizens' housing expectations. Recognizing the importance and value of nature in housing also provides opportunities for new innovations, such as developing different nature-based solutions to substitute the existing technologies, e.g., in living milieus.

T2.15 Innovations to support sustainability in non-timber forest products value chains

"Inov'Açaí" - Co-construction of knowledge, Innovations and Public Policies for the Sustainability of Community Production in the Amazon Bioeconomy.

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: The açaí value chain in the Brazilian Amazon brings together a wide variety of local, national and global markets, articulating research and development institutions,gatherer families, informal entrepreneurs, artisanal and industrial entrepreneurs, around production and commercialization. Since 2017, açaí is the product with the highest production value in Brazil, in the subgroup of non-wood vegetable extraction foods. This article presents the research agenda and results of the "Inov'açaí" research group, organized on two fronts; political and technological. The studies focused on the community-based açaí chain in the Pará municipalities of Abaetetuba and Santa Luzia do Pará and, in the State of Amapá, in the municipality of Mazagão and in the Bailique Archipelago. The first front of analysis addressed public policies and international cooperation while the second collaboratively proposed intervention in production and commercialization processes through the use of technologies and social innovations. The objective was to promote the co-construction and transfer of knowledge and technologies between the public sector, international organizations and civil society, producers and researchers for the elaboration, execution and diffusion of innovations and strategies of nature-society interactions for a sustainable and inclusive development in the chain. The guiding questions were: What strategies, with a strong positive impact on the production, processing and community-based commercialization of açaí, have producers, their organizations and local governments been developing and how do international cooperation agreements and the implementation of the SDGs support them? How, based on the demands of cooperatives and community-based agroindustry, can technologies make production visible, add value to the product and maximize the use of waste? The actions on each front were organized into specific tasks based on the methodological approach of action research and quali-quanti techniques, in addition to laboratory research. The results already achieved were: mapping of action strategies within the scope of public policies - coordination, execution and bottlenecks - as well as in relation to international cooperation projects; identification and application of technologies and social innovations linked to the study of the forest collection and the productive capacity of the açai groves, as well as bio(technologies) for the reuse of açaí seeds.

25 years of non-timber forest product value chain and livelihoods interventions: Experiences, impacts and lessons from Cameroon

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: Cameroon represents "Africa in miniature" with high levels of forest cover but increasing rates of deforestation, and variable but common use of forest products for multiple subsistence and commercial uses. Despite the national development situation moving from low to medium level development status, rural poverty remains high, particularly among marginalized societal and ethnic groups, and is associated with forest product use, dependence, commercialisation and social-ecological resilience.

Over 25 years of development, conservation and research interventions have sought to support "sustainable" commercialization, value chain development, alternative livelihoods, cultivation and domestication of non-timber forest products (NTFPs)in Cameroon. Over this period, narratives on NTFPs, value chain development, rural development, forest-people relationships, justifications of interventions and impact logics, measurements of impacts using top-down or science based-knowledge - have changed little. Indicators of the effectiveness of interventions, such as changes in prices, profits, value adding, harvesting practices, cultivation rates, resource availability, empowerment, deforestation and conservation have been mixed. This raises questions of what have been the legacy and impacts of such interventions in the long term? What has changed, for who and why? What's worked and not worked? What lessons can be learnt from evaluating successes and failures of intervention concerning NTFPs on livelihoods and ecosystems – looking at the (un)expected outcomes and impacts? and, what do these lessons imply for future policies, projects, programs and interventions?

This article examines the evidence by taking a long-term view identifying 10 projects/programs, and then involving the beneficiaries and implementers in evaluating long-term socio-economic, political (governance and policy) and ecological outcomes and impacts of these interventions. The discussion is conceptualized in terms of Sustainable Livelihoods Approach and Social-Ecological systems thinking (i.e. impacts on both livelihoods and -ecosystems of the landscapes where these products originate from) and taking a value chain approach to look at direct (and indirect) actors in NTFP value chains and interventions. Implications for scientific research, local knowledge and practices, and policy will be presented.

Boosting Forest Value with Non-Timber Forest Products and Extended Management: An Examination of South Korea's Practices

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: Despite South Korea's commendable green transition, the limitation of its forestry development lies in the low profitability of timber-focused practices. It's clear from Net Present Value (NPV) and Land Expectation Value (LEV) analyses that exclusive reliance on timber yields inadequate returns. However, the incorporation of the 2022 direct payment for forestry system and the exploration of non-timber forest products have shown significant potential to enhance forestry income. The direct payment system alone amplified the income derived from Japanese larch and Korean pine by five and nine times, respectively. Moreover, the inclusion of non-timber forest products lengthens the cultivation period, yielding a substantial increase in overall revenue. When cut at the optimal age of 70 years, the income from timber production of Japanese larch and Korean pine multiplies 40 times and 12 times, respectively. In addition, extended forest management periods amplify the public value of forests. By taking into account aspects such as direct payments, non-timber products, public value, and optimal cutting age, the economic value of Japanese larch and Korean pine forests skyrockets 48-fold and 29-fold, respectively. Overall, moving away from a strictly timber-oriented approach to a diversified production model, in conjunction with lengthier forest management durations, considerably augments profitability and enriches the non-market values of forests.

BOOSTING THE SUSTAINABILITY OF THE MONTESINHO NATURAL PARK OAK FOREST THROUGH INNOVATION AND VALORIZATION OF ACORN AND HONEYDEW

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: In the Montesinho Natural Park one of the most abundant and relevant types of habitat are oak forests dominated by Pyrenean oak. Current knowledge concerning this species mainly focuses tree growth, while there is a clear lack of research regarding acorn, a product with growing market demand for the production of flour and derivative products. Topics of interest cover yield, biology, edaphoclimatic drivers, and acorn abortion, the latest a limiting factor for both forest natural regeneration and development of new products. The Acorndew project aims at minimizing these knowledge gaps.

This work summarizes results obtained from the data collected between 2021 and 2023 in four monitoring sites (altitude varying from 600m to 1000m). The surrounding area was subject to forest and acorn inventory, showing a quite dense forest with 527 to 5858 trees.ha^{-1} (average 2905). The following research topics were addressed: i) acorn yield, availability and abortion rates quantification; ii) relationship between altitude, forest composition, forest structure and light availability and the variables in i). Light availability was characterized at tree level using the Clark index, which was then used to compute weighted stand variables.

Results show a large inter-annual variability of acorn availability, with 2021 (severe drought conditions) showing lower values compared to 2023. Significant inter-site variability was also observed: 0 kg.ha^{-1} to 896 kg.ha^{-1} (average 154 kg.ha^{-1}) considering only fully developed acorns in 2022, and 0 kg.ha^{-1} to 1230 kg.ha^{-1} (average 225 kg.ha^{-1}) considering all sampled acorns. The proportion of acorn abortion was found to vary between 74% and 90% out of the total number of sampled acorns, with phenology monitoring indicating abortion mainly occurred from mid-July to mid-August. Stand characteristics showed a weak correlation with the dependent variables considered, in particular due to the presence of three outliers in the data set. The correlation with these variables is higher considering only the acorns sampled in stages prior to full development, raising the hypothesis of mature acorn predation.

Future work focus on the study of the interaction between stand variables and light availability, and on the identification of pathogens possibly involved in the high percentage of acorn abortions.

Development of a science-based system of allocating Almaciga resin in the Philippines

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: Harvesting of almaciga resin is a major source of livelihood for indigenous peoples in the Philippines. A permit is required prior to harvesting and it indicates the annual harvestable volume, which is based on an inventory and computation using operable area and average number of tappable trees per ha. Some tappers relayed that they harvest more resin than their annual allowable volume, suggesting an oversupply of resin. However, there is no baseline study that could support whether these claims are true. With these, the study investigated the tapping practices and resin yield of three (3) groups of tappers in Southern and Northern Palawan and Davao Oriental. A total of 281 trees were measured for location, diameter, height, crown width and frequency of harvest (3 and 6 months) and were subjected to a year-long monitoring of resin yield. For monitoring, local tappers were trained on how to properly weigh, record, document and report their resin harvests and local coordinators verify the reports. The tapping practices of the three groups were also documented and compared. Results of the study shows that tree diameter and frequency of tapping affect resin yield. In Davao Oriental, the average tree diameter is 37 cm with an average tree height of 16 m, growing at an elevation of 200 to 600 masl. In Northern Palawan, the elevation is between 400 to 700 masl and the average tree diameter and height is 56 cm and 20 m, respectively. Bigger trees can be found in Southern Palawan with a mean diameter of 91 cm and height of 19 m and are found in an elevation of 700 to 1000 masl. Resin yield for 3-months frequency harvest range from 0.72 to 4.58 kg per tree depending on the location and diameter size. On the other hand, resin yield for trees harvested every six months range from 1.99 to 8.92 kg per tree. These results could serve as baseline in determining the actual resin yield of Almaciga trees and will serve as significant input in developing a science-based determination of annual harvestable volume towards the sustainable production of Almaciga resin.

Forest ecosystem services conservation focusing on social-ecological dynamics of non-timber forest products in Japanese horse chestnut populations

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: In order to develop conservation strategies for forest ecosystem services, this research aims to evaluate the conservation value of tree populations from an interdisciplinary perspective, focusing on the social-ecological dynamics of non-timber forest products (NTFPs) in Japanese horse chestnut populations (*Aesculus turbinata* Blume). First, based on the hypothesis that naturally variable forest ecosystem services are culturally and socially stabilized through the maintenance of populations, I systematize the sustainable conservation mechanisms of NTFPs and the local knowledge for conservation that has been newly developed by the private sector in recent years. Second, in order to quantitatively understand the conservation effects of the populations, I compare and evaluate the ecological-economical effects of harvesting or utilization of non-timber forest products, such as nuts gathering and honey production, with those of harvesting and utilization of woody materials such as wood craft and furniture. Third, to model and generalize conservation strategies for forest ecosystem services, I collect case studies of the social-ecological dynamics of Japanese horse chestnut populations on a national scale and conduct a comparative analysis of the commonalities and differences in population conservation.

Impact of commercialization, a serious drops in NTFP production from Natural Forest: Proposed Innovative Mechanism to reconcile the sustainability

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: The contribution of non-timber forest products is highly precious for rural people.NTFP resources are considered as a pathway to achieve bio-economy and are much more relevant for developing countries. Our natural forests have some limited ability to supply products that are used for the supply of medicine, food, cosmetics, and various other purposes. In the South Asian region where population pressure is very high and rural poverty is rampant, the NTFP-based enterprise is considered as a popular model for rural livelihood development.

But in a recent NTFP-based livelihood generation project in India, the ground reality was different, the ecological security of the forest is under serious threat due to over and untimely harvesting of NTFPs, low regeneration of tree species, forest fire, weeds infestation,climate vulnerability, and limited rainfall. In the last five years, there is a reasonably big project in the name of the '*Van-Dhan'* (forest wealth) innovative scheme introduced by the central government in 20 states with a proposed layout of 200 billion rupees business in rural areas based on NTFP collection, processing and value addition. The creation of the new local institution of 1205 new*'Van Dhan Vikash Kendra* (NTFP development center), 18075 self-help group (SHG) with 3,61,500 members in the collection and processing network dealing with 55 products.

The current exploratory survey in 34 sites in 9 states of India, shows that such commercialization plan of NTFPs cannot be successful in the long run as there is no backup support for explicit resource base management. There is a dichotomy in the approach, only the maximum collection, processing, and value addition were focused on assuring minimum support price (MSP) to collectors. Such a forest-based scheme has no future, as the NTFP supply has reduced from most forest divisions(about 60-200%). The organic link between conservation and sustainable utilization is difficult due to a reduction in the volume of supply and one-sided planning. To address the above challenges, it is suggested that enrichment planting, assisted natural regeneration, rotational harvesting, creating the people's protected area (PPA) as well as application of certification may be useful for the sustainable flow of natural products.

Innovating in cone mechanical harvesting to boost Pinus pinea cropping

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: Stone pine (*Pinus pinea* L.) is a Mediterranean species that produces the most expensive nut worldwide. In Chile, the species cropping is considered an emergent business, with over 4,000 hectares planted for pine nut production in the last years. In this country, stone pine trees show vigorous growth and high cone productivity, being relevant advancing in the efficiency of cone harvesting under different site conditions and plantation characteristics. Three harvesting trials were performed to evaluate mechanical and manual harvesting in one traditional 46-year-old plantation and in two grafted orchards (12 and 13 year-old) located in central Chile. Mechanical harvesting was run with an Orchard-Rite shaker (US) considering different levels of pump flow rates (38% to 65%) to avoid harvesting 1- and 2-year-old conelets developing simultaneously on the tree; and one and two vibrations of 3 second duration each; and constant 2,200 rpm. Manual harvesting was performed by a long- experienced Spanish professionist with poles from the ground and/or by climbing the trees. Tree size was measured before harvesting. Recorded variables included number of harvested 1-, 2- and 3-year-old cones, 3-year-old cones remaining on the trees (non-harvested), partial and total time of harvest per tree, and damage to branches, trunk and soil. In the traditional plantation, mechanical harvesting was significantly faster than the manual one; the percentage of mature harvested cones ranged from 60% to 100% of total cones. However, mechanical harvest is not feasible in all site conditions, including sandy soils. In grafted orchards, mechanical harvesting, a worldwide innovation, showed a good performance (70% to 100% of total mature cones harvested), without damaging the trees. Manual harvesting allows a complete tree harvesting (98% to 100% of total mature cones harvested). The obtained results contribute to the stone pine cropping intensification.

Reimagining Mayan Forest Gardens: Linking forest conservation to sustainable livelihoods through 'analog' forestry systems in the Yucatán of Mexico

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: The 10 million ha Mayan Forest ecosystem in the Yucatán of México is the second largest area of tropical forests in the Americas and home to Mesoamerica's largest indigenous population, sustaining thousands of indigenous families and farming communities. The Yucatán Peninsula is losing forest cover every year due expansion of intensive agriculture and coastal development, threatening biodiversity and traditional livelihoods. To address forest loss, government officials have set ambitious goals to achieve net zero deforestation, but innovative, science-based solutions are needed to address competing needs for forest conservation, sustainable agriculture and concerns about impacts on indigenous farming. Here, we describe new research on innovative 'analog' forest systems, which aim to strengthen rural communities, both socially and economically, by emphasizing conservation of forests through sustainable cultivation of high value, organic forest crops. These experimental analog forest systems are modeled after Mayan "forest gardens" with an initial focus on cultivating organic vanilla in natural forests and forest honey production in coastal mangrove systems. In both systems, pollination and honey production are derived from indigenous, forest-dependent bee species to investigate the potential to restore connections between forests, bees and human livelihoods. The experimental emphasizes the importance of community engagement and participation at each stage of the research process. Here, the community partners are women's groups interested in conservation, sustainable livelihoods, and equitable benefit sharing within communities. The possibility of communities obtaining additional income from forest carbon credits associated with forest gardens is also discussed.

The bark side of tree utilization

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: Bark protects trees against insects, browsing by game, forest fire and mechanical damage. In addition to its protective function, bark transports nutrients, stores carbon and reduces water evaporation and hence fulfils multiple functions.

During the processing of timber in wood industries, up to 170 million m³ of bark is produced annually worldwide and is considered a by-product or waste product: mostly for energy generation through incineration or as bark mulch. Due to these large quantities and the simultaneously low added value as well as its multifunctionality, bark is seen as a material with high potential to increase the raw material efficiency within a cascading utilisation. For this purpose, in-depth knowledge of the accumulating quantities, the composition and structure of bark and innovative utilisation options of bark from different tree species is indispensable.

Therefore, several studies on bark of native tree species (especially pine, oak, larch) were carried out. The investigations focused on 1) bark thickness, structure and bark volume, 2) carbon storage in bark, 3) processing techniques including weaving and flexibilisation of bark for design applications and 4) development of options for the production of binder-less bark panels.

The results have shown that 1) the bark thickness in pine pulpwood is very thin due to the high proportion of logs with mirror bark and 2) the carbon fraction in pine bark decreases with increasing tree height. Furthermore, 3) textile/ (design) applications, such as a jacket made of bark, were designed and 4) new approaches for the production of binder-free bark panels from bark pieces of different native tree species were conceived.

Both the resource availability of bark and the innovative possibilities for utilisation (in connection with long-term material utilisation and corresponding carbon sequestration) show the high potential of tree bark, which should be researched in more detail and thus exploited especially in times of a strongly growing bioeconomy.

The miracle mix of Moringa: Status of Moringa research and development in Malawi

T2.15 Innovations to support sustainability in non-timber forest products value chains

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Abstract: *Moringa oleifera* and *Moringa stenopetala* are grown in Malawi in different agro-ecological zones. *Moringa oleifera* is the most widely cultivated pan-tropical species of a monogeneric family, the Moringaceae, regarded as versatile because of its ability to provide edible food, oil and purify water for local communities. The tree is sometimes referred to as a "Miracle Tree" because of nutritional and pharmacological properties. Despite its great importance, *M. oleifera* is still not well exploited and hence considered as underutilized in Malawi. Natural distribution of *M. oleifera* in Malawi and elsewhere reveals rich variability in fruit types of semi-domesticated populations. Distribution pattern among others has had an influence on domestication trends in Malawi in terms of diversity. Despite the great variability of *M. oleifera*, there is no properly established genebank or database with either cultivated or spontaneous accessions in Malawi and elsewhere. Absence of elite varieties adapted to local conditions and use of seeds obtained through open pollination from planted plants are some of the major factors that limit productivity. In Malawi, there is limited knowledge of available genetic diversity present in Moringa species to warrant serious breeding programmes for meaningful scaling up. Furthermore, commercialization of *Moringa* products in Malawi is still very informal making it difficult to get reliable information of production volumes and prices thereby making it unattractive for scaling up. There is however a growing interest to upscale *Moringa* species distribution nationwide. *Moringa oleifera* is fairly distributed in specific agro-ecological zones of Malawi and easily adapted to new sites. This offers an opportunity to be planted much more widely by introducing the species within the existing farming systems as the species can also survive in degraded soils. As such, increased use of the species could have a positive impact on the nutritional and health status of people of Malawi.

T2.16 Innovative technologies for the development of bamboo and rattan products

A Multi-Faceted Net Zero Biorefinery for Production of Bamboo Pulp

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Wood pulping technologies, invented in the1800s for paper and materials production, continue to be utilized today. These methods involve chemicals to dissolve a majority of the hemicellulose and lignin present in wood, generating the desired pulp product. While chemicals used in the process can be recycled, hemicellulose and lignin are typically burned during the chemical recovery phase.

Traditionally, there has been limited value in recovering the hemicellulose and lignin, making burning them the most practical and profitable approach. However, increasing energy prices and a growing demand for carbon-neutral fuels such as sustainable aviation fuels (SAF), are currently making the recovery and conversion of these materials highly desirable.

As market dynamics shift and interest in establishing biorefineries in developing nations increases, technologies have evolved to prioritize pulp production and the recovery of hemicellulose and lignin. This shift, accompanied by the transition from laboratory-scale experiments to commercially viable operations, necessitates multidisciplinary partnerships capable of maximizing value and streamlining complex supply chains.

EcoPlanet Bamboo, in collaboration with technology provider Comstock Fuels, is spearheading the development of bamboo-based biorefineries in Latin America, Africa, and Asia. EcoPlanet has established a resource base of climate-positive bamboo on degraded lands. Comstock's patented biorefinery technology leverages purpose-grown bamboo biomass to produce pure bamboo pulp and BioleumTM, a converted mixture of hemicellulose and lignin used as feedstocks for SAF production. The bamboo pulp has demonstrated properties comparable to the highest grade of Northern Bleached Softwood Kraft pulp, while BioleumTM can serve as a substitute for crude oil in refineries, enabling the production of carbon-neutral or even negative-emission transportation fuels.

The production of approximately 100 gallons of carbon-neutral transportation fuels is anticipated per ton of bamboo pulp (production yields are currently undergoing testing and confirmation). This increases revenue for the pulping operation and contributes significantly to advancing the journey towards a carbon-neutral economy.

This presentation will delve into the technology itself, outlining the plans for its implementation across our expanding portfolio of sustainable bamboo resources. Moreover, it will address the challenges that have been overcome to establish a platform capable of scaling and replicating this unique multidisciplinary partnership.

A novel mechanical kiln for bamboo molded charcoals manufacturing

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: To upgrade the industrial techniques of bamboo molded charcoals (BMCs), a novel mechanical kiln was designed with the new heating method, high pyrolysis efficiency, and reuse of self-release gaseous. In this research, BMC-1 and BMC-3 were produced by novel mechanical kiln with pyrolysis temperature 650 °C and 389°C. BMC-2 was produced by brick kiln with pyrolysis temperature 680 °C. Proximate analysis, kinetic parameters, Cone Calorimetry, and X-ray fluorescence were used to investigate the energy properties and ash fusion characteristics of BMCs. It was concluded that the efficiency of novel mechanical kiln was increased by 320.44%, compared with brick kiln. The physical and mechanical performs of BMCs were improved by novel mechanical kiln. The ash, fixed carbon and moisture content of BMC-1 and BMC-3 met the requirements of EN 1860-2:2005. All BMCs had a stable combustion process, but BMC-1 and BMC-3 owned a higher reactivity and a lower mean yield of CO (1.78 kg/kg) and CO_2 (15.12 kg/kg). In addition, the novel mechanical kiln increased the content of SiO_2 and reduced the content of alkali metal in ash samples, resulting in variation of fusion characteristics and reducing the risk of fouling. These findings will be helpful to provide a scientific guidance to optimize the manufacturing process of BMCs.

Advancements in Bamboo Products as Sustainable Substitutes for Plastic

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: The alarming environmental issues caused by plastic pollution have garnered global attention. From 1950 to 2018, about 6.3 billion tons of plastics have been produced worldwide, 9% and 12% of which have been recycled and incinerated, respectively. More than 70% of the plastic products is accumulating in landfills or sloughing off in the natural environment as litter, at some point, much of it ends up in the oceans. By 2050, oceans might contain more plastics than fish in terms of weight. The accumulation of plastic waste in landfills and natural environments, including oceans, has reached unprecedented levels, highlighting the urgent need for sustainable alternatives. Bamboo, with its versatile properties and numerous applications, has emerged as a promising substitute for plastic products. This study provides a comprehensive overview of the recent developments in bamboo products as substitutes for plastic items. Various sectors, including industrial cooling towers, soil reinforcement, automotive parts, composite pipes, electrical appliances, sports equipment, medical products, and daily necessities, have witnessed significant progress in utilizing bamboo as a sustainable alternative. The wide range of bamboo-based products explored in this study has the potential to alleviate plastic pollution and contribute to a more sustainable future.

Analysis of International Trade Status and Potential of the Products Concerning "Bamboo as a Substitute for Plastic"

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: The global bamboo and rattan industry has developed rapidly over the past 20 years, with more and more bamboo and rattan products and application functions. As a kind of non-scarce environmental resources, the global flow of bamboo and rattan products is a good carrier for countries to balance economic benefits and environmental effects. The soil and Marine environment have been seriously polluted, and posed a serious threat to the earth ecology and human health due to the large use of disposable plastic products. The Chinese government and the International Bamboo and Rattan Organization jointly launched "The Bamboo as a Substitute for Plastics Initiative", which is a major strategic measure to deal with the global plastic crisis. The international trade of products concerning "Bamboo as a Substitute for Plastic" is an important impetus for this initiative. Products concerning "Bamboo as a Substitute for Plastic" in the international trade market have a new opportunity with great potential for development.

This study presents the current global situation of products concerning "Bamboo as a Substitute for Plastic" through the visual analysis of the data from the United Nations commodity trade database, including trade scale, trade market and trade structure. Moreover, this study compares and analyzes the global international trade of plastic products, and puts forward the international market opportunities. The results show that: the current global quantifiable trade value of products concerning "Bamboo as a Substitute for Plastic" has been growing rapidly, showing a strong international market demand. Asia, Europe and North America are the main trade areas, and China is the largest trading country of products concerning "Bamboo as a Substitute for Plastic". Bamboo articles of daily use, bamboo tableware and kitchenware and bamboo panels for construction are the most potential products in international trade concerning "the Bamboo as a Substitute for Plastics Initiative". At present, the global consumption of plastic products is high, and the demand for plastic replacement is large. The results can provide support for facilitating the development of international trade and strengthening international cooperation in the field of trade policy.

Analysis on the Development of World Bamboo Industry under the Framework of the One Belt and One Road Initiative

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: The bamboo industry, as a recognized green sunrise industry in the 21st century, has received high attention from the international community. The bamboo industry plays an important role in increasing farmers' income, promoting targeted poverty alleviation, and transforming development methods. It also makes positive contributions to maintaining global ecological security, addressing climate change, and promoting green growth. China has set a positive example in the development of the bamboo industry, playing an important leading role in promoting the development of the world's bamboo industry. However, the development of the global bamboo industry still faces many difficulties that need to be addressed urgently.

The development of the global bamboo industry is still uneven, with relatively high levels of development in Asia, led by China. The development direction and product types of the bamboo industry in Latin America are relatively single, and Africa is just in the early stages of development, and there is an urgent need for improvement and improvement in all aspects. Different countries attach varying degrees of importance to the bamboo industry, and many countries have just realized the importance of bamboo industry development, and many policy documents have not yet been issued. The scientific research and development of bamboo in most countries are insufficient, and there is a shortage of professional researchers and skilled workers, which greatly restricts the development of the bamboo industry. Under the framework of the "the Belt and Road", bamboo producing countries can, with the help of international organization resources and projects, strengthen capacity building, promote the flow of bamboo resources and technology, formulate support policies, guide regional demonstration, drive scientific and technological innovation, and strengthen talent training, which is an effective way to promote the development of bamboo industry in countries along the "the Belt and Road".

Anatomical Changes in Bambusa spinosa Roxb. induced by Alpha–Naphthalene Acetic Acid

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Bamboo has been ascending as one of the alternative materials for economic, social, and environmental activities. Recently, the advancement of propagation methods with mining soil interventions is still developing and progressing in literature for possible bioremediation purposes. This paper highlights the leaf and root anatomical response of *Bambusa spinosa* Roxb. planted in a mined-out soil treated with Alpha-Naphthalene Acetic Acid (ANAA – 0 ppm, 100 ppm, and 200 ppm) in LNL Archipelago Minerals Incorporation, Zambales, Philippines. The 3rd leaf and average-sized root were collected from each treatment and underwent freehand sectioning using a stainless blade. A microscopic investigation was performed using a compound microscope (Olympus CX21FS1). The photomicrographs taken were analyzed in ImageJ (version 1.54b) to measure the anatomy of leaves and roots. R (version 4.2.3) was used for data analyses considering the 95% confidence interval. Results revealed that the treatments increased the leaf anatomy, such as the thickness of silica bodies and plicate cells and sizes of bulliform cells, xylem, phloem, and fusoid cells, excluding only the total epidermal thickness. It was also observed that treatments induced changes in root anatomy, including the increased thickness of the epidermis, sclerenchyma layer, cortical cells, endodermis, and pericycle, as well as the sizes of pith, phloem, protoxylem, and metaxylem. These results significantly contribute to the efficient and effective propagation method of bamboo in sites with heavy metals due to mining activities. This paper also entails the importance of *B. spinosa* as a bioremediation species and promotes thorough economic development of the bamboo industry in the country.

Keywords: *ANAA, bamboo, leaf anatomy, root anatomy, mining sites*

Bending and shear performance of a cross-laminated composite consisting of flattened bamboo board and Chinese fir lumber

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Bamboo-wood composites are effective for utilizing the mechanical properties of bamboo and fast-growing wood resources. Investigation the application of flattened bamboo in engineering structures provides added value to bamboo resources. This paper analyzes the flatwise bending and shear properties of cross-laminated bamboo and timber (CLBT) panels consisting of flattened bamboo boards and Chinese fir lumber. A three-layer cross-laminated timber (CLT) panel made from Chinese fir lumber was used for comparison. The mechanical properties of the CLBT and CLT panels in the major strength direction were obtained through experimental tests, and theoretical and finite element models were developed to predict the panels' bending stiffness and strength. The calculated values were compared with the experimental data. The results showed that the failure modes of the three groups of CLBT panels were similar to those of the CLT panel and were predominantly rolling shear and bonding delamination. The bending strength and modulus of the CLBT were higher than that of the CLT. Increasing the number of layers of the flattened bamboo board improved the maximum bending moment and bending stiffness of the CLBT. The bending stiffness and strength of the CLBT/CLT obtained from the finite element model were in better agreement with the static test values than the theoretical model values. The results of this study provie new information for future engineering applications and the structural design of CLBT.

Keywords: Cross-laminated bamboo and timber (CLBT); Flatwise bending performance; Shear performance; Flattened bamboo board; Chinese fir lumber.

Changes of cell wall structure and chemical components during biodegradation of moso bamboo

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Biological pretreatment of lignocellulosic plant cell wall gains increasing attention due to its advantages of being environmentally friendly, less energy consumption and fewer by-products. However, the mechanism of the biodegradation of cell walls is not fully understood. In order to explore the structure and chemical changes in moso bamboo (*Phyllostachys edulis*) due to microbial degradation, 4.5-year-old moso bamboo was degraded by brown rot fungi (*Gloeophyllum trabeum*) and white rot fungi (*Coriolus versicolor*). The structure and chemical composition were observed through high-resolution imaging and spectroscopy. The results show that during the same period of fungal degradation, the vessels were broken most seriously, followed by the parenchyma cells, while only a small number of mycelia perforation was found in the fiber cells in the later stage of degradation. Mycelia mainly spread between cells through pits, and at this time, the extracellular enzymes secreted by mycelia degrade the cell wall, resulting in the further enlargement of pits and the formation of perforation. The fungal degradation of cell walls is a complex process. The degradation of each chemical component by fungi is carried out simultaneously, but at different rates. After 16 weeks of biological pretreatment, the relative content of cellulose in the cell wall decreased less than that of hemicellulose, lignin and ethanol extraction. White rot fungi had a stronger degradation effect on lignin and preferentially degraded S lignin. During pretreatment, relative crystallinity changed with the degradation of crystalline cellulose and other amorphous substances by fungi. The crystallinity of bamboo treated with brown and white rot fungi increased after 16 weeks. This study characterized the chemical changes in moso bamboo due to biodegradation, which will provide a reference for the efficient utilization of lignocellulose and bioconversion.

Effect of temperature on the structure and properties of rattan carbon-encapsulated iron particles

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Biomass-based carbon encapsulated nanomaterials is the proposed new carbon material with potential for commercial development. The inherent pore structure of the rattan is more conducive to the direct penetration of the metal salt solution, which can create an effective combination of carbon and metal source. In this study, rattan carbon-encapsulated iron particles were prepared by one-step pyrolysis using *Plectocomia himalayana* Griff. rattan as carbon source and ferric nitrate as metal source, and the effects of six pyrolysis temperatures (600, 700, 800, 900, 1000, 1100 ºC) on the structure and properties of the carbon coated nanoparticles were investigated. The results showed that the core/shell boundary was obvious, and the particle size was uniform when the temperature was 1000 ºC. When the temperature was 600 ºC, no core/shell structure was formed and the product was a mixture of carbon and Fe_3O_4, and the core/shell structure of carbon encapsulated iron nanoparticles could be prepared when the temperature was 700 ºC and above. Meanwhile, the phase of the core was mainly α-Fe and Fe_3C at 700-900 ºC, while it was mainly α-Fe with the increase of temperature. When the temperature rose to 1100 °C, the hollow carbon shell increases, and the proportion of complete carbon cladding structure was less. The saturation magnetization as well as increased with the increase of temperature, and the coercivity decreased with the increase of temperature, showing a better ferromagnetism. The adsorption effect of methylene blue showed the best at 1000 ℃, the maximum adsorption capacity was 186.22 mg/g, corresponding to the specific surface area of $135.29 m^2 g^{-1}$. This study indicated that using rattan as the carbon sources prepared by in-situ one-step pyrolysis at the 1000 ℃ could obtain the carbon encapsulated nanoparticles with uniform size and structure. This study provides a way to development of high value-added products of low-quality rattan.

Engineering Bamboo lumbers and its Utilization in buildings

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Bamboo, fast-growing tree grasses, is a cultural and ecological feature of many countries in Asia, America, and Africa. Comparing with trees, bamboo has a faster growth, shorter rotation, bigger yield, higher strength and better fiber, besides, bamboo can be used renewably and is sustainable once planted, which can provide environmental, social, and economic benefits. At present, there are nearly 10,000 bamboo products constituting over 100 series now being used in more than 10 fields, such as architecture, decoration, furniture, papermaking, packaging, transportation, medicine, food, textile and chemical industry. In this study, we present the resource and distribution of bamboo resource, introduce bamboo mechanical qualities, bamboo based Engineering materials and utilizations, especially substituting bamboo for plastics. Aside from its economic benefits, Bamboo has enormous positive implications on environment – reduced deforestation, carbon emission reduction and other improved ecosystem services. The global applications of bamboo and its products have a sustainable and greener future.

Life Cycle Assessment of Structural Glued Laminated Bamboo Products

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Since 2000s, engineered bamboo products have gradually gained commercial importance in the international market. Glued laminated bamboo products used for structural applications in buildings have been well demonstrated in China for many years while the development of international standards for structural uses of engineered bamboo has evolved steadily in recent years. Currently, no database includes data on environmental impacts of structural glued laminated bamboo. The aim of this study is to provide reliable life cycle inventory data based on current industrial practices in China and make them available to global users. This study was developed in collaboration with international IGO, universities, manufacturer and will be supported by ecoinvent with the goal of integrating the data within the ecoinvent database. The life cycle inventory data for production of structural glue laminated bamboo products, was analyzed using the impact assessment method of IPCC 2021. Further considerations for biogenic carbon storage were assessed using the method GWPbio. Several strategies for the reduction of environmental impacts during the production process were tested, showing that the carbon footprint of these products can be reduced without major changes to the current practice in the industry.

Micro-propagation and Development of high yielding new bamboo variety BFRI bamboo BB1 of Bangladesh.

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Abstract:

Bamboo is emerging as one of the most important 21st century crop, since it produces food and wood. It is one of the fastest growing, annually renewable and harvestable plants with highest productivity and short harvesting cycle. It has a great potential in poverty reduction, industrial and sustainable development in rural areas. It also playing important roles for preserving our environment i.e. soil conservation and flood control, soil health, river bank protection, wind break etc. Bangladesh has 37 bamboo species. Among them *Bambusa balcooa,* local name (Borak bans) is one of the important thick wall village bamboo.

Tissue culture protocol of *Bambusa balcooa* was developed from branch nodal bud culture and produced bamboo seedlings for mass propagation and wider distribution in 2002. *In vitro* multiple shoot production of a single shoot was optimized and observed a vigorous growth in culture media. Each shoot produced a mini clump within 2-3 weeks with maximum shoots in the culture vessels. The rooted shoots were transferred in soil for hardening under green house. The hardened plantlets were produced profuse multiple shoots and grew luxuriantly in polybags. Field trails were done at different locations of the country in 2005. Performance of the tissue culture produced bamboo seedlings was observed at different locations and it was found promising. A three years old clump of BFRI bamboo BB1 produced maximum number of culms which was recorded as 30.40 nos in the field. This value is at least three times higher than the rhizome produced clump of the parental stock. Average culm height and diameter was recorded as 19.30 m and 7.70 cm respectively which is also higher than the rhizome produced clump of the parental stock. With the proper management, each seedling formed a clump within 3-4 years of planting with maximum numbers of new bamboo. Seedling survivality in the field level was 100%. No infection of diseases was observed. Later on the developed bamboo variety was multiplied for mass production and wider distribution among the farmers. The new variety was conserved at BFRI bambusetum and farmers field as a source of germplasm for future use.

Multiscale analysis of bamboo viscoelasticity response due to partial hemicellulose removal treatment

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Hemicellulose degradation can improve the dimensional stability but decrease the stiffness for nature materials. In order to restrain the cracking/deformation phenomenon of bamboo products, the viscoelasticity response that a critical role in nature material processing and applications, were analyzed after hemicellulose removal treatment. The gradient structure-viscoelasticity relationship of bamboo has been obtained. In addition, a better flexibility treated method for bamboo material also has been indicated. The bamboo stem was cut into three slices and treated with hot water, steam, and acid. The outer slice, i.e., bamboo green, had the best strength and flexural toughness. Middle slice had higher viscoelasticity and best flexibility. Inner slice, also called bamboo yellow, had the best anti creep property and bad strength or modulus. The flexural toughness and flexibility of all three treatment groups increased. The acid group had more viscoelasticity response, and the increased deformation mainly recovered over time, which increased the flexibility of cell walls of macro bamboo. The water group and steam group had more elasticity response, and the increased deformation mainly recovered immediately, especially for water groups. This paper could be a reasonable selection support of bamboo materials for stiffness or flexible products.

Nutritional assessment of bamboo shoots from selected species growing in Kenya

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Bamboo are among the fastest growing multi-purpose plants on the planet with over 10,000 documented uses. Bamboo shoots is one of these uses and are delicacies for numerous communities in Asia, Africa and Latin America. However, information on proximate and mineral composition of bamboo shoots is scanty despite being used as vegetables in some parts of Kenya. In this study nutrient levels of five selected exotic species were evaluated namely; *Dendrocalamus giganteus*, *Dendrocalamus membranaceus*, *Dendrocalamus asper, Oxytenanthera abyssinica* and *Bambusa vulgaris* growing in Kenya. It was hypothesized that bamboo shoots are rich in nutrients of importance to human health. The shoots were collected from Nyahera, Nguriunditu and Karura in Kisumu, Kiambu and Nairobi Counties respectively. The samples were analyzed for proximate composition, minerals, vitamin, moisture content and calorific values using standard procedures. The moisture content for the shoots ranged from 89.9% to 92.1%. Results expressed in dry weight basis showed that crude fiber ranged between 17.6% and 34.8 %, protein content between 18.9% to 38.7%, ash content between 9.3% and 12.8%. On wet weight basis, vitamin C ranged between 2.03 and 4.17mg/100g, riboflavin from 0.02mg/100g to 0.05/100g, niacin (B3) from 0.19mg/100 to 0.08mg/100g while in *O. abyssinica* was below the detection limit of the equipment (of 0.01mg/litre). The shoots further recorded the minerals on wet weight basis as follows: magnesium content ranged between 0.09mg/100g and 3.31mg/100g, aluminium between 28.27mg/100g and 47.34mg/100; calcium between 2.33mg/100g and 31.25mg/100 while in *O. abyssinica* was below detectable level. Iron ranged from 0.83mg/100g to 5.31mg/100, copper from 0.15/100 to 0.19mg/100g and zinc ranged from 0.10mg/100g to 1.95mg/100. The sodium content ranged between 4.49mg/100g and 9.51mg/100g, potassium between 1.77mg/100g and 236.73mg/100g. Their calorific values on dry weight basis ranged between 393.99Kcal/100g and 464.86Kcal/100g. The findings on the nutritional content in terms of fibre, protein and minerals make bamboo shoots a potential meal of consideration for Kenyan households.

Preparation and Characterization of Cellulose Nanofibrils from Bamboo Holocellulose and Its Usage as Reinforcement in Starch Nanocomposites

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: The development of bio-based materials from renewable plant resources, crops, and their by-products can be done to circumvent environmental issues related to the use of petroleum-based products. Among the natural biopolymers, starch has been considered the most promising material due to its low cost, biodegradability, and renewability. Therefore, starch has been converted into a thermoplastic starch (TPS) by appropriately mixing with water or some plasticizer (e.g., glycerol, sorbitol). However, disadvantages attributed to the hydrophilic properties of TPS in starch-based nanocomposites lead to poor mechanical properties. To overcome such limitations, using mineral or cellulosic fillers (e.g., clay, glass fiber, cellulose nanofibrils) as reinforcing agents in TPS is an effective solution.

Bamboo belongs to the family of grasses and is considered an alternative source of non-wood raw materials due to its easy propagation, wide distribution, availability, fast-growing nature, short rotation, and high productivity. This work oxidized bamboo holocellulose by TEMPO-mediated oxidation system using the 2,2,6,6-tetramethylpiperidine-1-oxyl. Then the oxidized celluloses were converted to individual cellulose nanofibrils by mild mechanical treatment. After oxidation, the weight recovery ratio of TEMPO-oxidized bamboo holocellulose (TOBH) was 73%, with a carboxylate content of 0.65 mmol g-1. The water-insoluble TOBH was converted to an aqueous dispersion of bamboo TEMPO-oxidized cellulose nanofibrils (TOBCN) through mechanical defibrillation and centrifugation, with the nanofibrillation yield of around 90%. Transmission electron microscopy (TEM) indicated that the widths of TOBCN were estimated to be between 3 and 4 nm and lengths of several micrometers. The TOBCN dispersions had high light transparencies of 99% at a wavelength of 600 nm. These nanofibrils were used as reinforcing nanoparticles in thermoplastic starch (TPS) films. The TOBCN dispersions were added in dosages of 0, 0.3, 0.6, 0.9, 1.2, and 1.5 wt%. Glycerol was used as a plasticizer. Nanocomposite films were prepared through a solution-casting process. The TOBCN/TPS nanocomposite films exhibited high optical transparencies, and their tensile strength, Young’s modulus, elongation at break, and work of fracture increased compared to the TPS films without TOBCN. The presence of TOBCNs, at 1.5 wt%, improved moisture resistance. The work demonstrates the potential of using bamboo cellulose nanofibril as reinforcement in nanocomposite materials.

Research on high-yield clean pulping technology of bamboo

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: China is the country with the richest bamboo resources in the world, with a bamboo forest area of 7,562,700 hm^2, accounting for 1/3 of the world's total bamboo forest area, but 80% of which has not been effectively utilized. In order to develop a comprehensive utilization technology for bamboo pulping and papermaking with high utilization rate, low consumption, high added value and clean production process, the main bamboo species in China, moso bamboo and sinocalamus affinis, were selected as research objects. The unbleached chemi-mechanical pulp process was used to study the pulping performance of bamboo by appropriately increasing the amount of NaOH in the impregnation section. The results showed that after two stages of extrusion and two stages of impregnation of the chemi-mechanical pulping process, in the impregnation section of NaOH dosage of 10%-15%, the pulp yield was both about 80%, the yield of sinocalamus affinis was slightly higher than the yield of moso bamboo. The electricity consumption required to produce chemi-mechanical pulp with Canadian standard freeness(CSF) 300mL was both less than 350 kWh/BDT, and the bulk thickness was both between 2.1 and 2.5 cm^3/g, which showed that the softening effect of the fiber was good and the electricity consumption was relatively low with high chemical dosage. The strength performance of sinocalamus affinis pulp was much higher than that of moso bamboo pulp. When the amount of NaOH used for impregnation was 12%, the tensile strength of sinocalamus affinis pulp with the CSF of 300mL reached more than 28 N.m/g, and the tear strength was even better, up to more than 6.0$mN.m^2/g$, almost close to the tear strength of bamboo chemical pulp. The tensile strength of the corresponding moso bamboo pulp was only 12N.m/g and the tear strength was only 2.5$mN.m^2/g$. Corrugated base paper and household paper made from moso bamboo and sinocalamus affinis pulp can meet the requirements of the corresponding standards. With the development of bamboo pulping and papermaking technology, it is expected to alleviate the shortage of wood fiber in the paper industry.

The Bamboo City, a new urban architechture that brings back natural element

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: The bamboo city emphasis the relationship between human and nature, the buildings harmonizes with the surrounding natural environment. The construction focuses on sustainability and environmental protection, encouraging residents to interact with nature.

As the population of the world continues to grow, there is an increasing demand for new and innovative approaches to urban planning and development. One feasible approach is the construction of bamboo cities, which offer a sustainable and environmentally-friendly alternative to traditional building methods. The Bamboo City can provide a sustainable solution to the growing problem of urbanization and provides a healthier and more livable environment for residents. The concept includes urban large-scale public buildings and small-scale urban facilities such as public benches, garbage cans, street lamps etc., so as to replace steel or concrete instead. In addition, it can satisfy furniture and houseware function and household necessities, which can be fabricated with bamboo to some extent. Moreover, The Bamboo City could also rich in culture and be vibrant in trade, culture, and healthy lifestyle.

Bamboo is a fast-growing, renewable resource with good environmental properties, its related product could be widely used alongside modern city development, providing solutions for building a green and low-carbon urban and rural environment. In the future, cities around the world may use bamboo as an essential building material. By expanding the application of bamboo could boost the development of bamboo industry and increase employment.

One of the challenges in building bamboo cities, however, is the need for innovation and technology in building techniques. It is important to ensure that bamboo structures meet both safety and code standards without compromising its sustainability and environmental impact.

In conclusion, the bamboo city offers a sustainable and eco-friendly approach to urban development that has the potential to revolutionize the way we build our cities. And as innovation and technology continue to develop, we could explore new ways to create sustainable urban infrastructure and buildings that not only benefit the environment but also the health and well-being of their residents.

The Contribution of Bamboo to livelihood improvement in Cameroon

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: Bamboo sequesters 1.33 times more carbon than trees. The global market value of bamboo products is around €50 billion. Cameroon has about 1.2M ha of bamboo, second largest area in Africa after Ethiopia, a mix of indigenous and species introduced in colonial times. Bamboo contributes to the livelihoods of c.31,000 people, earning on average €708 annually for harvesters, craftspeople and sellers albeit these incomes are generally below poverty benchmarks. The potential for this grass to contribute further to livelihoods and to mitigate climate change however is under-realised due to a lack of, and inappropriate policy, and insufficient data. This study investigates the socio-economic contribution of bamboo for value chain stakeholders. Using an adapted Poverty Environment Network questionnaire and the Sustainable Livelihoods framework, a total of 233 interviews were conducted (9 village surveys, 128 harvester households in major bamboo production areas, 41 processors and traders and 55 consumers). Quantitative data was analysed using descriptive statistics, aggregation and extrapolations to estimate the sector's importance to stakeholder's livelihoods and economy. An innovative framework coupling Social-Ecological Systems focusing on the resource system, resource units, governance system, users and outcomes, will be used to analyse socio-economic benefits for direct (and indirect) value chain stakeholders and interventions. This data will be presented and how it will be used to provide input to a sectoral policy to be co-developed with bamboo value chain stakeholders, which considers trade-offs between the goals of conservation and climate change mitigation and development. Implications for scientific research, local knowledge and practices, and policy will be presented.

The distribution characteristics of vascular bundle and bending mechanical properties of Dinochloa orenuda in Hainan Island

T2.16 Innovative technologies for the development of bamboo and rattan products

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Abstract: *Dinochloa orenuda* is widely distributed in Hainan Island, China, climbing growth, the slender culms similar to rattan. To explore the feasibility of using it as furniture material, the density, vascular bundle morphology, bending strength and modulus of culms at different heights were investigated. The density of culms increased from the base to the tip, which was between 0.47~0.56g/cm^3. From outside to inside of the wall, four types vascular bundles of undifferentiated, semi-differentiated, broken waist and double broken waist were successively distributed, the distribution density and individual size gradually decreased and increased, respectively. With the increase of culms heights, the bending strength and modulus of each segment was slightly increased and relatively stable, respectively, which is different from the mechanical properties of some scattered bamboo. The stable modulus is due to the tiny axial variation of the vascular bundle distribution density and the wall thickness. The results show that *Dinochloa orenuda* has stable mechanical properties and cross-sectional dimensions, which is similar to the rattan and can be used as a new type of furniture material in its original form.

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

HARNESSING EMPERICAL AND INDIGENOUS KNOWLEDGE TO CONSERVE AFRICAN JUJU TREE, OKOUBAKA AUBRVELLEI PELLEGR. & NORMAND

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: *Okoubaka aubrvellei* Pellegr. & Normand (African Juju tree) is a rare totemic and hemi-parasitic tropical rainforest tree endemic to the Guinea-Congolian region of West/Central Africa. This mono-generic, non-pioneer light demander – highly revered because of its reputation for killing neighbouring trees – is currently very rare in Nigeria. Following its classification as endangered species on the IUCN Red list in 2015, we conducted two diagnostic investigations (ecological/phyto-demographic and socio-economic) in seven Local Government Areas (LGAs) located in the rainforest region of Edo State, Nigeria. First, inventory of relic tree population was carried out in the wild while count of natural regeneration was done under a matured mother tree. For the socio-economic study, responses were elicited from primary participants (local field staff of the Edo State Ministry of Environment (n=21) using the snowball sampling technique alongside questionnaire and key informants' interview. Recommendations from the primary participants were used to assess/elicit information from secondary participants: herbal practitioners/users (n=76) in 14 local communities, and vendors (n=38) of *O. aubrevillei* products in five markets in a metropolitan Council Area. Data were analysed using descriptive statistics. The results of diagnostic inventory revealed 13 individuals with *ca.*70% carrying various degrees of harmful lacerations/scars on their boles. For natural regeneration, 11 juveniles were counted under a mature mother tree while *Myrianthus arboreus* was the only tree found in cohort within 12m radius of all the species encountered. The results of socio-economic study revealed 135, mostly male adult respondents (87%) with average age of 54 years. Majority of the respondents (94%) opined that the species possesses magical powers; and that the tree bark is most harvested owing to its high demand and use in ethnomedicine (68%). Participants attributed the accelerated decline of *O. aubrevillei* population to harvest pressure (43%) and habitat loss (48.1%). While the key outcome of the diagnostic study was the affirmation that the species regenerates *in situ;* most respondents (76%) asserted that the mystical powers and ecological idiosyncrasies of *O. aubrevillei* can sufficiently sustain its ultimate survival in the wild without human assistance.

Intangible benefits of the forests: local ecological knowledge of plants for cultural ecosystem services in Western Ukraine

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: The use of plants for cultural purposes is a little-covered corner of biocultural diversity that has developed through time within a complex socio-ecological system. Ukraine is rich in both biological and biocultural diversity. One of the ways to interact with nature is to use plants for rituals, while rituals are complex interactions between humans and biodiversity shaped by history, culture, and ethnic belonging. Yet, in Western Ukraine, such rituals have been forbidden for over 50 years (1939-1991). The current revival of rituals by rural inhabitants is an untapped reservoir of local ecological knowledge. The aim of the present study was to identify the use of wild and cultivated plants for cultural purposes in two regions of Western Ukraine, Bukovina, and Roztochya, and to compare the findings with historical data.

Forty-seven face-to-face semi-structured interviews were conducted in the summers of 2018 and 2019. We document the use of plants for various ritual purposes in two ethnic groups of Hutsuls in Bukovina and Ukrainians in Roztochya. Based on interviews we identify seven holidays for which people used the diversity of plants both wild and cultivated. Our results show the re-emerging of those local ecological practices.

Among Bukovinian Hutsuls, we documented the use of 26 plant taxa while in Roztochya we recorded the use of 58 plants in 7 festivities (of which two were celebrated differently in both communities). Plants were mainly used in bouquets, but also for decorating churches, houses, or fruit baskets. We discuss the attitude, importance, and knowledge sources of those practices.

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Local Ecological Knowledge of Rattan species for sustainable livelihoods and forest management: Empirical Evidence from Ngambe-Tikar, Central Cameroon

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: Rattan is an important non-timber forest product (NTFP) supporting the livelihoods of millions of indigenous people in the tropics. In the West and Central African sub-regions, there are 22 rattan species, with Cameroon harbouring 19 of these 22 species. Local Ecological Knowledge (LEK) plays an important role in the harvesting, processing and trading of these rattan species in Cameroon. Despite the important role LEK is playing, limited research has been carried out to ascertain the importance of LEK of different rattan species to livelihoods and the sustainable forest management in Cameroon. This study fills this void. Data were collected mainly through a random survey of 120 households involved in rattan harvesting, processing and trading in Ngambe-Tikar, Centre Region of Cameroon. This was complemented by key informant interviews, focus group discussions and direct field observations. Findings reveal that LEK is used by the indigenous people to determine the different commercially important rattan species which are: *Eremospatha macrocarpa*, *Calamus deerratus*, *Laccosperma secundiflorum*, and *L. Robustum*. The maturity of the rattan species is determined by looking at the colour, size, thickness, and length of stems, as well as the presence/or not of thorns. Using these criteria for maturity ensures that only the well matured stems are harvested, thereby ensuring sustainability. LEK equally aids the indigenous people to know which species are more abundant and which species are experiencing dwindling supplies. LEK helps the communities to know that their forest is disappearing as scarcity of rattan is associated with forest loss. This motivates the local community to take measures towards limiting forest degradation notably by limiting slash and burn farming which is one of the main drivers of forest degradation in Ngambe-Tikar. LEK positively correlates with livelihood improvement and sustainable forest management as indigenous persons endowed with more LEK are involved in the sustainable harvesting, processing and trading of rattan products such as baskets, chairs, tables, caps, beds, sieves, TV stands, Couch/Sofa, cupboards, wardrobe, flower jars. Thus, LEK enhances understanding of the livelihood benefits derived from rattan species which pushes the community to conserve rattan and the forest from where the rattan is harvested.

Local knowledge of acorn collectors for sustainable management of oak forest ecosystems in Turkey

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: Oak forests in the Mediterranean basin is provider of various goods and services such as (1) biodiversity; (2) agroforestry and silvopasture systems for the production of fodder and pasture; (3) wood for materials and energy; (4) acorn-based foods and beverages; and (5) other uses such as the manufacture of drugs and extraction of tannins for the leather industry. The "Palamut" mountain, which takes its name from the “acorn” in Turkey, is the region where the existence of various oak species and closed stand forest forms are observed. Also, traditional acorn harvesting from *Quercus ithaburensis* still continues. The initial findings of the socio-economic research work package on acorn collection are as part of an ongoing project led by the Marmara Forestry Reseach Institute of General Directorate of Forestry. The social purpose of the project is to compile local information about acorn collecting and to investigate the basic motivations of the people living in the Palamut Mountain region for sustainable management of oak forests. Through face-to-face interviews with 384 local people, engagement in acorn collection, both presently and in the past was obtained. According to the findings, 16% of the participants are currently active acorn collectors. A significant proportion, 36.5%, have never been involved in acorn collection. Furthermore, 47.5% of the respondents indicated that they used to engage in acorn collection in the past but have since discontinued this activity. 30% of previous acorn collectors reported discontinuing their activities within the past five years. Participants primarily attributed the decline in acorn collection to two key factors: the lack of acorn buyers and buyers offering low purchase prices. Participants who had engaged in acorn collection on their privately-owned lands revealed that 83% of them opted to convert their lands into agricultural areas by felling oak trees after discontinuing their collection activities. Conversely, 17% of participants reported cutting down oak trees on their lands to create grazing areas for livestock, designating them as pasturelands. Additionally, the research examined the participants' views on agrosilvopastoral systems. It has been determined that the level of local knowledge does not adequately support integrated systems today.

Measurement and Influencing Factors of Willingness to Accept Compensation for Ecosystem Service Provision: A Case Study of a Leading Forest Farm

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: The Saihanba Forest Farm as a leading planted forest enterprise is an essential ecosystem services provider for the Beijing-Tianjin-Hebei region in China, the efforts of which in successful afforestation and landscape restoration have been recognized internationally awarded with the Champion of the Earth by the UN. However, few studies have focused on the value of ecosystem services from the provider's perspective. Understanding the providers' attitudes towards ecosystem service and willingness to accept compensation is crucial as it might affect the quantity and quality of ecosystem services provided in the future. In this study, a questionnaire survey was conducted among the staff of the Saihanba Forest Farm, the contingent valuation method was applied to measure their willingness to accept compensation for providing forest ecosystem services. A two-hurdle regression model was applied to analyze the influencing factors, and a tobit model was used for validation. The result indicated that the mean willingness to accept compensation was CNY 9800.84 (USD 1458.28) per hectare per year. The expected compensation increased with the age, education status family size. The variables of the number of families employed and cognition of payment for ecosystem services were negatively associated with willingness to accept the value. Among respondents who opted willing to accept compensation, those who realized the concept of payment for ecosystem services bid lower compensation amounts. The findings are meaningful for quantifying forest ecosystem services and promoting payment for environmental services for landscape restoration.

Non-timber forest products (NTFPs) as safety net in the era of COVID-19: Evidence from Northern Ghana.

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: The role of non-timber forest products (NTFPs) as safety net for the rural poor who use and depend on forest resources is widely acknowledged. However, this acknowledgement is often in the context of risks induced by seasonality, climatic change and environmental degradation. The global COVID-19 pandemic and the associated public health measures taken by national governments adversely impacted both local and national economies and people across the globe. In the same vein, the pandemic has also shed light on the safety net function of NTFPs during severe and unexpected events. In this paper, we expand this understanding by drawing on literature on safety net function of natural resources (including NTFPS) and field data collected in Northern Ghana. Overall, we underscore the role of non-timber forest products as a source of livelihood and food security for rural dwellers during the pandemic in Northern Ghana. Our findings support and build on previous research to underscore the significance of non-timber forest products as shock-absorber in crises periods and highlight policy implications for stakeholders in the forest sector as the world continues to "build back better."

Review and documentation of plant natural products and indigenous knowledge in Eastern and Northern region of Kenya.

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: The paper reviews and documents information on plant natural products and indigenous knowledge in Kenya. Reports on ethnobotanical studies of different communities in Kenya especially in the North Eastern parts of the country are meagre despite their extensive use. The threat of extinction of the knowledge on herbal medicine by factors such as deforestation, lack of proper regulation, over exploitation, land use tenure and changing socio-cultural issues warrants an urgent documentation of the information to preserve it. The study targeted the ASALs communities in Eastern and North-eastern of Kenya which include the Kambas, Somalis, Boranas and Rendilles. Data on various plants species, part of the plant used, natural products, uses, method of preparations and administration by these communities were gathered through desktop review of various journals, books, published theses and in different electronic databases including science direct, Medline, Google scholar, Web of Science, AJOL, Kenyan university websites and libraries. The data was tabulated and analyzed. The documentation contributes to safeguarding indigenous knowledge on medicinal and plants natural products in the study areas, which is useful for the development of data base in order to avoid the loss of this important knowledge. The paper recommends documentation of indigenous knowledge on medicinal and other natural products in the remaining Counties in the Northern Kenya, where there's limited information.

Key words: "medicinal", "spices", "food", "fodder", "pesticidal", "plants of Kenya", "ethnobotany of Kenyan communities", "traditional medicinal plants of Kenyan communities".

Rural communities' views on woodland benefits in Guinea-Bissau: the importance of wild edible plants

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: The West African woodlands provide an immense range of benefits to the livelihoods of many rural households inhabiting the region, but they have been severely degraded due to various land use pressures and climatic changes. While many studies in West Africa have evaluated woodland goods and services, few studies explicitly make the diversity of local people's values the focal point of research, which has been deemed critical for planning sustainable management strategies.

Using a sociocultural approach that combines focus group discussions and walk-in-the-woods in 20 villages located in the north of Guinea-Bissau, our research investigates how rural communities of different ethnic groups value the nearby woodlands and perceive vegetation trends.

We found that Wild Edible Plants (WEPs) are an important woodland benefit for all ethnic groups, particularly in times of food shortages, and that all perceive their declining availability due to woodland clearance for the establishment of cashew orchards. Differences in the benefits cited as important were more evident between farmers (Manjack, Balanta, and Mandinka) and pastoralists (Fulani) groups. For example, all famer groups showed the symbolic connection with the woodlands linked with the existence of *irãs* which are spiritual entities that inhabited those places (not mentioned by the Fulani).

Fulani consume a higher diversity of WEPs, including more root tubers and leafy vegetables, but apart from the WEPs most traded in urban markets (which are also managed locally), an imminent dietary change was noted with reduced WEPs consumption in response to the increased availability of rice (the main staple in the country).

Our study highlights the need for further in-depth studies of local people perspectives and values surrounding the West African woodlands. This will allow a better understanding of the possible synergies and differences that can be further promoted to sustainably manage this ecosystem. Specifically, we argue for the urgent need of adapting woodland management to account for the provisioning of wild foods.

Significance of local ecological knowledge, experiences of non-timber forest products for sustainable forest management in Chilgoza forest, Pakistan

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: Non-timber forest products(NTFPs) are vital for subsistence and meeting the source of daily nutrition and household food security in Pakistan. In Chilgoza pine forest ecosystem more than 2300 NTFPs are harvested as the livelihood of million of poor is heavily dependent upon the utilization of NTFPs due limited other options of earning in the poverty affected rural areas. According to an estimate more than 85 percent of the population get the livelihoods from the Chilgoza Ecosystem.

Throughout the human history these products are being used for a variety of purposes including food, fodder,, fiber, traditional medicine and several other uses. In Covid 19, the NTFP provided additional income to the local people due to its high demand. The wildlife is also a key NTFP in the pine ecosystem.

Due to the high level of dependency of the local on the NTFPs, they have plenty of traditional ecological knowledge and experiences regarding the sustainable utilization of NTPs. The local female population is the main stakeholder and direct beneficiaries of NTFPs and they have the required ecological knowledge and best practices to cope with the changed situation resulted from the external factors like socio-economic condition, natural disasters and climate change.

Under the GEF Chilgoza Project" Reversing deforestation and degradation in high value Chilgoza pine forest in Pakistan" at the start of the project a comprehensive survey was conducted to know the status of the various NTFPs, the potential and opportunities for their scientific utilization. Some key NTFPs were identified including Chilgoza pine nuts, variety of medicinal plants and mushrooms. The project first organized the local communities in the form of NTFP conservation and Management Committees. They developed a community based NTFPs utilization and management strategy, where the local knowledge, experiences, and best practices have been incorporated. The project provided to these communities the required tools and training to better utilize the NTFPs for greater economic return. The market linkages were also established for better prices. The local community is registering this product (pine nuts) as Geographical Indication(GI) to protect this product for the local communities and get better prices in international markets.

Socio-economic drivers, intergenerational disconnect, lack of interactive governance & more: Addressing challenges in unsustainable harvesting of NWFP

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: The recently released IPBES assessment on Sustainable Use of Wild Species highlighted overexploitation as a major threat to many wild species and endorsed the need to integrate inclusive actions at multiple scales, employ participatory processes, build interactive governance approaches and support context-specific adaptive management. As a lead author for the assessment I propose this case study Central Himalayas where natural forests are a vital support to local subsistence providing diverse provisioning services. This includes food, fodder, leaf litter and crop support to local communities. Over generations harvesting of NWFP by the communities in the region was well supported by local and traditional knowledge systems that included informal calendars for harvesting dependent on seasonality of NWFP and also rotational harvesting to ensure sustainable use of wild species. However over the years enhanced commercial tourism, emmigration of local people for education and livelihood, reduced livelihood opportunities, socio-economic drivers, loss of intergenerational connect and deforestation have severely affected these practices. There is a disconnect observed between nature-people relations too because of loss of rights on their nearby forests that is widening. Present study provides an overview on NWFP harvesting that includes fodder, leaf litter and wild edibles by locals and their related temporal use calendars, taboos and the entire process supported by informal governance of women welfare groups that for ages ensured sustainable harvesting of NWFP in Garhwal part of Uttarakhand state in India. Study highlights with examples how the drivers of loss especially local socio-economics, migration from villages, intergenerational disconnect and lack of interactive governance approach that have resulted in loss of age old traditional practices has affected sustainable harvesting leading to loss of resources. Study will also highlight the relevance of NWFP based livelihood resource centres and community based seed banks especially for lesser known underutilised wild edibles for developing domestication models for future as potential future food, nutraceutical and medicinal support for human well-being. Temporal calendars needs to be preserved and can be a relevant contribution to NWFP policies that has so far been ignored but has the potential to help improve acceptance of these policies by local communities.

The argan (Argania spinosa (L.) Skeels) forest and the innovative use of its products for the sustainable development of rural communities in Morocco.

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: Argan tree is endemic of arid environments of Middle and Southwestern Morocco, where it forms natural forests, providing multiple socioeconomic and cultural benefits for the local communities since ancient times. Starting from 1980s, Argan oil has been appreciated by international cosmetic industry, becoming one of the most expensive vegetal oil, increasing the anthropic pressure on argan forest in addition to environmental shocks. The argan forest was declared a Biosphere Reserve by UNESCO in 1998, while in 2018, a part of it was included in the GIAHS (Globally Important Agricultural Heritage Systems) Programme by FAO. Although the socio-economic benefits of the argan oil are well known, a comprehensive assessment of the threats and opportunities related to the argan forest is limited. This systematic literature review identifies the main threats for the argan forest as well as opportunities related to innovative uses of argan non-wood forest products, with attention on its role for the sustainable development of rural communities.

Results show that the argan forests is facing high pressure from several human activities (overgrazing, growing demand for argan nuts, land degradation), combined with socio-economic inequalities and difficulties in argan tree propagation. However, innovative use and recycling of the waste deriving from argan nuts processing offer promising opportunities for supporting a local forest-based bio-economy. Argan press cake can integrate livestock feeding, produce nanocellulose for sudan dyes extraction, or innovative bioplastics. Argan nut shells among other benefits can be used to produce environment-friendly and low-cost purifying materials for a wide range of chemicals and pharmaceuticals and as a source of bioenergy. Argan pulp can be used for obtaining bioethanol or natural insect repellent, providing a product diversification to local women cooperatives by adding value to a by-product currently considered an agricultural waste.

Despite the promising opportunities, the impact of innovative uses in terms of socio-economic development and ecological preservation is still limited, because of lack of operational programs that stimulate applications of research results in local management and development strategies. Resilience empowerment of argan socio-ecosystem require inclusion of local population through integration of local ecological knowledge and science-based solutions in consistence with communities' values.

The Contribution of Non-Timber Forest Products to Local Livelihood and Forest Conservation in Neelum Valley, Pakistan

T2.17 Local ecological knowledge of non-wood forest products for sustainable forest management and human well-being in diverse contexts

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Abstract: Promoting the sustainable use of Non-Timber Forest Products (NTFPs) can create a mutually beneficial situation for poverty reduction and biodiversity conservation. In Azad Jammu and Kashmir, Pakistan, NTFPs collection and processing play a crucial role in the local economy. More than 5000 families in the region are engaged in these activities. NTFPs collectors are usually low-income households who pursue plant collection as their part-time activity besides farming and livestock. Hence, the study aims to investigate how much NTFPs contribute to the household income of forest-dependent communities and analyze their role in sustainable forest management. The research was conducted in three villages of Neelum Valley, AJK, in northern Pakistan. In March-April 2021, 90 respondents were interviewed through close-ended and open-ended questionnaires.

The study's findings reveal that most of the local population relies on small-scale farming for survival. At the same time, many individuals supplement their income by collecting and selling plant materials for use in herbal medicine. Furthermore, local communities utilize various plants for food, medicinal purposes, fuelwood, agriculture tools, and construction. Eighty-nine plant families were identified to be used in these three villages. Due to the remote location of the villages and economic constraints, they have limited access to commercially produced medicines and continue to depend on medicinal plants. The study identified 220 species used as a traditional medicine to treat 73 diseases. Notably, the study highlights that the benefits derived by these communities from NTFPs positively impact sustainable forest management. Therefore, it is recommended that the residents of Neelum Valley continue to use NTFPs for their daily needs. Local people in the three villages possess extensive knowledge about the specific plants and their respective parts that can be used for various purposes. This study concludes that the trade of medicinal plants can serve as an alternative livelihood opportunity for households with low to medium incomes in Neelum Valley. However, specific challenges threaten the availability of medicinal plants, including a need for more awareness regarding proper harvesting methods and post-harvest handling, unrestricted grazing, deforestation, and encroachments. Hence, this research emphasizes the importance of promoting sustainable practices using NTFPs.

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

Synergies and trade-offs in climate mitigation and adaptation potential of tree species mixtures: a synthesis across tree diversity experiments

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: The global forest area is expected to increase in the future, in an effort to increase the land carbon sink and hence contribute to climate change mitigation via afforestation. Forest plantations will form a substantial part of this forest expansion and, from a climate mitigation perspective, a thoughtful selection of species and mixtures with high growth and carbon sequestration potential is beneficial for carbon drawdown. Simultaneously, planted forests need to be resilient against the future impacts of climate change – i.e. adaptation. Choosing between various tree species during afforestation is essentially a question of trade-offs and synergies for mitigation and adaptation potential, which has direct practical relevance for forest management. Recent collaborative research across multiple tree diversity experiments has gathered empirical data on mitigation and adaptation potential, of the same tree species and stands and using harmonized protocols. Here we present a synthesis of these data, analysing which combinations of species and functional traits determine the mitigation-adaptation trade-offs and/or synergies. From this functional perspective, it will become possible to develop guidelines for tree species selection of mixed plantations where adaptation to climate extremes is paramount, in order to achieve the climate change mitigation potential of planted forest on the long term.

Admixtures of European beech with conifers show higher ecosystem and economic multifunctionality than pure beech stands without compromising multidive

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Forest management in Germany increasingly strives to achieve multi-purpose forestry on public lands, where ecological, recreational, structural, aesthetic, and other goals are as important as timber production. One of these practices refers to the establishment of mixed forests, which often show higher biodiversity (associated animal and fungi groups, for example) compared to single species stands as well as overall ecosystem functioning, but also lower profitability, particularly when mixtures consist of broadleaves with lower industry use and market value. Mixing European beech with non-native conifers could be a compromise solution to be explored, although research on the relationships between biodiversity, ecosystem functioning, and economic performance in German mixed forests has not been fully explored. Our main hypotheses are as follows: 1) there is an effect of forest type (single-species or mixed) on the overall functionality, biodiversity, and economic outcome, and 2) mixed stands show the highest performance for economic value, biodiversity and ecosystem functions compared to the pure stands. We studied pure and mixed forests of European beech, Douglas-fir, and Norway spruce in 40 plots of 0.25 ha located across the state of Lower Saxony, Germany. Data on biodiversity, ecosystem functions, and forest inventory were collected between 2017 and 2021. We simulated the plots' risk-free future growth for the next 30 years under the climate-change scenario RCP 8.5 and then estimated their mid-term economic potential. We used generalized linear mixed models to model the relationships between economic value and biodiversity and ecological functions. Additionally, we analyzed the effects of forest type on biodiversity, ecosystem functions, and socioeconomic indicators, and calculated the mean functionality, biodiversity and socioeconomic functionality. Our findings indicate that admixing beech with conifers increased the overall levels of biodiversity, functionality and economic outcomes in contrast with beech forests. Despite being a non-native species in Germany, Douglas fir´s inclusion in the portfolio of species, in small patches, had similar or even better ecological and economic effects than the European Norway spruce. Admixtures of deciduous species such as beech with conifers can be a nature-based solution to enable multi-purpose forestry in Germany and beyond.

Assessing tree diversity effect on tree resistance to drought through hydraulic safety margins

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Extreme droughts are increasing in frequency and intensity, leading to significant diebacks in forest ecosystems worldwide. Increasing species diversity in forests is often cited as a crucial factor in enhancing stand survival during droughts. Various processes, such as complementarity, facilitation, and competition release, could potentially alleviate water stress in individuals during drought events. However, there is limited available data, and existing data indirectly relate to water stress, with little consensus on this topic. Plant hydraulic ecophysiology provides a mechanistic understanding of how trees respond to drought. In this study, we relied on Tree Diversity Network experiments (i.e Experiments that manipulate woody plant diversity over wide diversity gradients and are designed to allow separation of diversity and identity effects) to explore the effect of species diversity on drought vulnerability of trees. We collected essential plant hydraulic traits related to water stress exposure (water potential) and vulnerability (vulnerability to cavitation) along diversity gradients during drought events. Our extensive measurement campaign took place between 2021 and 2023, primarily during the exceptional 2022 drought, at six network sites (Italy in 2021, France, Belgium, Austria, and Germany during the extreme drought of 2022, and Brazil in 2023). We analysed species richness and tree species composition using one-way ANOVA and observed a significant positive effect of species richness on HSM in approximately 25% of the studied species, which is concordant with existing literature. However, when considering species

composition of the stand instead of just species richness, more complex interspecific interactions emerged. This highlights the need for a deeper understanding of mechanisms that underlie tree interactions in such stressful dry conditions. By examining competition and diversity indices at the individual level, we gradually untangle the effects of individual neighbourhood structures on individual stress during drought events. Our findings indicate that species interactions, through yet-to-be-identify processes, or community size traits can better explain stress patterns than a species diversity index. This reinforces the notion that focal tree functional traits relative to neighbouring trees are key components in better understanding how mechanisms operate at the local neighbourhood scale in individual tree responses to drought.

Decision-makers' Perspectives of Mixed Tree Plantations in a Changing Climate

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Forestry and forest restoration are promising activities to mitigate climate change, as forests have a high capacity to sequester carbon in a short period of time. Mixed tree plantations for sustainable timber production can be a viable and scalable strategy to reconcile economic and environmental benefits and reduce the vulnerability of plantations to climate change. However, despite scientific evidence on the advantages of mixed tree plantations, conventional monocultures still prevail globally. Expanding mixed plantations depends on the decision makers preferences, which requires more than ecological and scientifical evidence of plantation performance. Here, our aim was to analyze the main barriers and opportunities to expand more sustainable mixed plantations in southeastern Brazil and southwestern France. In order to support policies and incentives to adapt forestry to climate change and increasing environmental demands. We identified the factors that govern landowners and forest managers decisions about mixed plantations based on a qualitative research method, developed through semi-structured focal interviews to identify the main barriers and possible future solutions, based on their experiences. The main barriers identified were: Dealing with species competition/dominance effect; Need for a genetic improvement program; Higher operating costs; and lack of technical knowledge. And the solutions presented were divided into three levels of mixtures: Level 1: Mixtures of clones - more common where there are massive *Eucalyptus* plantations, level 2: Mosaics of different species (landscape level), and level 3: At least 2 species in the same plot. We provide a basis for potential alternatives to promote mixed planting of trees in forestry, thus increasing the resilience of forests to climate change, in addition to their ability to provide multiple benefits to nature and people.

Effect of Regeneration Timing on Competition in planted Norway spruce and Birch Mixtures

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Establishing mixed forests plantations is more complex than monocultures, it requires knowledge of the individual trees in the mixture. Pioneer species such as birch are light demanding and fast growing early in the rotation. Conversely, spruce is a shade tolerant late succession species that, dominates the forest canopy over time. In southern Sweden, studies have shown the need to give naturally regenerated birch an early start when the goal is to intermix with planted spruce. Allowing naturally regenerated birch to establish before planting decreases the competition with planted spruce later in the rotation. Since naturally regenerated birch has a relatively low productivity, the production gains of intermixing with spruce is minimal thus it might be interesting to establish spruce – birch mixtures using improved material of both species in the regeneration. The aim of this study is to:

-Establish mixed stands of birch – spruce on former agricultural land by planting

-Understand how birch species grow at different planting times relative to spruce in the same stand

The mixed species experiment was established between 1989 - 1990 at Alingsås in southern Sweden. There are four (4) blocks with three (3) treatments randomly assigned within each block. In the first treatment plot, birch and spruce were planted at the same time, 1989. Birch was planted one year after spruce in the second plot while spruce was planted one year after birch in the last treatment plot. Mixture proportion of individual species is 50/50.

Data collection was carried out autumn 2023 with analysis completed in spring 2024. The results highlighted how the regeneration timing has impacted development of the mixture after three decades.

Effects of single- vs mixed-species restoration planting on biodiversity: A systematic review.

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Tree planting is expected to play a major role in achieving the restoration goals set globally to mitigate the impacts of climate change and to promote biodiversity and ecosystem services provision. However, the effectiveness of tree planting can vary depending on the contexts and methods employed. While there is growing evidence supporting the benefits of mixed-species planting for biodiversity, a comprehensive quantitative analysis of this knowledge is currently lacking. Moreover, specific taxonomic groups may respond quite differently to tree diversity at different spatial scales. To address this knowledge gap, we are conducting a systematic review to examine the effects of mixed vs pure planting on biodiversity. Our aim is to identify both global and regional patterns in the response of biodiversity to mixed planting, considering overall biodiversity as well as specific taxonomic groups.

Through a systematic search employing several search engines, we initially retrieved 6,374 studies potentially addressing our research question. Based on title and abstract we preliminarily selected 178 relevant field studies. These publications will undergo further selection through full-text assessment, considering their experimental design, the type of analysis conducted, and the format of the data provided. From the final pool of studies, we will extract data that allow us to conduct meta-analyses of experimental comparisons between mixtures and monocultures. In addition to identifying overall patterns in biodiversity responses, we will examine variations across different regions, climates, and ecological and management conditions. These analyses will provide insights into the underlying processes that drive the effects of mixed planting on biodiversity, and will allow us to offer case-specific recommendations for management practices involving restoration planting.

Fourteen years of research on the effect of diversity on trees : the IDENT-Montreal experiment

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Exploring the relationship between tree diversity and ecosystem functioning (BEF) has been an important focus of forest ecology in recent years. In particular, understanding the impacts of tree diversity on productivity has received special attention. After three decades of intensive research, there is now a general consensus that tree diversity positively affects forest productivity. This research also revealed mechanisms and environmental factors that, together, can strongly influence such effects across space. However, how and why tree diversity effects on productivity vary over time along stand development remain elusive.

This communication relies on growth and mortality records (among others) from the IDENT-MTL experiment that covers the early stages of stand development: stand establishment, canopy closure, and self-thinning. The experiment was established in 2009 and includes close to fourteen thousand trees of nineteen tree species (twelve natives, which we will focus on) in monocultures and mixtures of two, four, and twelve species.

We will demonstrate that not only is complementarity strong in mixtures, but that is as increased steadily with time. Self-thinning, or the density of trees in relation to their size, played an important role with now over half of the trees having died due to competition. We will also demonstrate that in fact not all species and communities react positively to diversity, and that certain combination of species are favoured.

Finally, we will look at how these fit with other results from this and other forest diversity experiments, and what may be the new frontiers in BEF research with trees.

Higher species diversity would benefit the two commercially significant conifers in Sweden: A single species perspective on mixed species forestry

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: A majority of forests in the Nordic region are managed as even-aged monocultures of pine or spruce. However, standard management methods have come under considerable scrutiny as society is demanding greater complexity in ecosystem services. This is often seen as a trade-off by the industry, relative to managing forest for productivity. However, there is a large body of ecological literature on how resource use complementarity of different tree species can actually enhance productivity, which could make productivity and complexity goals synergistic. Few studies have yet addressed how Nordic tree species grow at the individual tree level, when grown in monocultures or mixtures. Using tree core data from the Swedish National Forest Inventory, we set out to explore the effect of species mixtures on the 10-year basal area increment (BAi_{10}) of pine, spruce and birch, against the backdrop of the large latitudinal and temperature gradient of Sweden. Using linear mixed-effects models, we modelled BAi_{10} as a function of tree size, climate and stand composition, with stand density, soil characteristics, and year of sampling as random effects. Spruce growth rates were similar in monocultures and mixtures with pine above 60° north, but were higher in monocultures in the south. In contrast, pine benefited slightly from growing in mixtures with spruce, especially towards the south. Growing in mixtures with deciduous trees was beneficial for pine across the country, while spruce benefited significantly in these mixtures above 60° north, and was either not affected, or somewhat negatively affected towards the south. Growing in mixtures with conifers had no significant effect on the growth rate of birch.

In contrast with conventional knowledge, our analysis reveals that pine benefits from growing in more diverse stands. The response of spruce was temperature dependent; it grows best in monocultures in the southernmost parts of the country, while towards the north, growing in mixtures with deciduous trees becomes highly beneficial, and growing with pine is mostly neutral. Overall, we conclude that higher proportion of deciduous trees would benefit the growth of commercially significant conifers, at the same time substantially increasing biodiversity in the currently conifer-dominated forests of Sweden.

Meta-Analysis on the benefits of mixed plantations compared to monoculture

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Species diversity in mixed forests can be one important means of mitigate climatic change effects. However, complex plant interactions changing resource availability and use, lead to controversial results in the overall comparison of mixed and pure plantations across published studies. Discovering communalities among them is crucial. This study aimed to identify the main benefits of mixed stands. First, we performed a literature review of the last five years to search published comparative studies between mixtures and monoculture for several traits. Fifty studies involving mixed and pure plantations measuring tree growth, soil physics, chemical and microbiological characteristics were found. *Eucalyptus, Populus*, *Pinus*, and *Quercus* were the species most frequently used in designing mixtures. Second, we performed a meta-analysis of the ratio of means (ROM) of mixed and pure plantations for each trait. Our results indicated that the highest benefit of the mixing of species is found in biomass stock and most traits related to tree growth (ROM: 1.30 to 4 in average). Increased diversity of predator insects and fungi community were reported under mixed plantations. There was no agreement among studies on the effects of mixing on timber quality and soil physical and chemical properties. Our results summarize and confirm published findings about key benefits of mixed plantations in increasing tree yield and resilience to climate change. Site-species specific designs would be necessary to enhance the potential benefits of mixed plantations.

Mixed forests of Quercus suber and Pinus pinea: Enhancing the ecological and economic value of rural Mediterranean regions

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Challenges imposed by climatic uncertainty and global economy require a paradigmatic approach for forest management, rendering the existence of large monospecific areas an increased risk. The concept of mixed forest is consequently gaining interest, but is difficult to implement given the limited comprehension of these systems. Forest mixtures are far less investigated than pure ones and there is a need to fill knowledge gaps, such as the species that will be benefited/put in disadvantage by mixed systems or how and when to conduct silvicultural interventions. Forests around the Mediterranean basin are known for the production of a vast range of non-wood forest products (NWFP), such as pine nuts and cork. Currently, in Portugal, the mixture of the broadleaved *Quercus suber* (producing cork) and the conifer *Pinus pinea* (producing pine nuts) is gaining the attention of landowners, because of the potentially higher economic revenues and lesser investment risk under erratic climatic scenarios. This renewed interest is essential to counteract rural population abandonment, and may positively impact the spreading control of pests and diseases, soil conservation and biodiversity maintenance.

However, an interdisciplinary approach is needed, bridging ecology, economical and societal questions. Taking *Quercus suber* x *Pinus pinea* mixtures as example, this study address important questions like: What are the advantages/disadvantages of mixing these species? Which combination can provide higher revenues? Which management practices contribute more to enhance NWFP and fire prevention? Which composition is more susceptible to pests? Which mixture can sustain higher levels of functional diversity and promote carbon sequestration? How do forest managers perceive change and innovation in silvicultural practices and what is their willingness to adopt and implement them?

During three years, a set of plots was established in a north-south ecological gradient in Portugal where natural regeneration forests and mixed plantations were intensively monitored, engaging forest managers and landhowners in the project development. Together with greenhouse

experiments, where the two species were grown isolated and in combination, the results provide valuable guidance for managers who want to carry out the transition from monospecific to forest mixtures, maintaining ecosystem services without losing economic income.

Possibilities for increasing spruce and birch mixtures in southern Sweden: Insights from a simulation study

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Today most of the regenerations in Sweden have the potential to become mixed forests; however, Scots pine and Norway spruce monoculture dominates mature forest stands. The natural regeneration potential of birch species in southern Sweden presents opportunities to increase species diversity in planted Norway spruce stands. Nonetheless, much research is still required to effectively manage these mixtures and develop silvicultural guidelines. Other important aspects includes assessing productivity and economy of spruce-birch mixtures in relation to the business as usual scenario of growing spruce monoculture.

Inventory data after first pre-commercial thinning from well-replicated mixed species experiment composed of naturally regenerated birch and planted spruce were the starting values in Heureka decision support system (StandWise). These trials were established on high productivity sites in southern Sweden. The mixed stands, which had different initial species proportions B2S1 (66% Birch, 33% Spruce) and B1S2 (33% Birch, 66% Spruce) were managed following two pathways. First strategy involved thinning to maintain initial species proportion (_mix) until final felling while the second focused on removing the smallest trees of either species (_TFB). Thinning in the spruce monoculture was according to common silviculture of the species in Sweden (_mono). At the economically optimal rotation age, birch proportion (% basal area), growth (MAI_{max}), and profitability (LEV) of spruce-birch mixed stands were assessed in comparison to spruce monoculture.

Retaining 18 – 30% birch until the end of the rotation in the mixed stands provided similar and sometimes better growth (9.63 – 10.16 m^3 ha^{-1} yr^{-1}) compared to spruce monoculture (9.7 m^3 ha^{-1} yr^{-1}). These spruce dominated mixed stands were also more profitable than growing spruce monoculture. Conversely, mixed stands with a high birch proportion (c.a. 63% of basal area) had 14% less growth relative to spruce monoculture. Thinning out the smallest trees regardless of the tree species proved most effective in managing the mixed stands. Given the potential of birch regeneration in southern Sweden, this study indicates synergies between growing spruce-birch mixtures, optimizing growth and economic gain.

Potential areas for forest plantations with native species in the province of Talara-Piura

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: The study generated a model of potential areas to establish forest plantations with the native species Prosopis pallida and Colicodendron scabridum in the province of Talara, department of Piura, Peru, using Geographic Information Systems. The climatic, edaphic and topographic requirements of the site and of the aforementioned species were considered in the methodology, evaluating their aptitudes in the areas determined as potential for multipurpose plantations based on the model developed by the National Forestry and Wildlife Service, this input was validated with data collected in the field phase. To determine the potential areas for each native species, a Hierarchical Analysis Process was carried out. As a result of the research, areas with different degrees of suitability for both species were determined. For Prosopis pallida an area of 11 343.97 hectares with high aptitude and 10 478.44 hectares with medium aptitude was determined, and for Colicodendron scabridum an area of 7 634.17 hectares with high aptitude and 14 188.24 hectares with medium aptitude was determined. The results of this study show that there are potential areas not only for installing forestry plantations, but also that these can be carried out using native species through mixed plantations. Native species are better adapted to the terrain where they are installed because they meet the site conditions, having previously developed naturally in the area. Thus, plantations with native species are a proposed solution for mitigating and adapting to climate change.

Productivity and resources acquisition of Norway spruce and silver birch in monocultures and a mixed plantation in hemiboreal conditions

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Establishing mixed forests instead of monocultures is considered to improve the ecosystems' resilience to climate change. Mixing suitable tree species should give a complementarity effect, due to the mixture being able to use available resources more efficiently in comparison with a monoculture. Therefore, it is expected that mixtures will overyield monocultures of the same species and contribute to a higher climate benefit through higher carbon uptake. However, several studies in Northern Europe do not approve of the production advantage of mixtures over monocultures. Thus, the mechanistic understanding about resources utilization in mixture and monocultures are needed to design productive and resilient forest ecosystems under climate change.

A dual labelling experiment was established in monocultures and a 50/50 planted mixture of Norway spruce (*Picea abies* (L.) H.Karst.) and silver birch (*Betula pendula* Roth) in hemiboreal Estonia on abandoned agricultural site at the age of ~20 years. A solution of $K^{15}NO_3$ and $^2H_2$-labeled water were used to describe the vertical and horizontal rooting area of trees for nitrogen and water acquisition. Annual aboveground measurements were carried out to estimate current annual production. The present study does not support the generalization of mixtures overyielding at the current stand age. After two decades, the most productive forest type by stem volume was the spruce monoculture followed by birch monoculture and then the mixture with 198, 152 and 146 m^3/ha^{-1}, respectively. Birch benefited from the reduced intraspecific competition in the mixture as the mean stem volume of a single tree was 121% of the mean single tree stem in the monoculture. Spruce suffered from the interspecific competition in a mixture as the mean stem volume was 40% of the mean single tree volume in the monoculture. The growth advantage of birch over spruce in the mixture in comparison with their monocultures indicates interspecific competition rather than niche complementarity for soil resources in mixture. Based on the results new recommendations on forest management and silvicultural practices could be made to improve the establishment of mixtures in Northern Europe.

The significance of tree species richness, structural diversity and functional diversity for forest productivity and stability under drought

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: The increasing intensity and frequency of droughts threaten the world's forests and their potential to mitigate climate change. Mixed forest plantations may foster productivity and ecological stability compared to monospecific plantations under drought. However, the determinants, direction and drivers of tree diversity effects on productivity and stability remain elusive. Using a combination of dendroecological, inventory- and trait-based approaches, we examined if diversification in terms of tree species, structures, and drought-tolerance traits promotes the productivity and stability of forest plantations. With this aim, we studied diversity-productivity and diversity-stability relationships across spatiotemporal scales in both the tropical Sardinilla and the subtropical BEF-China tree diversity experiments located in Panama and China, respectively. Both experiments compare monocultures with mixtures of increasing tree species richness ranging from 1–5 species in the Sardinilla and 1–24 species in the BEF-China experiment. We found that tree species richness consistently increased productivity and stability. This effect was strongest at the highest levels of diversity. Disentangling the contributions of different diversity facets highlighted that structural diversity promoted productivity but was unrelated to stability. In contrast, diversity in functional traits related to drought tolerance fostered stability but not productivity. Studying drought-tolerance traits appears crucial for understanding the effect of species richness on tree responses to drought. Drought-sensitive species – those with traits indicative of low resistance to cavitation and a water-spending stomatal control – profited most from species richness under drought. Positive tree diversity effects on productivity scaled up from the local tree neighbourhood to the stand level, while positive diversity effects on stability were an emergent stand-level property. Species richness increased stand-level stability via asynchronous, trait-driven species responses to dry and wet years. Importantly, functional diversity and not functional identity in drought-tolerance traits increased stand-level stability. Overall, our experimental findings emphasize that promoting forest plantations diverse in species, structures, and functional traits can foster high productivity and stability and, thereby, their climate change adaptation and mitigation potential.

Tree diversity and functional traits as predictors of stand productivity

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Forests need to be resilient and adaptive in the face of global environmental change and mixed species forestry is a critical strategy for achieving this goal. It has been shown in many studies that mixed species forests can be more productive, more resilient to stress and disturbance while also providing a broader range of ecosystem services relative to mono-specific forests, yet the underlying mechanisms are not clear. Contrasting inter-specific functional trait expression and increased structural heterogeneity in mixtures may enhance community resource utilization, which could help explain synergistic effects on tree growth. Here, we conducted a meta-analysis of data from 21 tree diversity experiments across 5 continents to determine the extent to which mixed forestry can promote increased growth as measured by stand-level basal area and height mean annual increment. We then used structural-equation modeling to quantify the strength of linkages between species diversity and growth via vertical and horizontal structural heterogeneity, functional trait diversity, and functional stand composition. We will discuss our findings in terms of general growth trends identified, and potential mechanistic diversity-productivity pathways in tree species mixtures. The results can contribute to informing policy-makers and forest managers about the overall effectiveness of mixed forestry.

Tree diversity can improve forest resistance to insect pests at multiple spatial scales

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Faced with the spectacular increase in damage caused by forest pests as a result of global change, and with public opinion becoming increasingly demanding in terms of nature conservation, forest managers are looking for effective control methods that are also environmentally friendly. Converging results have shown that the diversity of tree species can improve the resistance of forests to attacks by insect pests. But this nature-based solution is not widely adopted by foresters because of the complexity of managing mixed forests. A recurring question is therefore how to mix tree species, and in particular at what spatial scale this diversity should be organised. Using the pine processionary moth as a case study, we studied the effect of mixing coniferous and deciduous trees at different spatial scales, from intimate mixing between trees, by juxtaposing plots of different compositions, to heterogeneous landscape compositions. We consistently found more pine processionary attacks in pine monocultures than in mixtures at the three spatial scales studied, but the effect of diversity varied according to the composition and structure of heterogeneous stands and landscapes. These results can be explained by the underlying mechanisms of associational resistance, both the bottom-up effects of host resource concentration and disruption of host tree finding processes, and the top-down effects of control by natural enemies, which also operate at different scales. This study opens the way to taking greater account of the diversity of trees in the design and management of forest plantations and landscapes to improve their resistance to increasing biotic hazards.

Tree growth responses to the Central European 2018-2020 drought as modulated by diversity, mycorrhizal type, and drought-tolerance traits

T2.18 Mixed forest plantations as natured-based solutions for climate change mitigation and adaptation

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Abstract: Climate change scenarios predict an increasing frequency of consecutive drought years, likely having negative impacts on tree growth in Central European forests. Although mixing tree species has been found to increase the temporal stability of growth in tree communities, the results of different studies are still inconsistent with respect to extreme drought events. Recent studies show that besides climatic conditions, it is the biotic context, i.e. the traits of focal trees and their local neighbors, that modulates biodiversity–ecosystem functioning (BEF) relationships. However, it is not yet clear if functional trait identity and/or diversity can mitigate the impacts of extreme drought events. Here, we studied how tree growth in experimental forest plantations is influenced by tree diversity before, during, and after the Central European 2018-2020 drought. In addition, we explored how these relationships are modulated by mycorrhizal association types and other functional traits. We used annual growth data (2015-2022) of 5,120 tree individuals growing in a young tree diversity experiment in Germany (MyDiv) and measured functional traits related to drought tolerance and resource use of 10 broad-leaved tree species to model BEF relationships under drought. We found a positive response of individual tree growth to diversity in the pre-drought period and the first drought years. Nevertheless, this relationship reversed in the last drought yearnd the early post-drought period. Further, these relationships were modulated by the mycorrhizal type of the tree species; most strongly in the post-drought period. Tree species' drought-tolerance traits and traits related to resource use formed a joint trait syndrome. We found two axes of trait variation mainly driven by cavitation resistance and stomatal control, respectively. Analyses on the modulation of diversity–productivity relationships by these trait syndromes are ongoing. Overall, this study contributes toward understanding the biotic context dependency of BEF relationships under drought and provides a functional basis for designing tree species mixtures able to cope with climate change.

T2.19 Non-timber forest products and the bioeconomy

A Study on the Situational Analysis of NTFPs in Asian Region for Selected Commodities: Enhancing Community Livelihoods and Sustainable Value Chains

T2.19 Non-timber forest products and the bioeconomy

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Abstract: This study addresses the challenges and opportunities associated with non-timber forest products (NTFPs) in Asia, focusing on enhancing community benefits and promoting sustainable value chains. The livelihoods of rural communities, including indigenous peoples and women, heavily rely on NTFPs. However, accessibility, sustainability, and development of NTFP value chains vary among countries.

In order to address these challenges, the study examines NTFP sectors in 12 Asian countries: Bhutan, Cambodia, Indonesia, Kazakhstan, Kyrgyzstan, Laos, Mongolia, Myanmar, Philippines, Thailand, Timor-Leste, and Vietnam. By conducting a comprehensive analysis, including the identification of community-based enterprises, resource management practices, market dynamics, policy frameworks, expert opinions, and case studies of selected commodities, the study provides strategies to enhance community benefits and promote sustainable NTFP value chains, and valuable insights for interventions at the country level.

Four strategies Identified are as follows:

1. Resource Sustainability/Enhancement: The study emphasizes securing and enhancing NTFP supplies through sustainable harvesting, plant management, and cultivation. Collaboration and knowledge exchange among participating countries can optimize resource utilization.

2. Market-Responsive Product and Service Development: Standardization, certification, and product diversification are crucial for increasing community benefits. Market research should guide the development of high-value NTFP products, such as crafts, bamboo-based goods, medicinal plants, and nature-based tourism.
3. Research and Knowledge Building: A regional research agenda is proposed, covering baseline development, sustainable resource management, harvesting methods, and market research. Knowledge creation and exchange support the transition to a knowledge-based NTFP sector.
4. Innovation and Inclusive Approach: Adopting an innovative approach to NTFP sector development and defining competitive edges for each country can enhance community livelihoods and contribute to national economic goals. Building an entrepreneurial ecosystem for community-based NTFP enterprises is crucial for long-term success.

Interventions at the country level should prioritize resource management, value addition, market research, community enterprise formation, and partnerships with stakeholders to maximize NTFP benefits. Developing policies and strategies through a roadmap will enable the NTFP sector to

thrive, benefiting communities and sustainable development goals. By adopting a regional approach, knowledge sharing, experimentation, and collaboration among countries can lead to resilient and inclusive NTFP value chains in Asia.

Application of Tea Buffer Zones for Prevention of Forest Encroachment and Livelihood Improvement in Forest Reserves

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Forest encroachment in indigenous natural forests in Kenya has been one of the major contributors to forest deforestation. Kenya lost about 50% of its forest covering about 300,000 hectares between 1980 and 2000 due to extensive logging, charcoal burning, and extensive clearing of forested regions for food crops plantations. Various strategies have been employed to stop and reverse this negative trend, Forest buffer zones using tea crop has been one of the approaches implemented over the years through the Nyayo Tea Zones Development Corporation. This study investigated the effectiveness of the 100-meter tea buffer zones as a management strategy for the prevention of forest encroachment and livelihood improvement in Kakamega forest reserve Kenya. Geographical Information Systems (GIS) was used to map the extent of protection attributed to the tea buffer zones between the period 1985 - 2022. The household survey and Focus Group Discussions were conducted among 108 forest-adjacent communities to obtain their views on the importance of the tea buffer zones and their perception of forest conservation. The results from GIS indicate that along the tea buffer zones, 4.5% of forest ecosystem recovery was realized between 2005 and 2022. Socioeconomic results indicate that 30% of the forest adjacent communities were employed on the buffers tea farms, additionally, the communities rated the forest as a very important natural resource (69.7%) as it provided them with key benefits including the source of food and medicine (31.2%), provision of firewood (24.8%), environment conservation (14.7%) and preservation of cultural sites (7.3%). Based on their opinions the communities rated the forest buffer contribution to forest conservation moderately at 43.1%. These outcomes show a perfect association between forest conservation strategies and livelihood improvement. The decision to place tea buffers along the forest reserves proved to be an effective tool in preventing forest encroachment and improving the livelihoods of the forest-adjacent communities through the provision of alternative income.

ARE NON-TIMBER FOREST PRODUCTS CONCENTRATED AT REGIONAL AND STATE LEVEL IN BRAZIL?

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Brazil is the country with the largest tropical forest in the world and second in forest cover. The conscious use of natural forests permeates plant extraction of non-timber forest products (NTFP). The vast national territory, the diversity of the population and the forests mean that different products are produced, with a great variability of use. Understanding where it is produced, and the quantity allows us to indicate improvements and advances to encourage and increase their production in the country. Thus, the objective of the work is to determine the degree of concentration of production of the main PFNM between the years 1991, 2001, 2011 and 2021. they are: Açaí, Yerba mate, Brazil nut, Carnaúba (powder) and Babaçu (almond). The data was obtained from the survey of the production of vegetal extraction and forestry (PEVS) in Brazil. Two indices were used, the adapted concentration ratio (CR1) and the Herfindahl-Hirschman index (IHH). Both present results in percentage, where 100% indicates higher concentration. Concentration at regional/state level was analyzed. The 5 products are highly concentrated at a regional level (>85%), with emphasis on the North region, which produces Açai and Brazil nuts, and the Northeast, with carnauba and babassu. Carnaúba and yerba mate are 100% produced in a single region, Northeast and South, respectively. At state level, only Açaí and Brazil nut are deconcentrating their production, increasing production in different states of the region. Yerba mate and Babaçu are considered of high concentration (>75%) at state level, Paraná and Piauí, respectively. Only Yerba mate and Brazil nuts changed the dominant state in production between 1991 and 2001. The main NTFPs in Brazil are highly regional, due to the immense Brazilian diversity and phytophysiognomies, and largely concentrated even at the state level. Cases such as Açaí and Brazil nuts are becoming less concentrated at the state level, thanks to national recognition. As these are the products with the highest production, it is important to encourage their expansion, especially in the states of the domain region.

Assessing harvesting and postharvest handling practices of Strychnos cocculoides fruit in the Kavango West Region of Namibia.

T2.19 Non-timber forest products and the bioeconomy

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Abstract: The purpose of this study was to asses harvesting and postharvest handling practices of *Strychnos cocculoides* fruit in relation to the quality of the fruit in two study sites namely: Kaguni and Mile 20 in Kavango West Region; Namibia. The study identified existing harvesting and postharvest handling practices. It assessed the level of postharvest losses of *S. cocculoides* fruit at different handling practices and consumer preferences by evaluating Total Soluble Solids (TSS), taste, size, and weight when harvested at different maturity stages (fully mature, half mature and just mature). Semi structured questionnaires, focus group discussion and direct observations were employed for data collection. The findings indicate that fruits are harvested by women and children for consumption and income generation. Fruit were harvested fully mature, half mature and just mature. Climbing the tree and using the stick method to dislodge fruit were the two methods used for harvesting. Vehicle, donkey/oxen cart, head load or public trucks were used to transport fruit from the field and to other towns within Namibia. Poor harvesting and post-harvest handling practices were observed in both study sites. Community farmers lack knowledge of proper harvesting and postharvest handling practices. The maturity stages at which the fruit were harvested had no significant effect on fruit weight, size and TSS as well as taste in terms of consumer preferences. Fruit damage due to cracks bruises, rotting during harvesting, transportation, storage and marketing was the main challenges caused by poor harvesting and handling practices. Fruit were reported to be deteriorating resulting in short shelf life. The poor harvesting handling practices can have a negative impact on the income generated from the sale of the harvested fruit. Recommendations are made on how to improve on the existing fruit handling practices.

Ecological envelopes for species producing non-timber forest products in Portugal

T2.19 Non-timber forest products and the bioeconomy

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Abstract: The Portuguese forest ought to correspond to the main forestry and industrial sectors' needs, and an increase in the area covered with Mediterranean species has to be undertaken, also mitigating climate change effects. This study aimed at predicting the spatial distribution of species producing non-timber products (chestnut, cork oak, and stone pine) and to understand the future spatial changes expected in emission change scenarios. The ecological envelope methodology (assessing each species' ecological requirements) was applied to infer those species' potential area, in both present and future, in two Shared Socioeconomic Pathways (SSP2-4.5 and SSP5-8.5), and two slice-time periods (2050 and 2090). The bioclimatic data downloaded from WorldClim 2.1 and the elevation from the Shuttle Radar Topography Mission, with a spatial resolution of 1 km, were used for modelling in the present. For the future, we used the Model EC-Earth3-Veg and the Shared Socioeconomic Pathways SSP3-7 from the CMIP6 (Coupled Model Intercomparison Project Phase 6). The ecological envelope methodology used ecological variables temperature and precipitation-related, and elevation. To evaluate the produced model for each species, we used two maps algebra methods: i) the Boolean method, where the species' area was obtained by multiplying the resulting variables reclassified with the Boolean approach (0-Inadequate, 1-Adequate), and ii) the additive model, where a final map is classified in five ranks: (4) excellent, (3) good, (2) fair, (1) marginal and (0) inadequate, by summing the environmental variables binary maps. The maps produced with the Boolean method were tested with the Integrated Aptitude for Mainland Portugal maps for the studied species (available on *EPIC WebGIS*), through a performance indicator (F) ranging from 0.30 to 0.70. Maps made with the additive model were evaluated by the spatial join with the National Forest Inventory points and a match of 72% to 99% was verified in the classes (4) excellent for the present. The chestnut area will drop from the current 45% area to nearly 9% in the best-case scenario and to 1% in the worst-case scenario. The results will help in planning these species' afforestation under climate change scenarios. This project was funded by CULTIVAR (CENTRO-01-0145-FEDER-000020), and also by FCT projects CERNAS-IPCB (UIDB/00681/2020), MED (UIDB/05183/2020), and CEF (UIDB/00239/2020).

Economic and Ecological Potentials of Non-timber Forest Products in Chure Landscape (Siwalik Hills) of Nepal

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Non-timber Forest Products (NTFPs) contribute significantly to maintaining rural livelihoods in most parts of the developing world. Primarily, NTFPs are the source of subsistence but are often the source of regular cash income and also serve as a safety net in times of crisis. Recently, studies are also directed toward understanding the role of NTFPs to enhance the adaptive capacity of households in the context of climate stresses. The Chure landscape, the longest and largest landscape of Nepal, in the outer foothills of the Nepal Himalayas is one of the most fragile and vulnerable landscapes because of its weak geological formation and pressure from anthropogenic factors. The conservation sensitivity and needs of the landscape are the concerns of the authorities for the last two decades. NTFPs are an important source of income for the local people in Chure-Terai Madhesh. The Master Plan of Chure-Terai Madhesh Conservation and Management has identified a number of potential species for marketing and livelihood. In this paper, we analyzed the NTFP harvest and trade data for the last fifteen years from landscape and prioritized the species having the potential for trade and soil protection based on a number of variables. Fifty-seven species traded from the Chure-Terai and additional three species having the potential of soil protection were subjected to priority ranking. Based on the prioritization criteria 17 species are identified as high priority species, another 17 species as medium priority species and 26 species are prioritized as low priority species. We argue that the promotion and/or management of these NTFPs in the landscape help achieve the dual objectives of economic development and ecological protection and restoration of the landscape.

Examining New and Developing Value Chains of Ecosystem Services: A Comprehensive Analysis

T2.19 Non-timber forest products and the bioeconomy

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Abstract: This paper presents an examination of selected new and developing value chains of ecosystem services that are not yet established in the market or whose value creation is poorly understood. Our study focuses on value chains from diverse ecosystems, namely forests, agricultural lands, and water bodies. While the focus is on cultural services, some less developed value chains of production services, such as non-wood forest products, were included in the analysis.

To gain a comprehensive understanding of the overall development of value added in the bioeconomy, we analyze the relationship between newly developed ecosystem service value chains and the more established bioeconomy value chains. Through this analysis, we identify complementary, neutral, and rivalrous dynamics, particularly in terms of land use.

Furthermore, we conduct an in-depth examination of the key players involved in the value chains and their contribution to value-added formation within the selected ecosystem services. Additionally, we investigate the demand and distribution of value and costs along the value chain.

Finally, our study assesses the bottlenecks that hinder the realization of the full value potential of ecosystem services. We propose possible solutions to overcome these challenges and suggest strategies for increasing the value added of ecosystem services.

This research contributes to the understanding of emerging value chains within the bioeconomy and sheds light on the opportunities and constraints associated with the development and commercialization of ecosystem services. The findings provide valuable insights for policymakers, businesses, and stakeholders seeking to capitalize on the untapped potential of ecosystem services in creating sustainable and economically viable solutions.

Non-Wood Forest Products' related habits of Spanish households shaping bioeconomy demand: consumption and harvesting factors and trends

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Non-Wood Forest Products (NWFP) represent a substantial resource for recreational and commercial activities in forest areas. According to Lovrić et al. (2020), 26% of European households collect NWFP, mainly for self-consumption. This share indicates the high, often underestimated, bioeconomy potential of these forest resources. However, the existence of marked between-country differences regarding the harvesting of non-animal NWFP by households makes it necessary to focus on country-level patterns to get further insights into the use and harvesting of NWFP. In this contribution, we zoom into Spanish data on harvesting and consumption patterns of NWFP with the aim of understanding their main predictors.

We hypothesized that variables such as the presence of children in the household, household size and income, municipality population, urban/rural self-identification, surrounding forest area, and the purchase of NWFP could be potential determinants for being a picker household.

Descriptive and logistic regression analyses were conducted to check the influence of these variables, for all NWFPs altogether and for each NWFP category separately. Our results show that 18.4% of the households in Spain pick yearly some type of NWFP. Otherwise, 93.5% households buy, at least, one of this. Specifically, 13.4% pick wild nuts, 12% wild mushrooms, 11.8% wild plants, 10.3% wild berries, 8% decorative plant materials and 1.1% pick truffles. These figures reflect the degree of technical and physical accessibility to the resources.

Also, households with higher incomes and municipal forest area, purchasing NWFP, living in a less population municipalities and auto-perceived themselves as them who live in rural areas are more likely to (mostly non-commercially) pick NWFPs. Interestingly, the exposition to forests (with different buffer areas) only contributed significantly to explaining NWFP-picking patterns for a wild plants and wild berries.

These figures reveal the actual gathering practices and consequent socio-ecological pressures and bioeconomic potential, which contrast with their typical invisibility within official statistics. Policies facilitating the organisation of these dispersed activities would allow for checking their sustainable

practice. Besides, facilitating the health and fiscal requirements for commercialization could boost more regular marketing in rural areas.

Opportunities and Constraints in Green Economy within the Forestry Sector among Western Kenya Counties

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Green Economy dates back to 1989 when David Pearce et al., gave a report on green economy "Blue Print for Green Economy" that was commissioned by the UK Government. Green Economy focuses on sustainable use of renewable resources, sustainable agriculture and forestry among others. Ecosystems are facing risks due to increasing rates of depletion in natural resources to satisfy human needs and wants. Hence, a robust and regulatory framework is therefore important for effective implementation and management of green economy policies that will lead to the improvement of well-being. This research work looks at opportunities in green economy development in the forestry sector among stakeholders as well as challenges that hinder the attainment of green economy development.

Diverse stakeholders from 63 organizations in 9 Counties within the Lake Victoria Basin, were evaluated on how best to reverse unsustainable forestry related activities to promote sustainable development in production and consumption of forestry goods and services. The results indicate that women constitute approximately 78.7% of the persons involved in initiation and planning of green economy activities. The main funding sources are from organization's internal budgets (36.5%), businesses (19.1%) and contributions from family and women groups (12.7%). The stakeholders viewed green economy as an opportunity for job creation (50%), gender empowerment (35%) and for forest ecosystem services (15%). However, barriers that hinder the development of green economy include but not limited to; high dependence on forestry resources, inadequate funding and high cost of implementing initiatives. There is need for social inclusion and adoption of improved technology that will lead to the achievement of green economy within the country. The research work concludes that there is need for further assessment on the impacts of forestry green economy bio-enterprises and interlink forestry green economy practices with blue economy.

Resource Assessment and Marketing of Caterpillar Fungus (Ophiocordyceps sinensis) in the Buffer Zone of Makalu Barun National Park, Nepal

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Yarsagumba *(Ophiocordycecps sinensis)* is one of the highly expensive and potential medicinal mushrooms in the world. Owing to the herb's high efficacy and potency in curing various diseases, it is well known as an important nourishing tonic. The study has attempted to gather information regarding Yarsagumba, its associated species, various medicinal uses, and marketing channel. Out of 15 plots, only 3 plots were recorded the Yarsagumba with a frequency of 0.2 which was very low compared to other medicinal plants. We randomly recorded the Yarsagumba with a density of 833 (No)/ha equal to 0.5 kg/ha in the effective area. There was an imbalance between the population of moths and the spores of Caterpillar fungus. There were increasing trends in *Cordyceps sinensis* market, heavily dependent on Chinese buyers. The Chinese companies send agents to collect Yarsagumba directly from the fields. And they pay US$ 10/piece to villagers (according to the latest field study, June 2019). China is the largest producer of Yarsagumba and meets 95 percent of the world's demand. Nepal is the second largest supplier of fungus. Expansion of marketing channel is essential for getting more benefits focusing on local Yarsagumba collectors. It was observed that only 14.51 percent of men participated to collect the Yarsagumba because the majority of men migrated to India and overseas for searching jobs. Therefore, women would play a vital role in the sustainable harvesting of Yarsagumba. Different pharmacological actions such as antiasthma, antineoplastic, and antibacterial as well as actions on the heart and blood vessels, and on the smooth muscles of the intestine and uterus have been reported. The government of Nepal should prepare a national Yarsagumba management policy and local Yarsagumba management guidelines to address conflicts by clearly defining the roles, responsibilities, and rights of local institutions and actors. The Makalu Barun National Park should also prepare a separate management plan for sustainable harvesting so that local people would enhance their income, and the government would also increase income through royalties.

Keywords: Yarsagumba; Production; Collection; Sustainable Harvesting; Marketing, Policy

Rock rose produces potential non-timber forest products

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Global warming predictably will affect inland areas in the Mediterranean region, already distressed by extensive summers and severe drought. The rockrose (*Cistus ladanifer* L.), a shrub widely distributed in the Iberian Peninsula and North Africa, produces valued metabolites (e.g., labdanum resin), and could further be explored for biomass production, and as a food and feed source. Shrublands play an important role in the atmospheric CO_2 uptake, helping in global warming mitigation, since they act as carbon sinks. This makes the species a natural resource target in Mediterranean areas.

A rock rose common garden experiment installed in central Portugal, inland, was established by the end of October (2021) using 5 individuals (half-sibs with the same mother plant) from 5 different families (mother plants) collected from ten populations spanning the entire range of the species, in a randomized compact-family block experimental design. The common garden objectives are: 1) to establish a non-destructive method to estimate biomass production, 2) to estimate biomass production variability among and within populations and families, 3) to rank the populations, families, and individuals for biomass production, and 4) to select the best-suited rockrose lines to produce secondary metabolites. The first and second measurements were made 116 and 254 days after the plantation. The mean of crossed diameters and total height were used to calculate the cover area (circle) and the plant volume (inverted cone), to compare individuals' growth. In the 1st assessment, the differences between provenances were significant for the growth traits (height, canopy area, and volume). The provenance PG (Penha Garcia, Portugal), a local provenance, had always the highest growth traits, followed by a nearby located Spanish provenance, EVC

(Valdecaballeros, Spain). The PSV (São Vicente, Spain, subspecies *sulcatus*) and ESP (Sierra Palmitera, Southern Spain) had the worst growth traits performances. The mortality, in the 2nd measurement, was higher for the PBR, a northern provenance, followed by MKE and ESP, southern provenances. PAL (Alentejo, Portugal) had the lowest mortality. The populations and families will be further evaluated for biomass and metabolite productivity and profile, using the destructive analysis approach. This research was supported both by the CULTIVAR project (CENTRO-01-0145-FEDER-000020), and by Fundação para a Ciência e Tecnologia, projects CERNAS-IPCB (UIDB/00681/2020) and CEF (UIDB/00239/2020).

The hunting market - the market hunt: wild meat trade by indigenous communities in the Peruvian Amazon

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Little is known how bushmeat markets operate in the Peruvian Amazon and the influence they have on levels of extraction for food and commercial purposes. This paper analyzes the relationship between hunting intensity and the supply-demand interaction of bushmeat in the market in the central Peruvian Amazon region. It analyzes how the price of bushmeat relates to the intensity of hunting in native communities and to the demand for bushmeat in the market.

Price plays an important role in the use and trade of bushmeat. In the markets, bushmeat adopts supply and demand mechanisms, self-regulating. However, in the urban sector much of the bushmeat that reaches the city is sold outside the markets, which does not guarantee an efficient formal market.

The research confirms that the extraction, trade and use of bushmeat in the native communities of the Ucayali River near the city of Pucallpa are related to the commercialization of the resource in the city. The amount of meat shared, meat sold, and the average price are related to the total amount of meat hunted. The three elements interact influencing each other.

It is recommended to promote the legal sale of bushmeat of managed species in formal markets so that it can be subject to greater control, and allow prices to achieve a sustainable equilibrium level in the extraction and sale of bushmeat. Provider legalization should be promoted through registration requirements, management plans, and payment of fees and taxes. This guarantees greater monitoring of the flow of bushmeat to formal markets, allowing a price structure to be managed whose balance maintains supply and demand at levels that do not impose an increase in the quantities of meat hunted.

THE POTENTIAL OF NON-TIMBER FOREST PRODUCTS FOR THE BIOECONOMY IN LATIN AMERICA AND CARIBBEAN

T2.19 Non-timber forest products and the bioeconomy

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Abstract: South America is estimated to account for 21% of the world's forests. The countries of Latin America and the Caribbean (LAC) are the most biologically diverse in the world. South America alone is home to half of the Earth's biodiversity. Furthermore, biodiversity is embedded in the foundations of the cultures that have inhabited LAC. Within this context are non-timber forest products (NTFP), which have gained prominence in the last decade with the spread of the concept of bioeconomy in several countries. However, little attention is still being given to the potential of the bioeconomy associated with forests, given that it is not yet widespread and more in-depth discussions about its scope and challenges are needed. In this scenario, a forum has been organized with the aim of debating the bioeconomy of NTFPs used in the region. The BioForestALC – 1st Virtual Forum on the Potential of Non-Timber Forest Products for a Latin American and Caribbean Bioeconomy – through a set of events held between the end of 2021 and the beginning of 2022, brought together 350 participants from 20 countries, including civil society and government representatives, who discussed and formulated 142 action proposals to unblock the bioeconomy of NTFPs in Latin America. These proposals were systematized and grouped into 6 major lines of actions that should serve as the basis to guide future dialogues, activities and public strategies: (1) Capacity building considering the integration of different knowledge and the Food Security-Bioeconomy-Forest nexus; (2) Strengthening the commercialization, markets and value chains of the bioeconomy; (3) Inclusion of restoration in bioeconomy strategies; (4) Public/private promotion of research considering different types of knowledge and involving the various actors in society; (5) Promotion of financial mechanisms to develop bioeconomy chains; (6) Articulation for the elaboration, regulation and implementation of public policies. Although more discussions are needed, these action lines represent an important step and an opportunity to advance the promotion of a bioeconomy that is concerned to conserve forests and strengthen the livelihoods of populations in Latin America and the Caribbean, since NTFPs have been a fundamental part of hundreds of ancestral cultures.

Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Non-timber forest products and Geographical Indications: Will high quality be justified in era of climate change and population shrinkage in east Asia?

The production of non-timber forest products, such as shiitake, charcoal, and urushi (lacquer for wood products), in east Asia face multiple challenges from shrinkage of populations and climate change. To address these challenges, policy support instruments were introduced; Geographical Indications (GIs) at product level, Globally Important Agricultural Heritage Systems (GIAHS) at area designations or official instruments such as ordinance or notification including the one by Agency of Cultural Affairs for urushi. Such instruments frequently refer to the quality advantage of such products based on the domestic environment or terrior. The literature has separately discussed the effects of such instruments. Here we comparatively discuss and examine synergy and trade-offs of these policies and landscape management instruments for NTFPs.

There are three items of NTFP that are analyzed here to compare and evaluate the "taxonomy of support instruments."

Kunisaki City belongs to the Kunisaki Peninsula in eastern Kyushu Island. The Peninsula is part of Kunisaki Usa GIAHS. Log-cultivated shiitake production contributes to cyclical use of sawtooth oaks (Quercus acutissima). The government of Kunisaki City has been providing financial support on the purchase of spawn blocks. The city adopts a higher rate to purchase blocks of low-temperature varieties. Global warming destabilizes the production of these low-temperature varieties. Some government promotion now includes branding of mid-temperature varieties.

The Iwate Charcoal Association has made efforts to increase and standardize the quality for more than a century. This increased the carbonation level of charcoal. Because of these developed and shared production methods, the association applied for GIs hoping the price increase.

Joboji Urushi, Japanese lacquer of Joboji, increased its demand since 2015. The Agency of Cultural Affairs has demanded the use of domestic urushi for the preservation of cultural properties. Reacting to the increased demand, the city government of Ninohe started the preliminary resource management measure to map available urushi trees (Toxicodendron vernicifluum). Furthermore, the Joboji Urushi Association registered for GIs for the counterfeit prevention and the stable price. Historical production justified the registration.

Transition pathway for wild-simulated ginseng to forest-based bioeconomy

T2.19 Non-timber forest products and the bioeconomy

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Abstract: Non-timber forest products are useful foods and products, frequently vital income sources for forest communities. Wild-simulated ginseng is a non-timber forest product that has received attention for promoting the livelihoods of mountain villages and providing healthy foods. This study examined transition pathways to forest-based bioeconomy focusing on the wild-simulated ginseng industry in the Republic of Korea. Policy discourse on non-timber forest products has transited from quantity-oriented to quality-oriented, focusing on food safety in the Republic of Korea. This change in policy discourse on non-timber forest products supports the high value of wild-simulated ginseng in the market. The Korea Forest Service has adopted a quality management system targeting wild-simulated ginseng. Centralized governance mode controls food safety in cultivating and trading wild-simulated ginseng in the Republic of Korea. This research focused on adding values to non-timber forest products and developing strategies to enhance the wild-simulated ginseng industry for integration into the forest-based bioeconomy. This research proposes a pathway to revitalize the wild-simulated ginseng industry and transit to a forest-based bioeconomy. A biotechnology-based industry for wild-simulated ginseng can be developed focusing on specialization, technological innovation, and transparent governance to transit to a forest-based bioeconomy. The case of wild-simulated ginseng can be a model of biotechnology-based bioeconomy in the non-timber forest product industry.

Understanding the illegalities in the trade of central Himalayan medicinal plants

T2.19 Non-timber forest products and the bioeconomy

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Abstract: The increase in global demand for medicinal plants contributes to the bioeconomy at local, national, and regional scales but premature and over-harvesting, and illegal trade are posing threats to the survival of wild medicinal plants. Taking the case from Humla district of Western Nepal, this paper analyses the nature and scale of corruption in the trade of medicinal plants. Empirical trade data were obtained in two time periods: 2014-15 and 2021-22 using semi-structured and open-ended questionnaires. While the number of traders won't change in two time periods; 21 in 2014-15 and 23 in 2021-22; the volume of trade increased from 133.34 tons to 402.67 tons over two time periods. Concurrently, the value of trade increased from USD 1.39 million in 2014-15 to USD 1.94 million in 2021-22. The volume of jatamansi (*Nardostachys jatamansi*) records a massive increment: from 85.8 tons in 2014-15 to 224 tons in 2021-22 followed by Kutki (*Picrorhiza scrophulariiflora*): 35.5 tons to 48.8 tons in two time periods. Interestingly trade of setakchini (*Polygonatum cirrhifolium* and *P. verticillatum*) was unrecorded in 2014-15 but the volume of trade reached 107.8 tons in 2021-22, showing how the overseas demand shapes the trade. The trade is associated with different forms of illegalities like harvesters not receiving the collection permits, harvesting beyond the allocated quotas, premature harvesting, use of alternative names to save royalty, and rent-seeking from government officials. While there are not any shortcuts to deal with illegalities, the study proposes to transfer the management rights to local governments and adoption of cost-effective yet scientific methods (e.g., environmental niche modeling) for quota allocation to minimize the illegalities.

Keywords: Environmental products, Humla, Nepal, Premature and over-harvesting, Quota allocation, Rent-seeking

T2.20 Novel treatments for wood and biobased products

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

A Data-Driven Holistic Analysis Framework for Economic Impacts Assessment of Forest Biomass for Bioenergy

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: A data-driven holistic analysis framework was developed to aid the industrial development of forest biomass for bioenergy to promote the regional bioeconomy. Leveraging the existing but fragmented multi-source data, four components of industrial bioenergy development were integrated into the framework including spatial statistical analysis of biomass feedstock and bioenergy production, machine learning-based suitability assessment, bioenergy plant sites identification and ranking, and socio-economic impacts assessment. A case study was conducted for forest biomass to pellet fuel in the U.S. Mid-Atlantic region. Our results indicate that the great potential of forest biomass with high variation at the county level is primarily clustered in western Pennsylvania and eastern North Carolina. Integrating the datasets of biomass feedstock, road conditions, employment status, income status, population, and current bioenergy production, the machine-learning model demonstrates good performance for bioenergy industry suitability assessment, with the high-suitable areas accounting for 19.76%, medium-suitable areas for 34.74%, and low-suitable areas for 54.49% in the region. Forest biomass availability and distance to major roads are the two top factors affecting bioenergy industry development. We identified 65 industrial sites within the suitable areas and their rankings were derived as a reference of the bioenergy development priority. The socio-economic impacts assessment indicates that the one-year construction of a medium-size pellet fuel facility (75,000 dry tons/year) could create 127 jobs, $8.78 million of labor income, while the operation could create 202 jobs, $10.52 million of labor income, $14.66 million of value-added, and $33.61 million of output in total per year for the state-level economy.

Keywords: Forest biomass; Bioenergy; Holistic framework; Machine learning; Suitability assessment; Economic impacts.

A multi-criteria decision support system for the optimum provision of forest ecosystem services in a forest-based bioeconomy

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Forest ecosystems and therefore also the forest-based bioeconomy are affected by rapidly changing climatic and market conditions. Climate change makes it essential to increase the resilience of forests to protect them from storms, fires, pests and drought. At the same time, forests should serve as the basis for a sustainable and circular bioeconomy: for carbon sequestration and water retention, ensure a sustainable supply of wood and non-wood products, and serve for recreation and tourism. The complexity of stakeholder demands, as well as the natural influence of the changing climatic conditions, make it difficult to decide on sustainable forest management for the optimum provision of forest ecosystem services towards a forest-based bioeconomy while strengthening the resilience of forests.

The EU Horizon 2020 project ONEforest presents a multi-criteria decision support system that provides stakeholders of the complete forest-wood value chain with information for decision-making. Partially contradictory ecological, social and economic objectives of stakeholders in the forestry and wood industry are assessed, and synergies and trade-offs between different forest ecosystem services and their effects are simulated over the next decades.

In four case study regions representing different climatic and geographical regions (boreal, alpine, Mediterranean and continental climate), different forest management options and their impacts on forest ecosystem services are analysed. In an interdisciplinary approach involving stakeholders, the decision support system is based on forest growth models and combines them with a multi-criteria optimisation approach to reflect stakeholders' demands on the forest-wood value chain. The corresponding impacts on the wood industry are presented with an additional system dynamics model. This system dynamics model is based on material flow analyses and (social) life cycle assessments. Using a scenario technique, future developments in the political, technological, environmental, economic and social fields are considered. The multi-criteria decision support system serves as a blueprint for other European regions to balance forest ecosystem services taking into account the impacts of climate change and the regional situation. Stakeholders (from e.g. forestry, industry, politics and NGOs) can use this support system to optimize their decisions towards a sustainable and circular forest-based bioeconomy.

Assessing the circularity and cascading resource use of Danish wood flows using national material flow accounts

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Understanding how wood is used has important implications for forest management, economic policy, and climate action. While individual wood streams are documented by various sources, a comprehensive, economy-wide mapping of wood use, its circularity and cascading has been lacking in Denmark.

Our study presents a comprehensive national wood flow analysis for all wood products, to include harvest, import, export, and domestic flows through the economy, as well as to assess the level of circular and cascading wood resource use.

The analysis builds on Physical Supply-Use Tables compiled by Statistics Denmark in combination with other sources to construct wood flows including documented and undocumented harvest, import, export, flows between industries and to final consumption, as well as residues and waste. We estimated total Danish use of wood fibre in 2018 to be around 17,747,000 m^3 Solid Wood Equivalents (SWE), of which more than 15 million m^3 was used for energy production. Most wood used in Denmark is imported, with a net import of more than 11 million m^3 SWE.

Based on Eurostat's Circular Material Use rate indicator, 8.4% of wood used is recycled and reused domestically. The overall cascading factor for wood in the Danish economy was calculated to be 1.44, indicating that wood is used almost one and a half times before oxidation or final consumption.

By using simple mass balancing principles, we identified significant undocumented flows of wood into the economy which are currently used for energy purposes, representing more than 1 million m^3 SWE per year from 2015 to 2021.

Ongoing monitoring of wood flows in national economies is paramount in supporting and documenting a transition to a circular bioeconomy and to increase environmental and climate benefits of wood products and materials.

Assessment of the sustainability of apiculture, a forest-based enterprise for improved livelihoods and provision of ecosystem services in Kenya

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Studies were carried out in 2020 to document the status of beekeeping in Kenya's arid and semi-arid lands (ASALs) where rain-fed agriculture is quite limited but opportunities may be explored for non-wood forest products. The baseline survey was complemented by a value chain analysis of beekeeping enterprises in Kajiado, Tana River and Siaya Counties of Kenya. These Counties were until recently sparsely populated and naturally endowed with honey bees and appropriate bee forage plants. The studies incorporated the random administration of questionnaires, key informant interviews and focus group discussions (FGDs) amongst diverse value chain actors. A gross margin analysis was thereafter undertaken to assess the potential and profitability of the beekeeping enterprise. It pointed out an average profitability of USD 88 and USD 13 for crude and refined honey/year per hive respectively, in all three counties. Traditional lifestyles were reportedly facing increasing pressure from land use changes occasioned by human migration and an increasing local population, conversion of rangelands to crop production, livestock overstocking of animals and deforestation for charcoal production. The studies revealed several barriers that limit the commercialization of the sector. They included poor enforcement of laws and quality standards (policy), inadequate knowledge of production, harvesting and processing methods (technical), perceived high initial cost of inputs for setting up apiaries (financial), marketing limitations and taboos that forbid women to participate in apiculture or its association with witchcraft and poverty (cultural). There was little local appreciation of the ecological services offered by bees. The apiculture value chain was thus not fully functional as a forest-based bio-economy in the selected counties, which could reflect the situation nationally. Kenya, therefore, remains dependent on imports to meet a deficit in quality honey and hive products. We recommended the development of comprehensive beekeeping policies incorporating capacity building of actors along the value chain for improved household income and enhanced supply of ecosystem services at the county level. The apparent need to adopt and strengthen enforcement of national and global standards to improve the quality and value of hive products should be addressed.

Key words: Case study, bioeconomy, beekeeping, policies

Açai: Success story of integrating a global product through informal markets with marginal indigenous and local communities

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: In the last decade, açai (*Euterpe oleracea*) has become part of a global chain, with growing markets mainly in the United States and Europe. At the same time, it represents a staple food for a large part of the Amazonian population, including indigenous and traditional communities. Until today, the coexistence of local informal circuits has been possible with the structures of global chains. In our research, we sought to understand how indigenous and local communities participate in the açai chain, both in local marketing circuits and in national and international supply chains. Data on the açai value chain were collected from official documents, interviews and observations during field missions in the Brazilian states of Amapá and Pará. The greatest production and consumption are found in the state of Pará, but the largest exporters are companies in the state of São Paulo. Informal circuits are important to guarantee the food and nutritional security of the local population; however, they are not yet being contemplated by public support although these markets need to improve transport, storage, processing, marketing and communication infrastructure. In global circuits, purchasing companies depend strongly on local communities regarding fruits supply. In this sense, producers coordinating through associations, cooperatives or collective brands makes possible to group larger supplying volumes, as well as requirements for different types of certifications. Challenges arise for both local and global markets, mainly in terms of logistics infrastructure, communication and training of actors, not to mention the variation in production between harvests as it is a predominantly gathering product, and the decrease in supply during the off-season. Fruits providers and enterprises commitments may also enhance natural and social production factors, such has forest management – to avoid process of açaization (increase in the density of açai groves with biodiversity loss) and gathering labour conditions. The success story of açai, to be sustainable, needs to maintain the participation of local actors in the production and marketing activities, as well as local consumers since the fruit is the main food for Amazonian communities and generates thousands of jobs in the Amazon urban centers.

Bioenergy and landscape restoration in Indonesia

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Land degradation is becoming a global challenge, with Indonesia being no exception. Rising populations and their associated food and biomaterial demands have accelerated the conversion of forests for other land uses; a trend that persists in many parts of the world. Forest landscape restoration (FLR) is being promoted as a means for reversing land degradation while providing multiple products and services, including bioenergy. FLR using biofuel-friendly trees under climate smart agroforestry practices and utilizing fruits, nuts and biomass for energy could solve multiple issues by turning unproductive degraded lands into productive landscapes; preventing further conversion of natural vegetation for other uses; compensating for the high initial investments required for FLR; and providing multiple ecosystem services, including climate regulation. This talk highlights multiple issues associated with FLR and bioenergy, such as policy analysis, geospatial assessment for identifying land suitability, farmers' perceptions and species-specific details useful for land managers, planners and policymakers.

Climate and energy policies and forest bioeconomy

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: This paper examines how climate policy impacts the use of wood and allocation of side streams between energy production and higher valued biochemical products in forest bioeconomy. The starting point is the European Union's (EU) climate policy, where burning wood-based side streams for energy is treated as carbon neutral, because emissions from harvesting are calculated in the land-use sector. This policy is compared to an alternative, where burning biomass or use of wood is taxed according to their carbon dioxide (CO_2) content. Emissions trading hits not only direct CO_2 emissions but also increases the price of electricity. We demonstrate that emissions trading favors energy production instead of biochemical production and cascading use of wood, and green certificates may slightly increase use of fossil fuels. As an alternative policy, a carbon tax on harvested wood does not change incentives concerning allocating side streams between energy and bioproducts but a carbon tax levied on burned side stream decreases use of side streams in energy production, thus, promoting cascading use of wood-based side streams.

Does forest contribute to food security? Insights from a study case among small-scale farmers from the northern Peruvian Amazon.

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Forests have a decisive role for achieving SDGs, including those related to livelihoods and food security. A body of literature has illustrated that forests can support food security in some settings, however, this contribution is still not well understood, underestimated and not sufficiently included in policy decisions. The present study attempts to fill this gap by focusing on the forest direct contribution (provision of food and cost-saving) and indirect contribution (sale of forest products) to food security, by measuring the subsistence and cash income of a wide range of forest products and its contribution to the household income. For doing so, quantitative socio-economic data were collected from 400 households (HHs) located in fifty villages from two districts in the Department of Loreto. The research area comprises contrasting districts regarding tenure regimes, levels of remoteness and deforestation. We used the Household Food Insecurity Access Scale (HFIAS) to investigate the degree of food insecurity (access) and the Coping Strategy Index (CSI) to identify the most utilized coping strategies by the households. Our findings evidence that forests play a significant subsistence function on the livelihoods of rural households, particularly in poor and remote settings. The contribution of forests to food security is mainly through the provision of wild food and indirectly through the cost-saving from the use of fuelwood, NTFP (e.g., medicine and construction materials) and timber. We found that forest products such as NTFP and game are important sources of food, particularly for remote and poor households, lacking of alternative incomes. These products are also important coping strategies when HHs cannot access enough food. Even if cash income has a minor contribution to food security, NTFP such as fruits are important cash income sources while providing food for subsistence. Differences were found between tenure regimes and levels of remoteness regarding food insecurity. Our findings evidence the essential contribution of forest to food security (provision of food and subsistence goods) and should call the attention of policy makers and user managers for forest conservation and the sustainable use of forest products, especially in areas affected by deforestation and lacking of alternative income sources.

Efficient utilization of waste wood in a Circular Bioeconomy: Potentials and barriers

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: This abstract focuses on circularity in forest-based bioeconomy and its contribution to achieving sustainability by integrating the economy, environment, and social dimensions. The circular bioeconomy concept is augmenting the academic and political interest since it aligns with the eleven Sustainable Development Goals of the UN 2030 Agenda, where it can contribute to a broader range beyond biomass production. The research comprises a comprehensive literature review on wood waste as a biomass affiliated with a forest-based bioeconomy, explicitly focusing on Germany. The evaluation of the wood waste position in the forest-based bioeconomy examines the integration of the frameworks for policies, initiatives, and influential projects and the most effectively used practices in German territories.

The outcome presents several recognitions of the forest-based bioeconomy benefits beyond the biomass potential. It stimulates research innovation, development, and job opportunities in the economic dimension. Advancing environmentally fosters ecosystem services and improves biodiversity conservation through sustainable forest management. In terms of the social dimension, it empowers the communities with public involvement to feel included and to bring awareness, knowledge, and benefits to society.

This research marks the value of the circular approach in the bioeconomy with a particular emphasis on the Forest sector, the importance of moving beyond the wood biomass perspectives, and the appreciation of the multi-dimensional benefits of forest-based bioeconomy. By adopting circularity in the forest sector, Germany and Europe, in general, can encourage forest-based resource efficiency to reduce environmental impacts and boost economic growth. To unlock the circular economy potential within the bioeconomy, it is crucial to embrace the cooperation of all the stakeholders throughout the whole value chain, involving the policymakers, the research institutions, and the industries. Embracing the cooperation of all these stakeholders throughout the whole value chain not only creates a path for a prosperous future but also emphasizes the significance of a holistic and circular path to a forest-based bioeconomy.

Empirical facts about forest-based production and product transformation on a global level: A stages approach

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Global resources and potentials for wood biomass and other forest products are declining, while the demand is increasing rapidly and the numerous positive effects for people and the planet are well documented. The use of forest products on a global level is hardly investigated from a meta-perspective of a bioeconomy. There is a need for the implementation of efficient forest resource production and use systems. In the context of the Sustainable Development Goal (SDG) 12, especially target 12.2, a far-reaching application of mechanisms of a bioeconomy and technological innovation which provide ample opportunities to optimize the value chain and resource use efficiency is essential.

The global normative system of optimally resource efficient use is contrasted by specific local contexts of socio-cultural, political and socio-economic realities, technological standards, level of development and environmental conditions. These often do not allow the instant shift and implementation of technologically optimal solutions and, therefore, the realization of the bioeconomy.

A stages approach is proposed to characterize contexts and to initiate changes towards improved resource use efficiency and value chain upgrading, thereby leading to bioeconomy transformation strategies. Three exemplary stages, demonstrating the sequence from low to high utilization intensity, are described by case studies: (1) fuelwood production for cooking and heating in Ethiopia, (2) the transition from Acacia wood chips to furniture in Vietnam and (3) steps towards the integrative use of bamboo in Southeast Asia. The lessons drawn from these cases are further discussed using some instruments to enhance utilization efficiency - vertical cooperation among actors across different value chains, innovative financing mechanisms, and the implementation of Participative Innovation Platforms, a recently developed and tested instrument that is used to induce innovation.

Forest-based Sector and SDGs- How this relationship have been measured?

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Established by the United Nations in 2015, the Sustainable Development Goals (SDGs) are a collection of 17 objectives that must be accomplished globally by 2030. The SDGs aim to reduce hunger, increase gender equality, assist sustainable production and consumption, promote decent work, and improve life on land and below water. Forest-based bioeconomy emerges as a significant lead in combating climate change and advancing sustainable initiatives. The SDGs are a well-known acronym, but studies that quantify and delve deeper into this connection are still lacking when it comes to the forest sector's contribution to them. It is essential to understand how the link between forests and the SDGs has been explored in order to fully understand its synergies and trade-offs. In order to identify the approaches that have been employed, a review of methods to measure the Forest sector's contribution to the SDGs was performed. Articles from popular databases were analyzed according to inclusion and exclusion criteria, and 83 articles were chosen for investigation. Studies from 2015 to 2022, written in English, from different geographic regions, were grouped into eight methods categories, named: content analysis, personal perceptions, interpretative analysis, frameworks, models, impact analysis, time series data, and SDG Indicators. Along the studies, common approaches include Earth observations, remote sensing, the iSDG model, literature reviews, systematic reviews, SWOT analyses, case studies, the Delphi approach, online surveys, critical and theoretical analysis, macroeconomic modeling framework, Life cycle assessment (LCA), satellite image processing, SDG 15 targets, nature-based solutions, among others. The study aimed to encourage more research by providing an overview of approaches that have been used to address the issue. However, having a broad range of measurements available to address the SDGs can be challenging, since a large variety of methods applied also leads to difficulties in comparing, analyzing, and tracking them. In conclusion, future opportunities will demand more holistic approaches that should be used in order to understand all aspects involved in this context and more dynamic and systemic approaches must be further investigated.

Forestry beyond growth: Natural disturbance, degrowth, and the forest carbon sink

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Economic growth is a major driver of climate change and biodiversity loss. Proposals to avert catastrophic climate change by downscaling economic growth (i.e., degrowth) are hotly debated, but the implications for forests remain largely unexplored. This presentation aims to introduce degrowth to forestry and forestry to degrowth. We show that previously-identified degrowth trajectories consistent with 2°C can generate negative Ramsey discount rates, complicating the use of the standard Faustmann formula. To address this, we derive an inclining rate schedule for the degrowth to steady-state transition and use it to explore how optimal management under disturbance risk might be altered by the expectation of a sustained economic contraction. To our knowledge, this is the first microeconomic analysis proposing a potential link between degrowth and forest composition. It suggests that even bioeconomy sectors which are not directly targeted for degrowth might be impacted by discount rate effects, including changing carbon dynamics and disturbance vulnerabilities. It also highlights that by simplifying their treatment of forest carbon dynamics, past efforts to model degrowth pathways may have neglected an important feedback: forest managers' expectations about the economic future.

From branch to beam: The resource-smart transformation of low-quality tree assortments into structural building materials

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Defossilization efforts in the construction sector require the increased use of modern engineered wood products, which are mainly produced from conifers at present. But, in the face of climate change adaptation, Europe's vegetation shifts towards potentially more resilient hardwood and mixed forests. Since hardwoods differ fundamentally in their habitus and mechanical-technological properties, new approaches are urgently needed to increase efficient hardwood utilization. Indeed, bridging forestry and the wood processing sector is essential for mastering this challenge.

Therefore, the presented utilization concept starts in the forest, where deciduous trees including *Fagus sylvatica, Quercus petraea* and *Populus alba* were inventoried in their entirety using Personal Laser Scanning (PLS). Thereby, information on branch volume, diameter, length and inclination is collected since this assortment, together with the stem top, accounts for up to 50% of the aboveground biomass in deciduous trees.

The PLS data allows efficient sorting and breakdown of the non-uniform assortments into easy-to-transport dimensions. Furthermore, the PLS data can partially enhance our understanding of branch wood's variability in mechanical material properties.

Downstream processing is carried out using a technology, whereby the wood segments are processed in longitudinal - radial direction and split into elongated macro-fibres. Compared to traditional sawmilling a higher yield can be achieved with this technology. At the same time, the natural wood structure, which is important for the final mechanical properties, can be retained. In the final step, the fibre elements are further processed into structural beams and panel products relevant to construction.

This highly material-efficient utilisation concept for low-value hardwood is expected to enable a high proportion of forest product utilisation also in the future, contributing to a resource-smart use of biomass in the emerging bioeconomy.

From Neglect to Opportunity: Exploring the Potential of Non-Wood Forest Products in Europe's Bioeconomy through Innovation Cases

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: The contribution examines the overlooked potential of non-wood forest products (NWFPs) in the context of forest-related bioeconomy research and policy. Taking an innovation system perspective, the study identifies barriers to NWFP development and proposes strategies for their support. By analyzing 20 innovation cases in Europe through document analysis and semi-structured interviews with experts, the research reveals that there is no singular innovation system dedicated to supporting NWFPs. Instead, sporadic support is provided through specific programs within different sectoral or regional innovation systems such as forestry, agriculture, nature conservation, rural, or regional development. Unfortunately, the institutional system exhibits a notable neglect towards NWFPs, resulting in a lack of statistical data, research, educational programs, training initiatives, and focused support structures. This study uncovers significant potential for NWFPs in the forest bioeconomy, particularly for private forest owners and producers. These opportunities range from subsistence-based NWFP collection to collectively organized production that benefits rural areas. The identified activities primarily involve product innovations, with some instances of service or social innovations, and a few cases combining multiple types of innovations. Drawing from successful examples, the study proposes suggestions to enhance innovation support structures

How to define and measure substitution effects in bioeconomy: A scoping review

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: The substitution of bio-based resources instead of fossil-based ones is an important goal of the bioeconomy. Reviews and methodological approaches already exist on this topic; however, such existing scientific basis encompasses a wide diversity of definitions and quantification methods. Identifying how substitution effects are defined and what methods are used for their quantification will serve as the basis for the development of a framework concept for the evaluation of bio-based resources usage. This review, following the PRISMA extension for scoping reviews, documents the working definitions and quantification methods of substitution effects within bioeconomy. Appropriate peer-reviewed literature was searched for using databases from SCOPUS and Web of Science. Following an iterative identification process, selected articles for review included a mention of the term “substitution effect”, the type of biomass (agricultural, woody, fish), and the type of substitution (for material use or energy conversion). The resulting selection of articles was limited to publications in which a definition for substitution effects has been provided and a corresponding quantification method has been explained. From the selected articles we extracted information on methods applied for quantification of substitution effects, biomass types used for substituting fossil-based products, as well as on bio-based products and sectors. Preliminary results show that life cycle assessment methods are predominantly used and that a significant number of articles focused on the substitution of wood-related products for non-wood products. The findings of the full review will be used to develop an assessment of substitution effects within the German Bioeconomy Monitoring in order to identify more efficient and sustainable uses of bio-based resources.

Investigation of a Set of Indicators to Support the Establishment of Wood Biomass Heat Supply Projects: A Case Study in Japan

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: The demand for woody biomass energy in the region creates market value for small diameter wood and low quality wood. This will increase production opportunities for the main product, wood, from an economic standpoint, resulting in a synergy that improves the supply and stability of woody biomass as a by-product, contributing to the sustainability of forest resource use. Therefore, the promotion of appropriate woody biomass energy use is an important factor for sustaining a forest-based bioeconomy. Avoiding the risk of feedstock shortages is important for the establishment of woody biomass energy use. On the other hand, it is necessary to stably procure a certain amount of woody biomass to ensure the sustainability of the energy business. Therefore, an accurate evaluation of the amount of available woody biomass and improvement of its supply potential are required. Promising measures to increase the supply potential include higher purchase prices, subsidy policies, and infrastructure development, but there is a cost trade-off. On the other hand, the use of biomass energy has multifaceted benefits such as ensuring energy security, revitalizing local economies, and reducing GHG emissions. Therefore, in order to support and evaluate the energy use of woody biomass, it is important to present a comprehensive set of indicators such as the amount of available energy, the possibility of improving the supply potential and its cost, and the benefits to be obtained. In this study, these indicators are calculated for Shiwa Town, Iwate Prefecture, which is an advanced case study site for wood biomass heat supply in Japan. The town is currently planning to further expand the scale of heat supply, and this study examines the feasibility and necessary measures for this expansion.

Less grey more green, less concrete more wood? Construction material narratives toward sustainability

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Purpose: Given historical developments in the construction sector and the path dependencies inherent in current practice, this study aims to capture the rhetoric amidst construction industry (wood vs concrete). We focus on the competing narratives employed by supporters on both sides of this “material warfare” and specifically investigate their advantage and disadvantage arguments.

Design/methodology/approach: To meet our objective, we looked at news articles through Google search tool using keywords “wood vs concrete building construction”.

Findings: The articles are published as early as 2006, and along the years, the competing conversations are more prominent with the “birth” of mass timber. The topic is also becoming an interest for specific audiences such as the architects, engineers, and insurance companies. Through inductive thematic analysis of 100 articles, we find that cost and sustainability are two dominant factors in the narratives.

Originality/value: Each sector claims to be more cost effective and sustainable than the others, typically sniping at each other. This rhetoric, we argue, will not be beneficial for society and environmental sustainability. A sustainable built environment requires cross sector collaboration between wood and concrete companies to handle difficulties that they cannot address successfully within their own sector.

Monitoring public perceptions of forest-based business in the drive towards the bioeconomy

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: *The pathway to a forest-based bioeconomy requires a higher level of interest and investment in forest-based business, including the need for increased propagation, planting, forestry operations, processing and consumer use of wood and fibre products. Each stage presents risk due to lock-in of existing production flows and industry investment. An inherent risk is that of public acceptability of new bioeconomy production, circularity, and desired consumer behaviour.*

This research has been underpinned by a gap in knowledge about public perspectives of forestry and forest management practices, as well as growing awareness of the cost of losing social licence or resistance to new forestry developments. As many national bioeconomies are heavily reliant on forest sector strength, and others look to increase their forestry plantings and investments, we need a better understanding of forestry's social licence. Industry-level support from publics is needed for forest bioeconomies to thrive. Policy makers need to be confident that developments to meet circular and biobased production goals are not shut down by societal concern, and investment returns are not undermined by unforeseen developments in the consumer marketplace.

A segmentation survey revealed five clusters of typologies based on concerns for plantation forest practices, values, worldviews and environmental identity, levels of trust in forestry and support for commercial forestry. Clusters also showed differences in degrees of agreement with social, cultural environmental and economic values; different orientations to scientific, western and indigenous worldviews; and a characteristic tendency towards specific demographics associated with some clusters.

Identifying public views that lie outside of dominant media voices or opinion leaders creates a baseline from which future changes in social licence can be measured, anticipated and responded to. Social reactions can be monitored, and proposed solutions provided to address negative reactions before they become an issue. In addition, the range of personas present within these typologies supports targeted messaging towards certain public groups, identifying segments of society that may require specific social impact assessment, or personas that will be more likely to give support to forestry-based bioeconomy initiatives, particularly those large in scale or that may change the landscape or social fabric within communities.

Novel natural capital approach to value creation in the development of forest-based business: resilient and socially just economies

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Natural Capital refers the world's stocks of natural assets which include geology, soil, air, water and all living things. The natural capital provides a wide range of raw materials, products and ecosystem services making human life possible. In this, the Planetary Boundaries set the safe operation space for humanity (Steiffen et al., 2015). Especially two of the global challenges, climate change and biodiversity loss, influence directly on the natural capital-based bioeconomy. The changing operation environment, such as awareness of environmental pressures, EU policy regulation, and regional policy targets related to, for example, energy security, industrial policy, and just living call for 1) strengthening the resilience of the natural capital business models and 2) innovating new businesses for integrated value creations based on climate and biodiversity wise solutions.

The novel natural capital business challenges the prevailing silo-structures of the natural capital sub-sectors, such as agriculture, forestry, renewable energy, mining. In this the recent cases indicate both financial profitability and environmental sustainability of integrated agri-forest-environment business models, e.g. from Indonesian forest-plantation context (Mikkilä et al. 2021) and circular bioeconomy models in Southern Finland (Leppäkoski et al., 2021; Luhas et al. 2022). Furthermore, the Forest Biodiversity Program for Southern Finland (METSO) shows the voluntary forest protection by landowners based on public-private partnership. The program enhances biodiversity by developing permanent and temporary protection agreements and compensating a part of the commercial value of forest and land to landowners (https://mmm.fi/en/forests/biodiversity-and-protection/metso-programme).

Novel approaches integrating more holistically natural capital related sub-sectors and operations needs to be addressed in research and economic development to turn the grand challenges to opportunities in novel natural capital business. The scale of the solutions can vary from micro to global ones, but the sustainability of the models should lay on the strengthening of the resilience and social justice of societies. To address the need for new natural capital business, we model in this paper, employing a literature review, 1) what active management and productizing of forest nature values (specific ecosystems) is, 2) how pricing and trading models can be developed, and 3) how the required banking model is outlined.

Opportunities for a sustainable and circular development of the wood sector in Wallonia

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: In the framework of its strategy for smart, sustainable, and inclusive growth, the European Commission has introduced the concept of Smart Specialisation Strategy (S3) with the objective to enable Members States to adopt new regional strategies for scientific research and industrial innovation. The Walloon Government adapted its Strategy S3, for the period 2021-2027. Its objective is creating new and robust ecosystems of innovative "academic and industrial research" around five main strategic areas, amongst others circular materials. Wood can be a circular material, and within this framework, the initiative "VALorisation du BOis en WALlonie - VALBOWAL", leaded by the University of Liège and supported by other Walloon Universities and organizations/companies, has been accepted with the goal to support Walloon circular economy development while diversifying the Walloon forests, strengthening their resilience to climate change and increasing their carbon storage, whilst stimulating the local economic development of the wood sector, and optimizing the carbon storage in wood products. Three research axes, completed by a transversal axis focusing on professional training and wood promotion, have been proposed, to encourage fundamental developments in three major fields:

- **Resilient and diversified Walloon forests** with the objective to rethink the constitution of regional forests with more diversified, more dispersed and multiple ages species, while striving to make it more productive and relying on digital technologies (inventory, resource mobilization and traceability).
- **First and second transformation of wood from Wallonia** with the objective to strengthen the use of hardwoods, underexploited in Wallonia, and the recovery of wood waste in the development of structural elements and by-products for construction and green chemistry.
- **Valorisation of local Walloon wood in building sector** with the goal to encourage the use of innovative and circular wood products, to achieve the objectives of carbon neutrality and circular economy in the building sector

This contribution will present and discuss the first research results and its action plan for research and innovation and the role of this initiative within a European context for the coming years.

Potential mismatches between forest management and relevant targets of global sustainability

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Global climate and biodiversity crises pose imminent challenges to meeting global targets for sustainable development in 2030. Forests are essential components of the Earth system as they contribute to local communities' wellbeing and social-economic development through e.g. mitigation and adaptation, biodiversity conservation, energy and material supply. Efforts in global decision making for ensuring short term sustainable development targets have been made so far, but downscaling remains largely uncertain. The way forests are currently managed determines whether the contribution of these key ecosystems to sustainable development goals will be met in the near future. By further developing UN stats at global scale, we evaluate the country-based correlation between forest management intensity and the most relevant indicators of sustainable development targets. To refine the indicators' set and improve their scientific soundness and replicability, we gap-fill the information with remote sensing data. By global region, we find that forest management positively correlates with most of production and economy-related targets under investigation, but negatively with targets dealing with reducing the human impact on environment, including the resulting risks for local populations. Also, the historical signatures of these correlations do not show a linear increasing or decreasing trend, likely due to the complexity of processes at stake. Based on our findings, we argue that: correlation between forest management and sustainability targets should involve multi-sectoral analysis to be fully explained; our analysis is a primer addressing this correlation, but the complementary causation can only be disentangled with more specific studies; the indicators currently used for sustainability targets can be improved by including impact and response functions. In conclusion, our study sets the stage of the current correlation between the intensity in use of global forest resources and the variation of sustainable development targets in a broad context. Our findings stimulate the multi-scale monitoring of forest resources and the assessment of the contribution of forests and forest management to reaching sustainable development from global to national scale.

Preparation of Oleocanthal and Oleacein from Canarium oleosum Based on CPC Technology and Their Antioxidant Activities

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Olive oil, as an important part of the Mediterranean diet, can prevent type 2 diabetes, cancer, neurodegenerative diseases and cardiovascular disease, which is mainly attributed to its rich monounsaturated fatty acids (C18:1,55%~83%), as well as alcohol, sterols, hydrocarbons, phenolic compounds, especially phenolic alcohol and cyclic ene ether derivatives. Total polyphenol extract (TPF) in olive oil is a complex mixture, including simple phenols, lignins, flavonoids, terpenoids, and triterpene acids, among which the most characterized components are hydroxytyrosol, tyrosol, oleuroside, OLEO (common name stimulating aldehyde), OLEA (common name oil essence), etc. OLEO is a nonsteroidal anti-inflammatory drug with stronger activity than ibuprofen, and also has strong antioxidant, neuroprotective, anticancer, and bacteriostatic effects. OLEA also has strong antioxidant, anti-cancer, bacteriostasis and other functions, and also prevents and suppresses cardiovascular diseases and cellular aging. However, the yield and quality of olive oil polyphenols are seriously affected by genotype, environment and processing technology, resulting in the separation and purification of OLEO and OLEA are very difficult.

Based on centrifugal partition chromatography (CPC) and supported by thin-layer chromatography, preparative chromatography or other purification methods, the total polyphenol extract (TPF) of olive oil extracted from extra virgin olive oil was used as raw material to separate and prepare oleocanthal (OLEO) and oleacein (OLEA) quickly in forms of monomer compounds, then characterized their structures by ^{1}H NMR and their antioxidant activities were also investigated. The results showed that 9 g of extract dissolved in 20 mL of methanol, and 14 fractions were obtained during the process of CPC with a solvent system of n-hexane/ethyl acetate/ethanol/water volume ratio of 3:2:3:2. After purification, OLEO of 422.3 mg and OLEA of 163 mg with a purity of above 95% were gotten respectively; the antioxidant activities of OLEO and OLEA at different concentrations (0~1 g/L) evaluated by their free radical scavenging capacity on $ABTS^{+}\cdot$, DPPH· and T-AOC total antioxidant capacity, it indicated OLEA had stronger antioxidant activity than OLEO, and the IC50 values of OLEO and OLEA for DPPH· were 0.029 and 1.85×10^{-11} g/L, respectively, and their total antioxidant capacities reached the highest of 0.1571 and 0.6462 mmol/L $FeSO_4\cdot7H_2O$, respectively.

QUALITY CRITERIA FOR INDICATORS MEASURING SUSTAINABILITY OF FOREST USES

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Assessing and enhancing the sustainability of forest use practices is a key element in transition towards more sustainable bioeconomy. Climate change and biodiversity loss are increasing the risk for severe disturbances and imbalance in key earth system processes. Transition to more sustainable consumption and land use are needed to avoid more losses in health and wealth of humankind and to conserve viable ecosystems and biodiversity. Forests and the ways we utilise them play an essential role in achieving this transition.

Being able to verify the effects of forest management to sustainability requires measuring it in a way that is reliable, cost-effective and acceptable for stakeholders. Hence developing such criteria and indicators to prove the sustainability of forest use is of great importance for forest-based bioeconomy's social acceptance and economic viability. With shared understanding about how to measure changes in sustainability the decision-making about the use of natural resources can be founded on widely accepted knowledge.

Based on literature review we created a set of six quality criteria for sustainability criteria and indicators to help decide which criteria and indicators are appropriate for practical decision situations. We tested the quality criteria in a process of developing sustainability criteria and indicators for measuring the sustainability changes of forest use in Finland.

We collected suggestions for sustainability criteria from a selected group of stakeholders in a series of workshops during autumn 2021. The workshop process followed a collaborative "joint fact finding" approach. We thematised the collected data and tested the created criteria and indicators against the quality criteria. Instead of the widely used categories of economic, ecological, and social-cultural sustainability we created six main categories for relevant indicators that can support the decision-making. The tested set of criteria was then discussed again with stakeholders and other researchers and amended accordingly.

Our study advances the methodology of measuring sustainability of the use of natural resources,

especially forests. In our presentation we discuss the selected six quality criteria and their use as well as the six main categories of sustainability criteria.

Shaping the bioeconomy: Challenges in aligning the German National Bioeconomy and the German National Biomass Strategy

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: At the beginning of 2020, the German Federal Government adopted the National Bioeconomy Strategy. For the Federal Government, the bioeconomy encompasses the production, development and use of biological resources, processes and systems in order to provide all sectors with products, processes and services within the scope of a viable economic system. The aim of the National Bioeconomy Strategy is to develop bioeconomic solutions for the sustainability agenda, recognise and harness the potentials of the bioeconomy within ecological limits, expand biological knowledge and turn Germany into a leading research and innovation site of the bioeconomy.

The German National Biomass Strategy compliments the German National Bioeconomy Strategy. It provides clear political guiding principles and specific policy tools for the management of biogenic material streams against the background of climate protection, biodiversity conservation and food security, as well as to aid producers and users of biomass with regard to the sustainable, efficient and climate-friendly production and use of biomass.

This presentation discusses the challenges in aligning the two strategies; it highlights the task of sustainable bioeconomy policy to shape the political framework conditions in such a way that biomass is provided and used sustainably and where it is most effective; it reflects the role of science in providing information about sustainability and effective use of biomass and finally, it points to the areas where further research is needed to shape a sustainable bioeconomy.

Sharing economy in the forest-based sector

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: The potential of sharing economy has been investigated in various fields of economy, but not yet in detail in the forest-based sector, although the principles of sharing economy are in line with sustainable bioeconomy. Because current economic situation is rather turbulent and societal preferences have been changing too, information efficiency and costs saving remains crucial for decision-making in all companies, irrespective of their legal form and size. Economic benefit is one of the main reasons for adopting sharing economy by companies. The main aim of the contribution is to answer questions of potential and future utilization of sharing economy principles in companies along forest-based value chain. The methodological approach consists of two main methods, questionnaire surveys among Czech and Slovak companies in the forest-based sector and semi-structured interviews with representatives of these companies with decision-making power (mostly management bodies of these companies). Selected results obtained from the surveys are processed statistically to provide relevant conclusions. The findings indicate potential for utilization of sharing economy principles in the forest-based value chain, however there are also important limiting factors, e.g., time and regional factors and information deficiency. Findings of the research are important primarily for management of the companies in the forest-based value chain, mostly in Czechia and Slovakia, but the findings are potentially applicable to all companies in the above-mentioned value chain in central Europe.

Shedding light on the obstacles in the way of doubling the Finnish forest bioeconomy

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: The forest industry's contribution to the value added of the Finnish national economy per cubic meter of wood has decreased markedly since the heyday of paper production. Finland's bioeconomy strategy aims at doubling the value added of its bioeconomy by 2035, and thus also doubling the value added of the forest bioeconomy. This would improve the industry's global competitiveness and ability to pay for wood while strengthening the Finnish national economy. The achieved increase in the overall wealth of Finland would help in balancing the downsides of growth and finance the necessary changes the ambitious target requires.

Doubling the value added of the forest sector requires extensive changes in the value chain and ramped up production of novel higher value products based on the principles of the circular bioeconomy without increasing wood usage and causing environmental harm. There are obstacles and bottlenecks in the way of the changes this transformation requires. Shedding light on these is necessary to direct public resources efficiently and sustainably. In this project commissioned by the Finnish Prime Ministers Office, the aim is to produce quantitative information on the potential of increasing the value added of the bioeconomy and the obstacles in its way.

This research will focus on the obstacles and bottlenecks for increasing the value added of the forest-based bioeconomy. The research will be conducted by carrying out a literature review in autumn 2023 and interviewing companies in the forest bioeconomy sector in the beginning of 2024. The literature review will focus on the past 5-7 years to guarantee its topicality. The interviews will focus on the obstacles and bottlenecks inhibiting or slowing down the scaling up of the company's production and value chains. The interviewees will also be asked for suggestions on how to get rid of these obstacles and bottlenecks or ease their effect.

Stakeholder perception of climate change adaptation measures along the forest value chain

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Context: Climate change poses a growing threat to the resilience of European forests due to the increasing frequency and severity of natural disturbances on an increasingly larger scale. As a result, the wood value chain is subject to periods of under- and oversupply. Efforts to enhance the adaptive capacity in the wood value chain are often not streamlined between forest management and the processing industry.

Specific topic of the study: In our study, we aim to find out how different stakeholders along the wood value chain perceive different climate adaptation measures, regarding their feasibility and effectiveness over time and on a spatial scale. By the feasibility of a measure, we understand how difficult it is to implement a measure regarding financial, human and time constraints. By the effectiveness of a measure, we understand the success of a measure to cope with climate change-related disturbances.

Methods: We are conducting an online survey from May-August 2023 with a sample of stakeholders working along the wood value chain or in governing authorities in Europe. We focus on nine regions: The New Forest (UK), Catalonia (ES), Bauges, (FR), Galicia (ES), Finland, Ireland, Istria (HR), Kostelec (CZ), and Upper Rhine valley (DE). However, stakeholders from other regions are also welcomed to participate.

Preliminary results: We expect that stakeholders along the wood value chain assess it to be more important to take adaptation measures in the future than at present time. This effect is expected to be stronger for the processing industry than for forest management. Furthermore, we hypothesize that stakeholders along the wood value chain assess it as more important that an adaptation measure is feasible than effective. Lastly, we expect that stakeholders in regions with a high frequency and severity of forest disturbances consider adaptation measures more important.

Conclusions: In the end, we hope to point out adaptation measures that lead to synergies between forest management and the processing industry. Subsequently, we would like to formulate an advice to improve communication and strengthen resilience in the growing bioeconomy. At the time of the IUFRO Stockholm 2024, we will present the final results.

Towards a sustainable forest-based bioeconomy in Germany– socioeconomic indicators and resource productivity

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: The monitoring of socioeconomic indicators of the forest-based sector in Germany was initiated as part of the Charter for Wood initiative in 2004. The objective was to increase the per capita use of wood and wood products from sustainable production. At this time, sustainability referred to sustainable forest management and production of wood and wooden products, climate change mitigation effect through increased CO_2-storage, and the creation of jobs and value added. To monitor these goals, wood use and socioeconomic development of the forestry and timber cluster have been quantified on an annual basis in wood balances and cluster statistics. These approaches provide data on jobs, turnover, and gross value added of forestry-based economic activities as well as on total supply and use of wood and wood-based products.

Since its initiation, the German Charter for Wood has evolved and is dealing with more sustainability aspects. In today's circular bioeconomy approach CO_2-storage in wood-based products remains an important aspect, as does employment. However, the transformation of fossil-based towards bio-based economies is bringing the obvious limits in availability of wood and biomass in general to the front. Circularity aspects for a sustainable use of biomass are becoming increasingly important.

However, circularity still remains an ambiguous concept covering a range of approaches. Two main approaches are the operationalization of circularity within the existing economic system and the transformation of the socio-economic structures. The forestry and timber cluster is not yet characterized by fully closed production loops, and efficient material use of wood, i.e. reducing, reusing and recycling, needs to be further implemented in wood-processing value chains. In 2020, gross value added of the German forestry and timber cluster was approx. 60 billion Euros and a total of almost 126 Mio. m³ of woody resources (including roundwood, wood residues, and post-consumer wood) were used. To link outcome of wood processing to resource use we calculate resource productivity and use available data on wood material flows and socioeconomic output indicators. We present disaggregated results and discuss implications for reducing, reusing and recycling woody resources in the forestry and timber cluster on its way to circularity.

Unlock Potentials of Forest Sector in Bioeconomy Development: Case of China

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: China by far is the largest producing and consuming country on concrete and steel, coal, paper and paper board, fossil fuel based products like polyester fiber and plastic (PVC). Since 2000, China speeded up the swift from traditional economy development model to green economy development with increased demand on bio-based technologies, materials and products. In 2021, China National Development and Reform Commission issued the 14th Five-Year (2021-2025) Plan for the Development of Bioeconomy", pledged again China's commitment on promoting bioeconomy development since it's first National Bioeconomy Strategy was published in 2007. Forest sector could play curial role in bioeconomy development given by replacing the fossil fuel based raw material with renewable forest resource based products. 231 million hectares forest, 19.5 billion m3 forest stock, and the forest sector with total output value over 100 billion USD annually provided a solid foundation for forest bioeconomy development in China. However, the external challenges still along with the numerous opportunities. We first reviewed bioeconomy strategy development China, summarized the forest bioeconomy development history, current situation and challenges, then using PEST model to analyze impacting factors from political, economic, social and technological angel. In the end, we provided recommendations on how to improve the policy support, leverage successful business model and better unlock the forest sector's potentials in China's bioeconomy development.

Unlocking the bioeconomy of NTFP in the northern Amazon of Bolivia

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: Despite its great potential, the contribution of Brazil nuts (*Bertholletia excelsa*) to Bolivia's Gross Domestic Product (GDP) is low (close to 1-2%). However, it was not always so. The economy based on the harvesting of non-timber forest products (NTFP) is part of northern Bolivia's history and recent past. The fall of the quinine economy, which occurred towards the end of the 19th century, was followed by the exploitation of rubber (*Hevea brasiliensis*). The challenge was to transport the rubber up the river, to the Andes. Everything would change with the discovery that the Mamoré and Beni rivers flowed into the Madeira River and that before they converged at a junction, which was called Cachuela Esperanza. The activity of rubber promoted the establishment of the so-called "barracks", along with the often-forced migration of indigenous people. It is estimated that rubber exports fluctuated between 8 and 12% at the beginning of the 20th century and after booms and busts it reached its final collapse towards the end of the 80s. The history of the Brazil nut begins in the 1920s, but it was during the 1960s that it would reach its first peak with around 5-6 million tons of exports, a volume that was maintained until the early 1980s, when the conformation of beneficiary companies in Bolivia northern would consolidate a processing capacity that would end up taking off the industry as we know it today (20-25 millions of t exported per year). The geography of the Brazil nut in the north of Bolivia is a legacy of that of the rubber, with important participation of barracks, today, private properties. The big difference is in the presence of local communities' owner of these forests, who has undertaken another colossal challenge, to be the cornerstone of another resource, the harvest and sale of the pulp of açaí berry (*Euterpe precatoria*). This process is supported by the creation of sub-national protected areas and other effective area-based conservation measures (OECMs). How this revival of NTFP can get to participate in Bolivia's GDP is an open question.

Where does the wood come from? A physical accounting model to trace the origin of wood-based products

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: In today's globalized world wood-based products are often imported from countries other than those where the wood was grown. Bilateral trade statistics are thus only of limited help for getting a better understanding of how production-related environmental impacts are caused by consumption elsewhere. This study presents a novel physical accounting model that allows flows of wood-based products to be traced along international supply chains, therefore making it possible to consistently relate the consumption of wood-based products to the origin of roundwood. In comparison to previous studies, the proposed method covers entire supply chains, including finished wood and paper products, such as furniture and printed matter, and also accounts for flows of processing residues and recovered paper. The main results of the accounting model are detailed country-by-country matrices indicating the locations of origin of the products consumed in a given nation. For instance, it is revealed that out of the finished wood products consumed in the USA in 2018, 75.6% originated domestically, 10.7% from neighbouring Canada and the remaining 13.7% from other countries.

Wood construction and pulp and paper – two examples of circularity - in a long-lived wood products value chain and a commodity with short life span

T2.21 Pathways towards sustainable and circular forest-based bioeconomies: Advances in research to address challenges and realize opportunities

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Abstract: The forest sector is naturally situated both in the biological and the technical cycles of sustainable and circular bioeconomies. Wood itself, as a natural raw material has several advantages over other materials circulating in economies. It is therefore well fitted to embrace a bio-based economic model of the future. This paper analyzes how circularity concepts can be applied in two key forest-based industries: the wood construction as an example of long-lived wood products value chain, and the pulp and paper industry as an example of wood-based commodity with a short life span.

The paper analyses circularity and sustainability in at different stages of these two value chains, including, for the wood construction, the impact of different material development technologies (CLT, LSL, LVL, OSL, PSL) and building methods (mass timber, panelized construction, modular construction, off-site construction). It also looks at the circularity aspects of the retrofitting and demolition of existing buildings and the need for increased recovery and reuse of wood. For the pulp and paper industry, the focus is made at the sustainability and circularity of pulp production, different types of paper products, and industry processes using pulp to obtain end products with different qualities and applications, such as printing, packaging, and hygiene papers.

Whether or not evaluated practices are sustainable has been assessed taking into consideration on three pillars: environmental protection, economic viability, and social equity. The evidence and information reviewed comes from desk research, and an examination of scientific literature. Additional information has been provided from official government sources available to general public and supported by case studies and examples of good practice.

The conclusions in both wood construction and pulp and paper point out to the potential laying in improved design, innovation and the increased recovery and reuse of residues, in particular the post-consumer streams. Some measures, such as those related to extending the life of products, including reuse, recycling, and energy recovery, are known in the industry practice, while others, including waste management, need further promotion and mainstreaming wherever and whenever economically, socially, and environmentally viable.

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

Analysis of Forest Landscape Attraction Based on Machine Learning of Photo Content – A Case Study of Yulong Snow Mountain National Geopark in China.

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: Forests are renowned for their unique landscape, ecological and health values, attracting numerous tourists annually. Conducting perception research on forests can aid in unveiling their cultural and social significance. Recent research on environmental perception and aesthetic preferences has focused more on user-generated photos posted online, which employ machine learning to explore landscape features that attract visitors. To this end, this present study focuses on Yulong Snow Mountain in Yunnan, China, a national geopark, whose mountainous forests and Tibetan culture are popular tourist attractions. Over the years, the local government has invested heavily in infrastructure development to cater to tourists. This study draws from three data sources: 1) a set of photographs taken by botanist, Joseph Rock, almost a century ago; 2) photos token by researchers during site investigation ; 3) and photos posted by tourists on Twitter and Flickr. The photos are labeled by employing image recognition technology, followed by a clustering algorithm that leverages word-vector models to identify landscape elements, including tourism infrastructure, and the interaction among elements in forest imagery. Through photo content analysis, this research accomplishes three main goals. Firstly, it employs a comparative approach to reveal the transformation of Yulong Snow Mountain forest landscape in the past century. Secondly, it delves into the appeal of the forest landscape to tourists, exploring their perceptions and preferences. Finally, it uses photo content to discuss the influence of tourism infrastructure development on tourism.

ARF@Pt creating free easy-access economic analysis for Portuguese forests

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: Forest profitability has long been debated in Portugal. However, the few studies carried out over the years have always been scrutinized and criticized for not accurately representing reality. Controversial opinions regarding the management practices and silvicultural operation costs considered in these studies have been some of the reasons behind the discredit in the conclusion that forests are little to not profitable. The ARF@Pt is a task force created to tackle the limitations recurrently pointed in these studies. Coordinated by academia and involving stakeholders representing different groups (academia, public administration, research institutes, forest owners' associations, industrial and private owners, industries) the task force meets to discuss perceptions and knowledge sharing.

On a first stage, the participatory process allowed setting a common ground for preparing the inputs to be used to running forest growth simulations and economic analysis. These simulations intend to cover a range of tree species and site productivities, considering difficult and easy terrain conditions in combination with alternative management approaches, characterized by commonly agreed silvicultural operations' schedules, operation costs and stumpage prices. Once the simulations were run by academia, a second round of meetings was scheduled, where simulation results with integrated economic analysis, were presented and discussed with the group. Simulations were re-run whenever readjustments were required.

The ARF@Pt ultimate objectives are providing available analysis to stakeholders in a free easy-access dynamic web platform while contributing also with sound-results for the definition of appropriate governance measures that can properly assist the sustainable role of forests in bio-economy.

Climate change perceptions and environmental values in forest bioeconomy: the case of public preference for forest management in Norway and Sweden

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: Forests deliver multiple ecosystem services fundamental to human well-being. As forests and derived industries play a pivotal role in bioeconomy, the pressure on forests to supply both wood and non-wood products and services increases together. Climate mitigation and adaptation, and preservation of habitats stand out as the main overall aims alongside wood production in the Nordic countries. Provision of these ecosystem services is strongly modified by forest management, and understanding public preferences for forest management strategies helps create effective and socially acceptable policies. We implemented a binary discrete choice experiment through surveys conducted in Norway and Sweden to elicit public preferences to changes from the *status quo* in key forest management attributes – increased set-aside area, proportion of uneven-aged tree stands, and number and type of tree species, within privately-owned production forests. These changes represent adding more weight to non-wood forest values than the current regular management and are named as *alternative forest management strategy*. Willingness-to-pay (WTP) estimates for the selected attributes were assessed using a binary random-effect logit model. Particularly, we tested whether climate change perceptions – represented by psychological distance to climate change – and environmental values are significantly associated with preferences. The Norwegian public preferred larger set-asides and diversification of tree species but was indifferent to tree age distribution, while the Swedish public favored changes in all three attributes. Norwegian and Swedish public commonly attached the highest WTP to increasing set-aside areas but had much lower WTP for other attributes. Noticeably, we found that psychological distance to climate change and environmental values were significantly associated with preferences. Greater psychological distance to climate change was a strong determinant of preferring the *status quo,* while greater biospheric values had a significant relationship with preference for *alternative forest management strategy* in both countries. Our results imply unequivocal support for increasing set-aside areas in Norway and Sweden. It showcases an important example of incorporating behavioral approach in designing forest bioeconomy models.

Keywords: Ecosystem services, forest management, climate change perceptions, environmental values, public preference, willingness-to-pay.

Consumer acceptance of circular construction materials: Attitudes of building users towards reuse of wood

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: The built environment is associated with a high carbon footprint owing to the large amounts of resource utilization as well as waste generation. Reusing construction materials, especially low-carbon material such as wood, can help in reducing the carbon emissions of the building sector. Norway has a long tradition of using wood as a construction material due to its durability, lightweight and aesthetic qualities. Despite that, the reuse of wood is far from being a mainstream practice in Norway, and therefore, the bottlenecks for the use of circular construction materials need to be investigated.

Several research studies have focused on exploring consumer attitudes towards residing in wood buildings, however they focus on virgin wood. This study aims to gauge building dwellers' attitudes and acceptance towards residing in buildings made from used wood. By applying Roger's Diffusion of Innovation Theory, five variables of Relative advantage, Compatibility, Complexity, Trialability and Observability, affecting adoption of used material in their built environment are investigated. An online survey was distributed to residents in Norway, using a consumer panel at Norstat. We collected 1000 completed surveys which captured the representativeness of Norway demography and allowed further analysis with comparison of different demographic groups. The collected survey data were analysed via Confirmatory Factor Analysis (CFA) and Structural Equation Modeling (SEM) to examine relationships of the aforementioned five independent variables with the dependent variable of Adoption (i.e. acceptance of used material in their buildings). These relationships revealed the readiness of the consumer markets to adopt the innovation of circular construction materials, and the distribution of adopter categories (innovators, early adopters, early/late majority and laggards) was determined.

The study findings provide a snapshot of current consumer acceptance of circularity in the construction sector and indicate triggers and barriers that can be scaled up and counteracted in the favor of more wood circularity in the built environment.

Forest Stewardship Council (FSC) developing solutions for circularity

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: In its Global Strategy FSC recognizes the need to shift towards bio-based and low-carbon circular economies (CE). However, the current requirements for verification of FSC-certified products along the value chain from forest to end-users are basically based on linear business models. There is a need for the FSC system to accommodate, incentivize, encourage, and support a cascading use of forest-based fibers beyond the existing option of FSC recycled certification, which only caters for one of the five dominant circular business models.

To rethink the FSC system to enable circular use of fiber on large scale, we have conducted surveys and in-depth interviews to understand our stakeholders' current and future needs for such transition. Internal and external datapoints related to FSC, market potentials and risks for FSC in transition to CE were analyzed.

The shift towards supporting a CE for forest based fibers will require innovation of the FSC normative framework and certification infrastructure to enable and encourage reuse of fibers/ material and products and enable circular business models at scale. This includes exploring new areas beyond the existing FSC system such as how FSC can support the use of alternative fiber streams, such as agricultural waste streams, to minimize bio-product demand pressures for virgin forest-based fibers and maximize the value of ecosystems services from the same forest. It also includes putting safeguards in place for worker's rights throughout the supply chains – including currently not covered waste material gathering and sorting facilities. And it includes exploring how FSC can incentivize the use of fibers at the optimal point in the fiber cascade to ensure longest possible carbon sequestration.

It also requires partnerships with leading organizations, members, and stakeholders to scale the market and demand for circular use of fibers. And it requires for FSC to institute market incentives for uptake of circular use.

We discuss options and activities that contribute to the transformation of FSC systems towards CE, as well as the perspectives of FSC membership. We show how and when the research community can efficiently engage in the development of further improved requirements for more circularity in this sector.

Future pathways of forest ecosystem services – a stakeholder analysis in four European regions

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: Forests provide a wide array of services, and a sustainable use of forest ecosystem services (FES) is essential for achievement of sustainable development goals. However, as humans face climate change, societal and environmental challenges, fundamental changes are needed to ensure future prosperity in the growing bioeconomy and circular economy transformation. This transformation depends on both technical and social innovations together with societies adapting to a bio-based sustainable future. In policymaking, synergies need to be realised and trade-offs evaluated and addressed in forest management in general to support continuous provision of FES.

In this study, organisations that has an interest in FES was approached within ONEforest research case study regions; Catalonia (Spain), Estonia, Grisons (Switzerland), and Hesse/Thuringia (Germany). The purpose of the study was to identify key determinants of the use of forest ecosystem services and the effect of these factors on the provision of FES, and the downstream wood value chain. Interacting with stakeholders in a collaborative learning approach, a scenario-based technique further used PESTEL frame to identify key determinants to discuss future pathways for the societal use benefits of forest ecosystem services.

The results indicate that forest stakeholders identify different conflicts between FES, e.g., between timber production and recreation, or between timber production and carbon storage. However, the identified conflicts are context dependent. Stakeholders further identified decision-making and management challenges regarding FES. Finally, the study notes that prioritization of FES provision may become necessary due to increasing demand and potential conflicts. Overall, the result of stakeholder analysis FES help to inform more effective and inclusive forest management and governance including the needs and interests of stakeholders, which will contribute to a more successful policy implementation.

Government and industry perceptions of Bioeconomy: A Comparative Study of nine European Regions

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: The bioeconomy has gained significant attention as a viable solution to address complex global challenges, such as resource scarcity, climate change, and sustainable development. The European Commission's Bioeconomy Strategy provides a framework for advancing the bioeconomy in Europe. However, the successful implementation of the bioeconomy in Europe largely depends on the engagement and priorities of individual regions and regional stakeholders.

Government and industry are key actor groups in driving a sustainable future, with a paramount influence on the trajectory of the bioeconomy. Governments have the power to shape the future of the bioeconomy through strategies, policies, and regulations. They can also facilitate an enabling environment by removing bureaucratic burdens and creating favourable conditions. Meanwhile, the private sector contributes to the bioeconomy through direct business choices and investments, driving innovation and market implementation.

This study explores the perceptions of government and industry in nine European regions regarding the bioeconomy, shedding light on their unique perspectives and priorities. The study is based on an online survey launched in nine European regions, in the regional language, gathering a total of 713 responses.

Preliminary results indicate very positive attitudes towards the bioeconomy. It is perceived as highly related to sustainable land management and circular economy. Respondents perceive both socio-economic and environmental benefits of the bioeconomy, although the vast majority perceives environmental benefits as more important. When asked about most promising sectors, bioenergy emerges in first or second place, even though it may not be the sector with greatest positive environmental impact. Access to investment and scientific information are perceived as the main drivers for bioeconomy development; limited co-operation among different stakeholders and lack of supportive policy & legislative environment are identified as key barriers.

Government, and even more so industry respondents show high willingness to develop the bioeconomy, with greater willingness among those that feel more familiar with the concept (r^2=0.403). Interestingly, across regions, both government and industry actors seem to attribute a greater responsibility to the public sector in i) advancing in social awareness and communication, ii) ensuring positive environmental and social impacts, and iii) investing in the bioeconomy.

Insights Into Life-Science Students' Views on Bioeconomy Entrepreneurship

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: Societies are in the midst of a transition away from the linear fossil-based economy model, with much uncertainty about what will replace it. In Europe, the Green Deal provides a roadmap for action through its underpinning policy initiatives and strategies, such as the Bioeconomy Strategy. The greening of jobs is an important element across these initiatives, and entrepreneurship plays an enabling role.

Entrepreneurship in the field of bioeconomy varies between countries and regions, and there are different approaches for promoting it. Common measures include creating a favourable regulatory environment, improving access to finance, enhancing support structures and promoting education. In the end, the decision to pursue business opportunities depends on personal preferences, which is influenced by specific social, cultural, political, and economic contexts. Research on individuals' perceptions of environmental entrepreneurship can provide insights, revealing differences and similarities between regions and countries. This can then enable policymakers to address issues to ensure successful policy outcomes.

The objective of this study was to understand life-science students' perceptions of bioeconomy, and their experience with and interest in pursuing entrepreneurial activities in that 'solution space'. To this end, a survey targeting life science students in European institutes of higher education was conducted, gathering 764 responses.

Our preliminary results show that students' familiarity with bioeconomy and related concepts varies, but most respondents associate bioeconomy with nature-based solutions, ecosystem services, and circular use of resources. Moreover, entrepreneurship raises high interest among students, but it may be that many ideas do not get tested, as there are barriers that prevent the pursuit of business opportunities. Interest is driven by the chance of reducing environmental impacts and creating positive impacts on the life quality of communities, as well as the positive impact on personal life quality. In this work, we will propose ways to overcome the perceived barriers to entrepreneurship in the field of bioeconomy to support the greening of jobs.

Perception of Silver birch and the possibilities of its use in the framework of adaptation to climate change in the Czech Republic

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: Central Europe, especially the Czech Republic, has been affected by high temperatures and low precipitation since 2015. This has caused the decline of stands, in particular spruce. The result has been an increasing share of salvage fellings, culminating in 2020 with the felling volume of 35.75 million cubic metres (salvage fellings 95%). Of this volume, 96.5% was coniferous timber. The volume of timber logged in 2020 was more than 100% higher than in 2015. The impacts of the progressing calamity on the regions and local wood-processing industries were important. Large volumes of salvage logging started to occur in the north-east part of the country, with the calamity moving westwards through the regions with a higher share of spruce. High logging led to a significant increase in the formation of clearings and thus to an enormous extent of afforestation of these clearings. In view of these effects of climate change, previously less-used tree species have been sought for afforestation. One such example is the Silver birch (Betula pendula Roth), which was previously considered as a weed tree species harmful to the main economic tree species in the country (spruce, pine, beech, oak). Birch wood was mainly used as fuelwood. To motivate forest owners to use birch in regeneration, it was necessary to analyze the economic aspect of birch management in Czechia. This analysis reflected 3 types of soil stands: acidic, fertile, water influenced. It was also necessary to inform the forest owners about other possibilities of birch utilization, which lead to higher monetization of birch wood on the market. Results of the national research led to the conclusion that the economic efficiency of birch plantations is significantly enhanced by increasing share of natural regeneration. In birch wood utilization, marketing analysis of the concept testing phase was carried out to investigate the attractiveness of birch wood and thermally treated birch wood products to a sample of potential customers. Based on the experience from other countries (mainly Scandinavian countries) and the results of the national research, it was possible to recommend forest owners to use birch to an increased extent in forest regeneration.

Residents' experience of living in newly built wooden apartment buildings in urban context

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: This research examines experiences of residents purchasing and living in newly built wooden multi-storey apartments in Finland and Sweden. Wooden multi-storey construction (WMC) offers an alternative building solution for urban consumers seeking a low-carbon, sustainable lifestyle. This exploratory study develops an understanding about residents' views on sustainability of newly built wooden apartment buildings through thematic interviews in five cities across Finland and Sweden.

The study uses a qualitative approach involving in-depth interviews of residents and property managers in eight new wooden buildings conducted between January and June of 2022. While residents were generally satisfied with their living conditions, the study identifies main areas of concern for residents related to wood material. Issues such as material durability, ambiance of the building, costs of construction, and future maintenance requirements are discussed. Wood material was experienced as mainly positive and was assessed together with overall aesthetics, sustainability and durability aspects of the building. Residents trusted that the builders considered the apartment's sustainability criteria during construction (e.g., material durability and resistance to changing climate conditions).

The study concludes that while several prejudices related to wood material has been assessed, action is needed to ensure consistent quality in new wooden buildings. Furthermore, residents would benefit from better information available by the constructors on the unique features of wooden buildings.

REVIEW OF PELIS CONTRIBUTION TO PLANTATIONS DEVELOPMENT AND LIVELIHOODS IN KENYA

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: Kenya Forest Service manages an area of 152,000 Ha set aside for industrial forest plantations. Community role was recognized vide the Forests Act, 2005 and consequently retained in current Forest Conservation and Management Act 2016. Plantation establishment have been raised over time through shamba system, non resident cultivation and currently Plantation Establishment and Livelihood improvement (PELIS). Performance of PELIS has had mixed reactions from different stakeholders that have resulted in previous bans followed by reorganization to improve the system. The study aimed at reviewing plantation establishment method to give recommendation of the way forward following an earlier proposal to phase out the system. Literature review was conducted followed by a field visit to sample forest station numbering 135 spread in 7 conservancies.Field study was carried through guided group discussions and administering of data and information collection tools. Results showed that the existing PELIS regulations and rules if implemented to the letter would be effective in realizing the desired plantation establishment goals with adherence to the rules at 69.1%. However PELIS rules should be reviewed to capture benefits beyond establishment, revise current permit rules to safeguard planted trees by farmers with punitive clauses at hand over, develop audit standards and means to achieve them. Tree planting in PELIS areas has been a success with farmers fully engaged resulting to a reduction in backlogs from 40,000 ha to 14000ha in the last 4 years with an average survival rate of 69.9% . Contribution to PELIS farmers' livelihoods was significant, at Ksh 109,997 per farmer per year. Externalities found to affect PELIS success were;Changes in population pressure on farm land, declining household income, Climate Change due to delayed, inadequate or rainfall failure that contributed to poor tree establishment and crop failures. Changes in policies, legislations and guidelines are sometimes perceived and implemented differently by both farmers and KFS causing farmers to loose trust on PELIS. Study recommended sustainability to be included in the PELIS agreement where farmers are entitled to future benefits from final plantation incomes. The team concluded that PELIS should be continued with reviews on its implementation rules and guidelines.

Sustainable value creation and collaborative business models in the future forest-based sector

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: Human impacts to the Earth have been enormous in our era. Also forests ecosystems have been negatively affected by human-induced activities in numerous ways. Currently in many countries with plentiful forest resources (e.g. in Finland), the utilization of forests and development of new forest-based businesses are in focus for attaining a more sustainable, circular bioeconomy. Yet, there are not commonly accepted, widely applicable solutions to solve many of the key challenges -including the questions on what the environmentally sustainable uses and levels of harvesting are, and which modes of forest utilization should be supported and how. Widely applied organization-centric business models with focus on creating economic value for a certain company and its shareholders have limited potential to exert a positive influence on social or environmental sustainability and mitigate above-described complexities in forest utilization. Collaborative business models -leaning on the idea that businesses should incorporate sustainability perspectives, diverse needs of stakeholders and lead to shared and sustainable value for multiple players-could be enablers for such a sustainability transition. However, promoting shared value creation between different companies as well as between firms and diverse societal actors requires more knowledge on the involved actors, their views and relations.

This study aims to answer the question of how the sustainability transition in the Finnish forest-based sector could be facilitated by shared value creation. More specifically: What kind of collaborative business models and relations do already exist between involved firms and their stakeholders? Which factors promote or prevent shared value creation?

We conduct 65 semi-structured interviews with firms and their stakeholders in May–October 2023. Around 25 interviews will be conducted with the companies including as many different types of forest-based firms as possible; the firms will vary in terms of business models, maturity, size and networks. Around 40 interviews will be conducted with firms' societal stakeholders including forest owners, researchers, environmental NGOs, politicians, journalists, and interest organizations.

The interviews are ongoing, so the findings with in-depth views on shared value creation potential, collaborative business models and the involved actors will be presented at the conference.

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Sustainable Wood for Thriving Cities and Forests: How cities can support thriving forests nearby and faraway through Conservation Timber

T2.22 Perception – Awareness – Choice. How forest bioeconomy becomes a reality

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Abstract: Tropical forests are one of the world's most critical biospheres and assets for climate change mitigation (Roe et al. 2019) and continue to be at risk due to both natural disturbances and human-induced land-use changes (Curtis et al. 2018, Goldman et al. 2020, GFW 2022), representing 8-10 percent of global greenhouse gas (GHG) emissions annually (Harris et al. 2012, Seymour & Busch 2016). Furthermore, the discourse on sustainable and low-carbon construction often focuses on how to incorporate more wood into primary building systems and whether or not global forests can sustain a "timber transition" (Churkina et al. 2019). In balancing conservation and development interests, it is clear that supporting communities on the front lines of forest conservation is necessary, and that these connections and impacts be made evident to consumers through the wood products they specify.

Methods:

Case studies will be used to identify the systemic impacts of 2-3 conservation timber enterprises. Case studies will first collect primarily qualitative data using methods such as interviews, observations, and analysis of primary and secondary sources. Quantitative data will be collected from a wider range of conservation timber enterprises to determine the associated benefits to forest conservation, management , restoration, and forest communities.

Results:

Preliminary results and near-term projections will be presented from 2-3 programs in progress in conservation timber enterprises such as Bigi Poika (Suriname), Carmelita (Guatemala), Bambidié (Gabon), and Cheringoma (Mozambique). Long-term projections will also be presented to show potential environmental and social benefits of conservation timber.

Conclusions:

The methods underpinning the analyses of conservation timber enterprises present the opportunity to through engaging the complete value chain of wood products. Through these methods and metrics, the specification of sustainable, responsibly sourced wood can help to conserve forests, support community enterprises and lead to massive climate and biodiversity benefits.

T2.23 Planted Forests for Achieving a Sustainable Planet

Global economic, timber, and carbon implications of alternative forest plantation growth pathways

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Forest-based natural climate solutions such as reforestation have been proposed as cost-effective options to achieve climate change mitigation goals. Recent studies have debated how much land is available for reforestation and what forest types (e.g., plantation, natural) should be utilized to help meet increasing timber and carbon sequestration demands. However, many studies lack analysis of how alternative reforestation pathways and constraints can affect economic indicators like timber prices and wood supply. We build upon these studies by: (1) identifying key forest-use and planting constraints proposed in the ecological literature, (2) developing 20 reforestation scenarios that promote or constrain the use of plantation and natural forests for meeting timber and carbon sequestration objectives in various regions of the globe (i.e., a land sharing vs. sparing approach), and (3) quantifying the economic (e.g., timber supply, prices) and biophysical impacts (e.g., forest area, carbon stocks) for each scenario at the global and regional level. We apply a dynamic forest sector model (Global Timber Model) that maximizes total welfare in timber markets over time across approximately 300 forest types by managing forest stand ages, compositions, management intensity, and acreage given production and land rental costs over 200-year simulations. We conclude that climate change mitigation and timber supply goals can both increase over the next century through a combination of more intensive management of existing forests and the expansion of forest area overall. We also find that these objectives can be met more efficiently if plantations are able to expand under less constrained policy conditions. For example, constraining the expansion of plantation forests can increase roundwood prices by \$3 – \$266/m3 compared to the unrestricted plantation growth scenario. Further, constraining plantation area to only expand in temperate, developed country forests can increase in the global roundwood prices by an average of 8%, while carbon sequestration is reduced by about 4% relative to the unconstrainted plantation case. Our analysis provides new insight on how plantations could play an increasing role in helping meet future carbon and timber supply objectives, although potential ecological tradeoffs and related policy constraints (e.g., EU Zero Deforestation/Degradation policies) could limit their growth.

Allometric model and Carbon Sequestration Rates in Paulownia tomentosa (Thumb.) Plantations at ICIMOD's Living Mountain Lab in central Himalaya

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Allometric equations are important for estimating species-specific tree and forest biomass and carbon stocks. *Paulownia tomentosa* (Thunb.) is a fast-growing tree species native to central and western China and Southeast Asia. This species has recently been introduced in Nepal for agroforestry systems, its allometric equations have not yet been developed. This study used a destructive sampling method to develop allometric equations considering seven tree components (Bole, Branches, Leaves, Twigs, Tap roots, Lateral roots and Fine roots) in the ICIMODs Living Mountain Lab representing the central Himalayan region. An equation for estimating total biomass as a best fit for tree was y=14.228xDBH -120.81, r^2=0.973. Using the allometric model we calculated the mean biomass 150.42 t ha^{-1} in 2014 and 429.81 t ha^{-1} in 2022. The mean carbon stock was found to be 149.81 tC ha^{-1} in 2014 and 202.01tC ha^{-1} in 2022. The carbon sequestration rate based on the annual increment rate in *Paulownia tomentosa* was found to be 5.87 tC $ha^{-1}yr^{-1}$. The allometric equations assisted to estimate the biomass and carbon sequestration rates which could be helpful to address global climate change through mitigation. The allometric equations have potential application to similar physiographic and climatic zones as well as to smallholders and communities who intend to participate in climate change mitigation programs.

Bamboo as a Nature-Based Solution (NbS): Assessing the Transformative Potential and Constraints for Climate Change Mitigation

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Nature-Based Solutions (NbS) are gaining momentum as transformative responses to climate change and biodiversity crises. This study investigates bamboo, a fast-growing, woody grass, as a promising NbS in tropical forest landscapes. Through a systematic and comprehensive review of 91 articles, we reveal the potential and limitations of bamboo in climate change mitigation considering its role as a carbon sink in bamboo ecosystems, carbon storage in bamboo products, and carbon credits in bamboo projects. Our study illustrates that global bamboo forest ecosystems demonstrate significant carbon sequestration (up to 70 tCO_2/ha/yr) and storage capacity (up to 270 tC/ha), with abiotic factors and management strategies affecting carbon storage in bamboo biomass. Notably, research is predominantly Asia-centric (91%), underlining a pressing need for investigations in other pan-tropical zones like Africa (7%) and South America (1%). Additionally, bamboo forest ecosystems offer the potential for carbon storage through the production of durable goods. Our review suggests a net negative carbon life cycle of bamboo-based products compared to conventional industrial products. Yet, comprehensive assessments of product carbon pools from specific bamboo forests are lacking. Despite bamboo's considerable potential in carbon offset markets, the absence of internationally recognized methodologies constrains its wide global application. Recognizing these gaps, we propose developing inclusive methodologies and climate policies that recognize bamboo as an NbS. This study underscores the transformative potential of bamboo as an NbS, raising critical reflections on its role in promoting human well-being, social inclusion, power equality, and biodiversity benefits. Our findings offer insights into how science can integrate communities and stakeholder perspectives and resolve complex NbS project design and implementation trade-offs. Thus, bamboo presents a compelling case for incorporating multiple dimensions of NbS into complex governance contexts for effective climate change mitigation.

Business requirements for developing successful forest plantation projects

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Forest plantations play an important role in meeting our needs for wood products and environmental goods and services, and have emerged as a unique regulating Nature-based solution (NBS) for climate change adaptation and mitigation. Planted forests have been proposed as one of the most efficient and cost-effective means to store more atmospheric carbon. Consequently, increasing the area and productivity of planted forests is a crucial method to meet increasing timber and climate demands by capturing carbon in forests and subsequent wood products and providing short-run terrestrial energy. Increases in planted forests to achieve their promise for economic provisioning and climate regulating services mandate that a host of technical, research and policy issues must be resolved quickly. This presentation focuses on issues relevant to business success of forest plantation projects, including rural land tenure and rights, regulations promoting or limiting public and private forest land management, broadly defined infrastructure, policy implementation, investment opportunities, timber markets as well as markets for other forest products and services (e.g., forest carbon). We then address the opportunities, within the context of commercial plantations, for improving product quality, value added production, new product development, standardization, and a positive environmental perception of plantations in producing and consuming countries. Successfully addressing these issues can help bring much needed funds for plantations projects, while generating a range of benefits for producing regions.

Can public forest planning for private planted forests contribute to increased forest carbon sequestration? -The case of Japan

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Japan has a hierarchical public forest planning system, where prefectures and municipalities must develop plans for private forests. Forest owners or their agents can also voluntarily develop and submit plans. Every five years, each plan must indicate the expected amount of felling, planting and thinning, as mandated by the Forest Act.
This aligns with the obligations set forth internationally since the Kyoto Protocol, which, regardless of actual CO_2 absorption, requires the implementation of silvicultural tasks such as thinning, based on the definition of managed forests.
Conversely, while most logging targets coniferous planted forests, there has not been enough progress in promoting the reliable implementation of replanting after logging, or the selection of high CO_2 absorbing species.
Furthermore, the estimated CO_2 absorption is decreasing due to the aging of coniferous planted forests. Therefore, aging is often cited as a reason to justify clearcutting and increased timber production, but few plans intending to convert slow-growing species through harvesting have been found.
Therefore, it can be inferred that the current Japanese public forest plans fail to contribute directly and effectively toward enhancing the CO_2 absorption capacity of forests. The complexity of the system, coupled with the necessity for alignment with plans at other hierarchical levels, might inhibit the incorporation of effective initiatives within these plans. Future policy development would benefit from incorporating objective findings, such as scientific estimates of absorption on different scenarios. Such an approach would contribute to evidence-based policy making (EBPM) and the efficacy of the planning system.

Economic Analysis of Select Commercial Forestry Enterprises in Central Kenya, a profitability analysis.

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Forestry is an important sector in Kenya due to the role it plays in supporting productive sectors of the economy such as manufacturing and construction as well as the supply of ecosystem services. Over the past years, the country has been heavily relying on public forests to supply over 70% of forest products. This has contributed to unsustainable extraction, destruction, and degradation of forests. There is a need to profile commercial forestry as a viable investment option that contributes to employment creation and income generation while supplementing the supply of forest products. There however exists limited information on the potential for commercial forestry as a competitive land use option in the country. Using a Cost Benefit Analysis approach, we undertook an investment appraisal for three forest-based enterprises, Eucalyptus (Transmission poles), Pine, and Cypress (sawn timber) to assess their viability and potential economic returns. Eucalyptus enterprise had the highest profitability with a net present value of USD 6,824.54, followed by Cypress at USD 6,006.07 and finally, pine at USD 3,872.74 per hectare, respectively. Eucalyptus production is getting much prominence in the country due to its ability to grow fast, its high demand, as well as its multiple uses. There has also been an increase in private companies applying modern seasoning technologies to produce high-quality eucalyptus furniture, doors, and flooring panels, thus increasing demand further. Cypress and pine were mainly preferred by the construction industry for making roof trusses as well as furniture. Increased training and awareness on species-to-site matching and appropriate silvicultural management practices are essential in improving earnings from commercial forestry enterprises in the country.

Key Words: Forest-based enterprises, commercial forestry, cost-benefit analysis, competitive land use option

Economic and environmental benefits of selected state forest sector development programs—sources of success and failure.

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Several countries have developed their forest sectors based on policies that included the design of incentive programs. In the case of Latin America, some of the programs were designed with various objectives, including the use of commercial plantations. In South America, three relatively successful cases stand out: Brazil, Chile, and Uruguay. The case of Uruguay is the most recent development, with its Forestry Law passed in the late 1980s. The objective of this presentation is to analyze the components of the forest sector development programs of these three countries and their current challenges, with a particular focus on the case of Uruguay. It is observed that most of these programs had as a common characteristic the incentives to plantations and not so much to industries. The raw material was considered key for the development of the sector. Furthermore, increasing the forest area would generate environmental benefits, taking pressure off the use of natural resources, and providing ecosystem services. In recent decades, the discussion on the impacts of climate change on forests, as well as on their capacity to continue providing ecosystem services, has opened the discussion on the need to review forest sector development programs considering new scenarios and the lessons learned. In the case of Uruguay, there was recently a long discussion on the need to pass a new forestry law. While there was agreement on the need to make some changes, there was no agreement on the need for a new law. In the end, the latter position prevailed. At the same time, the government has taken initiatives that involve not only the forest sector but other sectors, such as the bond indexed to climate change indicators (BIICC) recently issued.

Global Forest Plantation Trends and Forest Product Markets and Forest Carbon Implications

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: This presentation will discuss the projections of global planted forest area and what they imply for global forest products markets and forest carbon, 2015-2070. Projections are made under alternate socioeconomic futures, as represented by the Intergovernmental Panel on Climate Change-(IPCC) inspired shared socioeconomic Pathways (SSPs). Depending on the SSP and modeling approach, the analysis suggests increases in global planted forests of 9% to 46% under a scenario of low economic growth (SSP3) to 14% to 66% in a wealthier world (SSP5), relative to forest area observed in 2015. Aside from the global results, projected trends in planted forest area varied substantially across world regions, suggesting that regions with higher projected economic growth, such as Africa, Asia, and South America, would experience the largest expansion in planted forest area in the future. Incorporating such projections into a global forest sector model led to a projected global increase in forest stocks (and forest carbon), a decline in roundwood price, and an increase in consumption (and production), with wide variations in their projected effects on national and regional markets, relative to a reference scenario without a future increase in global planted forests.

How forest carbon standards in the United States are hindering carbon sequestration from southern pine plantations

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: In the United States, cellulosic carbon sequestration in forests has several characteristics of forest carbon that can be traded in offset markets. The first is the period of sequestration which for regulatory markets is typically 40 to 100 years. The second characteristic is that only live forest carbon is counted in a carbon account; forest products and forest residues are excluded from carbon accounting. Lastly is the requirement of additionality, which restricts "common practice" that funded through other mechanisms. Using the Forest Vegetation Simulator for loblolly pine plantations, we project forest carbon, wood products carbon, and carbon avoidance from wood used for energy under scenarios of common practice, maximum forest mean annual increment, and 100-year rotations to address the issues of period and carbon accounts. Examining economic equilibrium theory, we estimated the quantity additional CO_2e that would be stimulated by forest landowners responding to carbon revenue from common practices. Findings show that if wood products carbon is part of the tradable carbon pool from loblolly pine plantations, rotations of 40-44 years that maximize mean annual increment sequester the most carbon, followed by rotations that follow common practice that maximizes land expectation value. The lowest total sequestration occurs using a 100-year rotation. Equilibrium market economics finds that payment for carbon sequestered from common practices alone can increase region carbon removals by 2-4%. If reduction of atmospheric carbon is the objective or offset markets, they are missing opportunities from one of the largest global forestry sectors.

Implementation pathways, partnerships, and policy coherence for advancing ambitious global planted forest carbon goals

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Planted forests have been proposed as one of the most efficient and cost-effective means to capture and store atmospheric carbon and reduce adverse impacts of climate change in the short- to medium-term. Innumerable tree planting programs have been established at local to global scales in recent years as part of a growing global movement promoting tree planting as a key component in proposed solutions for global climate change. Tree planting and reforestation efforts are primary components of many countries' commitments to the Paris Climate Agreement and are incorporated in targets for achieving the United Nations' Sustainable Development Goals, the New York Declaration on Forests, and the UN Decade on Ecosystem Restoration 2021–2030. Consequently, tree planting promises have received record and expanding financial, political, and societal support, yet myriad challenges exist in turning ambitious commitments into effective and enduring reforestation and restoration on the ground, planting 'the right trees in the right places', engaging and sustaining local stakeholder participation, and integrating tree planting policies and practices with other nature and non-nature based climate solutions. Effective implementation of major tree planting and reforestation campaigns can be particularly constrained where governance systems, institutional capacities, and financial architectures are limited and where the underlying causes of forest loss, degradation, and greenhouse gas emissions are not addressed or overlooked.

We examine major tree planting and reforestation initiatives in Brazil (Amazonia Sustainable Landscapes Reforestation Project), Philippines (National Greening Program), Tanzania (Kwimba Reforestation Project), United States (Appalachian Regional Reforestation Initiative), and other parts of the world, drawing on top-down/bottom-up perspectives on policy implementation to identify effective implementation strategies as well as key challenges and pitfalls. We provide insights into adaptive, effective implementation pathways at multiple, nested, and integrated scales for generating multiple measurable and enduring benefits from ambitious tree planting and reforestation initiatives for people and the environment.

Integrated Timber Investment Returns, Wood Fiber Stumpage Costs, and Forest Carbon Offset Costs for Global Planted Forests

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: This presentation will discuss our research on integrated timber investment returns, wood stumpage costs, and forest carbon production costs in 2023 for a representative selection of about 15 countries and 45 planted species/ management regimes, using capital budgeting criteria, at a real discount rate of 8%, without land costs. Despite a large amount of disparate research, few if any studies have provided integrated estimates of investments, wood fiber costs, and forest carbon offset costs using fundamental primary data and production economics approaches. We will build on our prior research that estimated present values and internal rates of return for timber investments, using

average plantation forest growth and yield, input management costs, and timber products prices by selected country and species. From that production economics approach for forest management, we will extend the calculations to estimate average stumpage costs for wood fiber per cubic meter per rotation. In addition we will calculate the costs to produce forest carbon offsets in terms of the now traditional CO2e metric. These investment returns, wood fiber costs, and forest carbon storage equivalent costs will be compared with other existing timber investment, timber stumpage production costs, and forest carbon literature. This production economics primary data research approach will be compared with other secondary data research approaches for investments, wood fiber, and forest carbon. The results can be used for private, government, or nongovernment investments and for public policy intervention considerations.

Mixed success for carbon payments and subsidies in support of forest restoration in the neotropics

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Restoring forests in low- and middle-income countries (LMICs) may contribute to global carbon mitigation targets. However, upfront costs and inconsistent cashflows associated with forest restoration pose challenges for many landowners. Two proposed solutions include carbon payments and third-party cost-sharing to incentivize and alleviate the financial burden of restoration. However, empirical evidence to support these approaches, based on robust, dynamic field sampling is lacking. We use large, long-term datasets from Panama to assess the financial feasibility of three forest restoration methods, considering cost-sharing and carbon payment designs where income is generated through timber harvests. The results provide insights into necessary incentives for landholders in LMICs to adopt forest restoration.

We evaluated the growth and timber-derived revenue of secondary forests, native tree plantations, and enrichment plantations on low-nutrient soils. We compared three cost-sharing models derived from loan program analyses conducted in the region – *full* payments where all upfront and management costs were assumed by a third party, *half payments* where only 50% of the costs were covered, and a *no payments* option where no costs were covered. Lastly, we incorporated a carbon payment scenario into the different treatment and financial support scenarios.

We found that not all options are financially viable. Relying solely on timber revenue from secondary forests was not economically feasible without the support of third-party cost-sharing and carbon payments. While two high-value native plantation species (*Terminalia amazonia* and *Dalbergia retusa*) generated positive net present values (NPVs) on their own (US$7,474 ha^{-1} and

US$37 ha^{-1} at 7% interest rate (IR), respectively), enrichment plantations, on average, did not yield sufficient financial gains without cost-sharing and carbon payments. However, when cost-sharing and carbon payments are included, secondary forests became more profitable than the two native plantations (generating NPV > $US10,000 ha^{-1} with a 7% IR).

Incentivizing forest restoration of secondary forests in tropical regions will likely require both financial support and carbon payments. While native species plantations have the potential to generate revenue without subsidies, the high establishment costs (US$1,500 ha^{-1}) may still pose a significant barrier for small landowners. Therefore, financial support remains crucial in facilitating land-use transitions.

Optimizing plantation forest management in Southern Regional State of Ethiopia

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Forest management strategies have significant effects on forest structures and functions. However, there is a lack of knowledge on the impacts of alternative management strategies on multipurpose forest ecosystem service in Ethiopia. This study aims to bridge this research gap by modeling the effects of various forest management prescriptions on the evolution of forest ecosystem services over time to select the most effective management strategy. Inventory data was collected from a total of 118 sample plots. These plots comprised 43 plots from Cupressus lusitanica, 70 plots from Eucalyptus globulus species, and 5 plots from mixed species. The collected data was organized and analyzed to generate a yield table and cash flows for a thirty-year planning horizon. Additionally, six different linear programming models were developed and analyzed to optimize single objectives. Furthermore, the Pareto Frontier tool was employed to assess trade-offs. The results of the study revealed that all plantation types, including Eucalyptus, Cupressus, and mixed species, yielded higher economic gains when higher thinning intensities and full harvest were applied, as opposed to lower thinning intensities. In unconstrained NPV maximization, the highest economic gain of up to 7.429 X 106 ETB/ha/year could be achieved with a thinning intensity of 37.5% in 2021 for Cupressus lusitanica, full harvest in 2025 for Eucalyptus globulus, and a thinning intensity of 37.5% in 2021 and full harvest in 2025 for mixed stands. To maintain tolerable annual soil loss and minimum carbon stock, out of the total area of 552.63 ha, 235 ha and 112.4 ha should be managed using lower thinning intensity. Furthermore, this study showcased the potential of the Pareto Frontier in analyzing trade-offs between ecosystem services in Ethiopian plantation forests. The findings indicated that maximizing NPV through forest harvesting comes at the expense of reduced aboveground carbon stock, the volume of ending inventory, and increased annual soil loss. The Pareto Frontier also provided multiple ideal points for decision-makers to select their preferred targets. This research can serve as a valuable reference for developing forest management plans that aim to maximize the diverse ecosystem services offered by plantation forests.

Optimizing tree planting to enhance China's afforestation carbon sequestration potential

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Tree planting is one of the cost-effective nature-based solutions to mitigate climate change impacts. It requires knowledge on where, which species, and when to plant, however, the knowledge remains largely elusive. Here, we assess China's afforestation potential by taking into account the local conditions of the ecosystems and the risks of future climate change, and develop a framework to optimize the afforestation plan, with the aim to maximize the carbon sequestration potential of afforested forests by 2060 to support China's net-zero commitment. Our results reveal a conservative estimate of 43.2 million hectares of land suitable for afforestation prior to 2060. With our optimized framework, we estimate a cumulated carbon sequestration of 2969.1 Tg C of afforested forests by 2060, with an average carbon sequestration rate of 84.8 Tg C/yr. Further, the age structure renewal can enhance their carbon sequestration potential, resulting in a 28.7% increase in carbon sequestration. Overall, we will plan 58.4 billion trees during the study period with, accumulated carbon sequestration of 3822.6 Tg C. Our findings underscore the importance of well-planned afforestation for enhancing carbon sequestration potential, and provide timely guidance to China afforestation and net-zero policies.

Restoring forests in a treeless land – challenges and opportunities

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Iceland has a history of deforestation with the native birchwood reduced from estimated 25-40% of land cover around 870 AD to less than 1% around the mid 20th century. This was followed with severe soil erosion, resulting with large areas of barren areas.

Organized forestry is considered to have started in 1899 and following an early phase of experiments with exotic tree species, the focus was first on protecting birch woodland remnants. Since about 1950, emphasis has been on afforestation through planting trees, both the native birch and introduced tree species. Today, the forest cover is 2% of land area, with native birch woodland covering about 1.6% and cultivated forests the rest.

With large areas that can be afforested, opportunities for climate mitigation through afforestation are great and enhanced action in forestry is a vital part of Iceland's 2020 Climate Action Plan. However, climate change and afforestation for climate mitigation also proposes several challenges, including the selection of tree species, tree improvements, the effects on biodiversity and ecosystem function, adaption of existing forests to new insects and pathogens, and conflicts between forestry and other land use to mention some.

The formation of planted forest in Kyushu, Japan - Analysis using the 1960 and 1970 World Census of Agriculture and Forestry-

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: The forest landscape in the world changed completely in the Anthropocene when human activities transformed the ecosystem. Japan is an example that has shown a dramatic change in the landscape, especially in Kyushu, which is one of Japan's main islands.The rate of planted forest in Kyushu was about 54 percent in 2017. It is over the rate in Japan, which is about 46 percent. Nowadays there is more logging in Kyushu than in other areas in Japan. Thus, it is necessary to determine the land use after logging. Natural regeneration is chosen as a land use after harvesting planted forests. It is implied that the amount of residual buried seeds affects whether natural regeneration will succeed. The amount depends on the vegetation history of the planted forest. Therefore, natural regeneration requires understanding of its history. The study will provide essential information to achieve sustainable planted forests in Kyushu. In addition, it will analyse the current situation of logging planted forests afforested in the 1960s and 1970s in Kyushu by the statistics of Kyushu's forest and field survey.The study uses the 1960 and 1970 World Census of Agriculture and Forestry. They classify land of pre-afforestation uses into three categories: (i) natural forests, (ii)planted forests, and (iii)non-forest. The afforestation rate in each land was calculated for regions based on the digitised data. As a result, landscape changes in Kyushu are indicated as follows. Firstly, it is obvious that the planted rate of non-forest in Kyushu was the second highest in all of Japan's regions in 1960 and 1970. Secondly, the afforestation rate in natural forest harvest sites in kyushu was the third lowest in and the rate of afforestation in Kyushu was also the highest in Japan in 1960 and 1970. The result indicates that the major characteristic of the forest landscape change in Kyushu was the establishment of planted forests, and their scale was larger than that of other regions in Japan

Timberland investment management organizations and carbon credits in plantation forestry - state of the art and prospects

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Timberland investment management organizations (TIMOs) have established timberland as an asset class in mature markets. However, the growing number of TIMO investment vehicles is increasingly at a mismatch with the universe of investable assets in these marketplaces. As a result, TIMOs are facing growth limitations and declining revenue generation opportunities in established markets and are considering expanding the business to emerging forestry markets. This paper focuses on the state of the art of TIMO market potentials in emerging markets and carbon credits from forest plantations as an additional investment incentive and revenue driver. Key challenges and prospects for promoting forest investments in emerging markets are discussed. TIMOs invest in brownfield assets with stable and predictable timber flows, and other revenue streams (e.g., from carbon credits) are not yet of high relevance. Nevertheless, carbon credits can provide a crucial early cashflow for afforestation and reforestation activities in emerging economies, and carbon revenues may increase TIMO investors' appetite for greenfield projects. We conclude that market liquidity is critical but sufficient e.g. in countries like Brazil, Uruguay or Chile. Supportive interventions in less advanced emerging economies are needed to stimulate greenfield investments and forest sector development in these locations. Such interventions may include the promotion of sustainably produced timber, tax and incentive regimes for forest plantations, industries and infrastructure investments, and developing robust carbon market and land tenure regulations. From the geographical perspective, Latin America shows clear signs of maturing markets, while Sub-Sahara Africa and Southeast Asia still require external support, such as blended finance investments.

Tree planting vs. natural forest regeneration: relative cost-effectiveness at mitigating climate change

T2.23 Planted Forests for Achieving a Sustainable Planet

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Abstract: Mitigating climate change cost-effectively requires identifying least-cost-per-ton greenhouse gas abatement methods. Here, we estimate and map the greenhouse-gas abatement cost ($/t$CO_2$) of the two most common reforestation methods: monoculture forest plantations and passive natural forest regeneration. We do so by combining 355 observations of implementation costs incurred by reforestation projects with new maps of opportunity cost, likely plantation genus, and carbon accumulation accounting for storage in harvested wood products. We find natural regeneration would be more cost-effective at mitigating climate change than plantations across two-thirds (68%) of the area considered suitable for reforestation across low- and middle-income countries. Using the more cost-effective method at every location, the 30-year, time-discounted abatement potential of reforestation at or below a cost of $50/t$CO_2$ is 24.6 GtCO_2 (15.4–27.9 GtCO_2 at or below $20-100/t$CO_2$)—13% more than natural regeneration alone, or 114% more than plantations alone. We find that reforestation offers more abatement at lower prices than previously estimated by the Intergovernmental Panel on Climate Change—more than six times as much abatement at or below $20/t$CO_2$, and more than twice as much abatement at or below $50/t$CO_2$.

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

An Integrated approach of risk assessment and insurance structures in forestry investments

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: It is a pivotal time for investment in forestry as this asset class is considered to behave very well for diversification with long term perspective. The multifunction forestry plan combining sustainable logging and conservation for climate and biodiversity purposes can provide ROI of 15%, much better that any other natural asset class. But climate risks can jeopardise this acceleration and risk-transfer options have to be associated with adaptation plan to insure the residual risks. We propose an innovative approach that combines mechanistic-based agent-based modelling with statistical change detection using satellite-based data to design new forest insurance products. This integrated approach enables to consider the climate adaptation measures and design products whose pricing will not only reflect the historical data but also future risks integrating adaptation plan.

A Study on the Establishment of Green Funds for National Park Conservation in China

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: China is one of the world's most biodiversity-rich countries, hosting many of the world's most important national parks for preserving forest and wetland eco-systems, and habitats for rare and endangered species, such as the giant panda and tiger. Though the Chinese government has issued relevant policies and measures to support national park management, financing gap remains huge because national parks in China still highly rely on public funding from the central and provincial governments.

Aiming to provide recommendations on mobilizing private resources and setting up long-term financing mechanisms for national parks, this Study first analyzed the financing challenges that national parks face in China, including lack of clarity in the designation of financial powers and expenditure responsibilities; short of funding sources; low efficiency and lack of monitoring and supervision in fund use.

Based on the in-depth analysis of the models and experiences of national park financing in both the developed and developing countries, such as the US, Australia, Japan, South Africa and Indonesia, the Study suggested to adopt market approach to broaden the funding sources of national parks and expand the involvement of the general public and the private sector in conservation in China.

Besides biodiversity bonds or public donations, the Study specifically recommended establishing the National Park Green Funds which is in line with the Chinese government's guidelines on green financing and conservation.

Built on the reflection of the operation of existing green funds in China, the Study provided detailed suggestions on the fundamentals of the National Park Green Funds, which include: Participants of a variety of financial institutions at central and local level with the central government being the initiator; A two-tier fund leveraging mechanism to replenish the funding for both the Fund of Funds at the top and the sub-funds targeting specific national parks; Market-based management of the sub-funds and prioritization of conservation and the value-for-money principle in the decision making of Fund for Funds; Investments in eco-tourism, carbon sink to address climate change and co-management.

The Study concluded with risk management recommendations and policy support for the smooth operation of the National Park Green Funds.

A win-win for restorations and value chains: Evidence from initiatives in African and Mesoamerican countries and Small Island Developing States

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: Restoration, when linked to the development of sustainable value chains, has the potential to tangibly benefit local stakeholders who therefore have a stake in its success and sustainability and promote bioeconomy. Linking restoration to marketable opportunities also facilitates the mobilization of private finance. The degree to which restoration initiatives have utilized these connections, or their level of success when they did it, is not well studied. This paper reviews experiences of integrating inclusive forest-based VCD in restoration initiatives with an aim to identify impacts, lessons learned, and good practices that could inform project development and implementation globally. The geographical focus of the paper is African drylands, Mesoamerican countries, and Small Island Developing States (SIDS). The key questions the paper attempts to answer are: what modalities are most used to link restoration to VCD? And do such links translate into investments and local actors' engagement? For the purpose of the analysis, a database is developed with a group of shortlisted projects that integrate both VCD and restoration activities. The projects are identified based on a set of selection criteria among databases of FAO, IUCN, UNEP and UNDP as well as of GEF, World Bank and GCF.

The results suggest that VCD generates income for smallholder farmers and small producers and thus giving them more resources and incentives to invest in restoration. Proximity to the markets, organizations of farmers and producers and strengthening of local support structures and institutions (e.g. NGOs, community organizations and government agencies) are the most common conditions to link VCD with restoration. To develop efficient linkages, these conditions need to be combined with a set of suitable modalities (e.g. improving access to markets and finance, and integration of small producers into the value chain) and tools (e.g. financial, technical and organizational capacity building, facilitation of partnership between small producers and primate companies and SMEs). Therefore, it can be concluded that the investments in VCD can support the restoration of forests and land given an optimal combination of conditions, modalities and tools are applied.

Assessment of factors influencing the adoption of e-commerce platforms by timber companies in Colombia

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: The challenges for forestry companies in the electronic timber market have been increasing due to various factors that affect its adoption. It has been shown that for adopting electronic commerce, different Technological, Organizational, and Environmental (TOE) factors influence companies' decision-making. This study seeks to evaluate the factors influencing the adoption of electronic commerce platforms by timber companies in Colombia. The evaluation of TOE factors allows us to understand the behavior of companies regarding the adoption of technologies and, likewise, includes valuable information for different actors that are immersed in the chain of commercialization of timber, as well as for the leading economic organizations and institutions interested in strengthening the timber industry in Colombia. A survey of 216 companies registered in the Elija Madera Legal platform is undertaken to identify factors based on TOE. In order to evaluate the incidence of the factors, an electronic commerce adoption index (IACE) for each company will be estimated using a Principal Component Analysis where the factors that have a greater specific weight will be identified, meaning that they have greater relevance concerning the adoption of electronic commerce.

According to the specialized literature review, some of the main factors are relative advantage, the expectation of effort, communication (technological), technological readiness, technological integration, obstacle management, company certification (organizational), regulatory framework, inequality, informality, traceability (environment), which have been identified as those that have the most significant incidence in the adoption of electronic commerce for the forestry sector and on which it is pertinent to carry out the analysis.

These findings are expected to present significant implications on the link of timber commercialization at the global level; international treaties call for more sustainable timber trade; in this regard, identifying factors that influence the adoption of technology will help the development of policies and capacity building at the national and regional level.

EUROPEAN TRENDS IN INNOVATIVE ENGINEERED WOOD PRODUCTS AND SYSTEMS FOR THE CONSTRUCTION SECTOR

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: Construction accounts for around 37% of global CO_2 emissions and it is the second largest EU industrial sector. The use of engineered wood products (EWP) in buildings is increasingly acknowledged as a major lever for decarbonisation of the construction sector and a contribution to sustainable forest management. The study, part of EU projects BASAJAUN and EUFORE, attempts an outlook on leading wood innovation trends and their role in the construction sector. Analysing the *European Organisation for Technical Assessment* (EOTA) database, a range of wood-based products were categorised as a) mature products, i.e. with CE marking complying with the *European Construction Products Regulation* according to harmonised standards, or b) innovative products, i.e. with CE marking via *European Technical Assessment* (ETA). ETA products since 2002 were analysed in *European Assessment Documents* (EAD) of the two *Product Areas* related to wood products (PA13 and PA14) and also from 34 other PA whose EADs include the term 'wood' or 'timber' in their titles, complemented by reviews of innovation topics observed in both literature, conferences and trade fairs. The results show an increase in certified innovative EWP since 2015, produced inside and outside Europe. They also highlight emerging types of technological innovations, such as novel products with enhanced properties regarding material efficiency and circularity, alternative wood species and advanced design and prefabrication systems. A main share observed relate to structural EWP and panels for use as slabs, roofs, or walls and their connections, thermal insulation products and building kits. Establishing innovative EWP on the market implies rethinking the way we design, manufacture and construct buildings. The emerging timber boom in multistorey buildings demands also novel timber engineering and constructive systems and components for more safety, comfort, health, resource efficiency and CO_2 neutrality. Many innovations originate from collaborations between wood manufacturers, engineers, building companies, research centres as well as architecture, design and digitalisation. Widespread national and European policy initiatives fostering building with wood, such as the New European Bauhaus, aim to create an enabling 'ecosystem' to facilitate exchange and co-creation across disciplines and domains, leading to a gradual mainstreaming of wood solutions in the construction sector.

Factors and criteria influencing financing decisions in wooden multi-storey construction

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: Wooden multi-storey construction (WMC) has experienced increasing interest in Finland during the past years. Wood is seen as an environmentally friendly and aesthetically pleasant alternative to dominant building materials. This research explores financial decision-making criteria affecting construction of multi-storey residential building from financiers' point of view. Specifically, 1) which factors and criteria the financiers consider while making investment decision on WMC projects, 2) how they assess risk and opportunities and 3) what is the role of sustainability in WMC.

The study relies on thematic interviews with professionals working in the field of financing and real estate investing, conducted between August and October 2022 to study how they assess risks and opportunities in WMC. The data consists of 10 interviews conducted to different types of financial organizations active in funding of construction projects.

Results imply that financiers emphasize traditional financial criteria (such as profitability and risk-return) over building materials and sustainability aspects. Alongside financial criteria, location and micro location, energy efficiency, apartment pre-marketing and maintenance costs of the building were identified as a criteria. Building material was not considered as significant factor as it is decided by the construction company and is part of the overall risk analysis of a project.

In general, construction phase was considered as the riskiest part of the project for the financiers. Specific risks associated with WMC was the construction company's capabilities for the project, their lack of references and unknown life cycle costs compared to concrete buildings. Good availability of the material, development opportunities for element construction to lower prices and ecological properties of wood were seen as opportunities for WMC.

Sustainability was seen as an important part of the financing decision; however, not all respondents found it as a part of the main financial criteria. In addition to organization's own sustainability goals, sustainability is guided by policies and regulation, including the EU taxonomy. To conclude financiers require more knowledge on long-term usage and cost experiences of WMC buildings.

Potential of Small Scale Tree growers in Plantation Development: Case of Nyandarua Tree Growers Association in Kenya

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: Kenya aspire to grow its tree cover to 30% by 2032 with 35% being contributed by commercial forestry. Private forest under small scale holders provide opportunity for forest growth. However they need to come together to do joint technical advisory services, value addition and marketing. The Farm Forestry Program with support of FAO have provided support to tree growers association to upscale commercial forestry with one being Tree Growers Association of Nyandarua (TGAN). This is a legally registered entity under the Societies Act with a membership of approximately 3,000 tree growers in Nyandarua County. It is a member of Farm Forest Smallholders Producer Association of Kenya (FFSPAK). To be able to trade members of TGAN formed a Cooperative society. All the activities that TGAN is engaged in are demand-driven. The demands are identified through a process of problem identification, project planning and project implementation facilitated by the Association in a participatory process. With support from FAO/FFF programme, TGAN implemented the tree census project in 2020 to support farmers undertake an on-farm tree inventory and develop a strategic business plan for sustainable production and marketing of timber products including wood fuel.The results from the census indicated that the net worth of the association is about 53million USD$ hence there is great potential in farm forestry.Eucalyptus constituted 48%, Cypress 44%, Pine 3% and other 6% of tree planted. By 2023, TGAN had 785 ha under trees and this is projected to increase to 1,578ha in 2,028 and 3.175 ha in 2033. Annual products offered projections by 2023 was 5022 tons of carbon, 6840 M^3 of sawlogs, 6840M^3 of firewood and 196,012 pcs of transmission poles. These figure will grow further through 30% tree cover strategy This shows that forestry under small scale tree growers have huge potential to increase forest cover and livelihood of participating farmers. Results recommend continuous capacity building in value addition and marketing and tapping into financial models that can support tree growing. Tree growing cooperative offers solution to small scale growers and should be upscaled in other Counties.

Potential to facilitate Large-scale Private Investment in UK Woodland Creation while accounting for local community preferences

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: To achieve its net zero and biodiversity targets, the UK Government has committed to increasing woodland cover. The Devolved Administrations have set targets for woodland cover to rise from 10% currently to 12% in England by 2060, and from 15% to 24% in Wales and 19% to 25% in Scotland by 2050. The overall UK target is to plant 30,000 ha of woodlands annually by 2025. UK woodland creation rates reached around this level in the late 1980s but have been lower in more recent years. In the year to March 2022, for example, 13,850 ha of new woodland was created.

It is estimated that at least a further £1.8 billion in investment will be required for woodland creation and management between 2022-2032 (roughly 2.5 times public spending committed as of 2021) for current targets to be met. A lack of available finance is not considered a principal barrier, but a lack of a pipeline of investment-ready projects at a suitable scale for large-scale investors is widely thought a significant barrier.

As part of the Nature for Climate Fund R&D project on ‘Economics of Woodland Creation’, this paper sets out to investigate innovative mechanisms to link different elements in the woodland creation investment chain to help overcome existing financial barriers to investment in tree planting. It explores how investment opportunities suitable for large scale investors that account for local community preferences could be created, as well as mechanisms to help overcome existing cash flow barriers faced by landowners in creating woodlands.

Approaches are investigated from both finance supply and demand perspectives. They include ways to foster economies of scale and reduce investor transaction costs through pooling information on project risks and returns, and potential use of blended finance to de-risk projects. Investment opportunities that help meet particular water-related challenges (e.g., improving water quality) and how they could be aggregated are explored. The exploration links with work by Forest Research on developing a UK Woodland Water Code designed to underpin a market for woodland water credits and increase private sector investment in woodland creation for its benefits to the water environment.

Role of Kenya Commercial Forestry Innovation Centre in Up-scaling offtake of commercial forestry in Kenya

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: The Commercial forestry sector in Kenya has witnessed tremendous growth over the past few decades occasioned by the Country's rapid population growth, economic growth, and urbanization. The growing demand has not been able to match the local supply of forestry products making Kenya a timber deficit country. Challenges that have impeded growth of commercial forestry include: competition from alternative land uses, inadequate technologies, lack of investment data, inadequate infrastructure development and rising population growth, lack of adequate information on tree growing and management operations, species site matching, valuation techniques, markets outlets and market specifications for the various products hinder the growth of the sector. A conference on Commercial forestry investment held in 2021 recommended establishment of a the Kenya Commercial Forestry Investment Centre (KCFIC) hosted KEFRI.. The key partners in supporting the centre include FAO and UNDP with strong private sector engagement.

This is a Centre for Commercial Forestry Investments, Innovations, Advisory and Linkages whose Objectives is to enhance adoption and promotion of commercial forestry in Kenya as a competitive land use option to diverse investors and landowners. The Vision is to make Commercial Forestry a competitive sector that contributes to economic growth with a Mission of enhancing commercial forestry investments in Kenya through providing a platform for generation of technologies and showcasing innovations. The Outputs of the centre include: Strengthening the role of private sector and international communities in the forestry industry; enhance co-financing for investment in commercial forestry to propel economic growth and environmental sustainability; Creation of opportunities to incentivize youth's participation in commercial forestry investment which include; digital technologies, capacity development and enable access to market and enabling policies;

The Centre's governance approach is multi-institution, multi sectoral approach where KEFRI plays a coordination role. An ICT based decision support system is in place and will be supported by technical officers who will provide additional information to entrepreneurs.Innovation centre will provide a game changer to investors in commercial forestry.The Centre has created a lot of interest from all stakeholders. The paper gives details of the centre and its role in upscaling commercial forestry in Kenya.

Unlocking finance for sustainable forest value chains: Bridging the gap between producers' needs and investors' requirements in East Africa

T2.24 Scaling up investments and finance towards a responsible forest bioeconomy

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Abstract: The East Africa region presents enormous opportunities to promote sustainable production and consumption of wood products. On the production side, for example, the Kenya Government has committed to plant 15 billion trees to achieve 30% of tree cover by 2032 (at an estimated cost of about USD 4.5 billion). On the processing side, improvements in sustainability and efficiency are being sought in the region, and especially in Uganda. On the end market side, various initiatives are underway to promote the use of wood-based products instead of more carbon intensive materials in sectors such as building and construction. The coordinated support to various segments of wood value chains, from wood production to processing to the development of markets for sustainable wood can have significant positive effects on the environment, biodiversity and development.

Yet, scaling up such value chains requires further investments, both public and private. Several obstacles prevent larger investments to reach forest value chains in general, and small forest and farm producers and SMEs in particular: the perception of forestry as a high-risk business, informal and fragmented value chains, unattractive investment conditions (e.g., weak governance, inadequate infrastructure, high transaction costs, lack of financial literacy in the sector), and limited capacity by SMEs and local market participants to attract and access finance (lack of bankable projects).

The paper provides a series of key findings and recommendations emerging from of a series of dialogues between forest producers, value chain stakeholders, government agencies, development agencies and financial service providers all aimed to unlock finance for smallholder producers in support of landscape restoration and sustainable production in Africa.

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

Advancing the science and application of forest farming in the Appalachian region of the United States

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

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Abstract: Forest farming in North America has become a popular way for landowners to diversify income opportunities, improve management of forest resources, conserve biodiversity, and sustain tradition. People have been farming in forests for generations, but in the last several decades this agroforestry practice has evolved into a formally recognized means for reducing pressure on wild populations in the face of growing markets and satisfying consumers who demand traceable, sustainable, and high-quality woodland natural products. In particular, the Appalachian region is an iconic supplier of forest food and medicine. The region is 534,000 sq/km and traverses 13 eastern states largely dominated by deciduous forests. It hosts ancient mountains that are home to some of the most diverse mixed-mesophytic forests in the world and estimates suggest that close to 50% of woodland botanical species traded in the global market are endemic. We present the trajectory of forest farming in Appalachia over the last 20 years and discuss critical advances in science and application that support adoption. Results of field trials indicate that site selection and configuration are imperative for successful cultivation. Site preparation, protective measures, and soil amendments, as well as manipulation of the overstory canopy to change shade dynamics are recommended to enhance growth and productivity. Price-premium markets for forest farmed products are growing and aggregation often is necessary to ensure forest farmers have access. Federal, state, and private investments, as well as legislator support are fueling growth in application by way of drawing attention to the economic, environmental, and social benefits of forest farming and supporting establishment or expansion of farms using science, extension services, and coalition-building. Efforts in Appalachia have inspired development of forest farming coalitions in other regions of the US and efforts to establish a national forest farming association are underway.

Biological issues of simultaneous cultivation of large-diameter bole and high-yield cones of Pinus koraiensis

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

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Abstract: Ecosystem services (ES) of forests is growing rapidly at the global level, multi-functional Korean pine (*Pinus koraiensis*) is a dominant big arbor tree species in forest in the humid temperate region in East Asia, and its large-sized high-quality timber and nutritious pine nut production ES is in the global level, but there is little biological understanding of simultaneous cultivation of bole timber and nuts. Biological and technological issues of stand density regulation, tree top-pruning, fertilization and irrigation, photosynthesis patterns and the photosynthate allocation, hormone action and genomics were investigated. The main results: (1) Rational stand density such as 600 trees/ha at 40 years old and 350 trees/ha at 60 years old was both favorable to large-sized bole formation and high yield of cone in term of single tree and per unit area yield. (2) Top-pruning could promote bole radial increment and cone yield but the pruning height should be controlled properly for ensuring certain length of bole timber and succeeding top-pruning may need for the wide crown formation. (3) Fertilization and irrigation could increase the bole radial increment and cone yield at the same time. (4) Three years continue measurement on trees with long term rich fruiting and non-fruiting features shown that fruiting had no inhibition effect on growth ring increment, the fruiting trees obtained more strong photosynthetic capability and product more carbohydrates to support cone growth. (5) Needle and twig NSC on fruiting branches was significantly higher than that of non-fruiting branches, and carbon-13 labeling shown that the current photosynthates were transferred to fruiting branches and cones from non-fruiting branches. (6) The functional gene control trehalose 6-phosphoric acid that regulating the photosynthetic product allocation was found in the genome and showed higher expression in cones and fruiting branches. (7) Cytokinin might be more important role related to cone production. The above results implied that the cone production may not affect the bole timber production for Korean pine, and the source-sink relationship and its regulation mechanism might be the key biological issues for determined the biological mechanism of synergistic silviculture of timber and nuts.

Determining the feasibility of value chain development for non-timber forest products: insights from the Cerrado, Brazil

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

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Abstract: The Cerrado region in Brazil features many indigenous species offering non-timber forest products (NTFPs), particular fruit trees and palm species. For a variety of these the commercial potential is considered high, including e.g. pequi (*Caryocar brasiliense*), baru (*Dipteyx alata*), or buriti (*Mauritia flexuosa*). Higher value processing of such NTFPs is a promising strategy to enhance smallholders' livelihoods and create incentives to sustainably manage the Cerrado forests, rather than making the area available for commercial agriculture. However, although some NTFPs of the Cerrado are already collected, processed and traded, these efforts often are on a small scale and only generate limited benefits for local populations. In order to make the use of NTFPs financially more rewarding to land users in the region, while simultaneously safeguarding their natural habitat, there is a need for research on how benefits to producers in these value chains can be improved. We aim to help aid the development of NTFP value chains in the Cerrado by applying a participatory, holistic research approach in collaboration with the relevant stakeholders active in the region such as cooperatives and enterprises and other value chain members involved in utilizing and processing priority NTFPs. As such, prevailing NTFP commercialisation in the Cerrado region will be assessed based on focus group discussions and interviews amongst value chain members in order to understand its current performance; relevant actors and product flows mapped in order to more deeply understand prevailing power dynamics in the Cerrado food system and current limitations for NTFP value addition; and prevailing laws, regulations, or advisory services affecting NTFP commercialisation assessed in order to determine the current feasibility of value chain development. This paper will present the initial results of the ongoing research.

Forest Fruits for Food Security: Identifying Uses & Socio-economic Significance of Selected Indigenous Fruit Tree Species in South Luzon, Philippines

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

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Abstract: The Philippines is home to a wide diversity of biological and cultural resources, including many indigenous fruit tree species (IFTS). Despite the potential of IFTS to contribute to the achievement of food security and alleviation of upland poverty, IFTS in the Philippines remain underutilized. This study, therefore, explored the uses and socio-economic importance of six (6) selected indigenous fruit trees (IFTS) namely, Kalumpit (*Terminalia microcarpa* Decne subsp. *microcarpa*), Bitongol (*Flacourtia rukam* Zoll & Moritzi), Tibig (*Ficus nota* (Blanco) Merr.), Libas (*Spondias pinnata* (Linn. F.) Kurz.), Binayuyu (*Antidesma ghaesembilla* (L.) Spreng), and Lipote (*Syzygium polycephaloides* (C.B.Rob.) Merr.) through structured and key informant interviews involving 270 respondents in Southern Luzon, Philippines. Tibig was the most cited IFTS in the region with a relative frequency of citation (RFC) of 80.6%, followed by Bitongol, Kalumpit, Lipote, Binayuyu, and Libas with RFC of 77.2%, 51.1%, 41.77%, 40.5%, and 29.5%, respectively. Three of the selected IFTS (Kalumpit, Lipote, and Bitongol) were also found to be socio-economically important in the region – these fruits were sold in the markets during their fruiting seasons and were sought after by the locals. Findings further reveal a range of uses for the IFTS, from dietary and medicinal to practical purposes. The most cited dietary use was the consumption of fruits as fresh, sweetened, or fermented treats. Some of the widely known medicinal purposes were the use of Tibig leaves as topical relief for headache and wounds, and the consumption of Binayuyu bark and leaf extracts to treat urinary-related illnesses. Although Tibig was the most cited IFTS, it has little to no use at all for the locals. Binayuyu and Lipote fruits were also recognized as a flavoring agent for alcoholic beverages (i.e., wine and nipa sap wine) while Libas foliage were acclaimed as a souring agent for local dishes. Results of the study strongly suggest that these IFTS, although underutilized, have a promising potential as valuable food and income sources. It emphasizes the need for further research, development, and national recognition of indigenous food resources in the Philippines.

Mediterranean stone pine production systems and the emerging bioeconomy in Chile

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

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Abstract: Stone pine (*Pinus pinea* L.) is a Mediterranean species whose edible seeds are a highly valued non-timber forest product with worldwide-unsatisfied demand. Cones are harvested mainly from natural forests, and cone or pine nut sales generate income and jobs. This study assessed the economic benefits of cultivating stone pine, an emerging crop in Chile, and its role in the transition towards a bioeconomy, due to the broad ecosystem services the species provide, along with socioeconomic benefits, allowing a value chain development. Primary and secondary data on costs, production, and income were collected, and an economic evaluation performed considering three management schemes (medium-intensity managed plantation, medium-intensity managed agroforestry system, and high-intensity managed plantation) under four production and price scenarios. The net present value was positive for all schemes under the most likely production and price scenario at 6% and 8% interest rate, with the high-intensity managed system being the most profitable; the medium-intensity managed agroforestry system was more profitable than the similarly managed plantation and easy to implement by landowners; it also had the highest financial resilience. The evaluation performed provide insights to better understand how stone pine cone and pine nut production can contribute to the bioeconomy development in Chile. Stone pine cropping under the three management schemes evaluated, showed attractive economic benefits; the high-intensity managed system proved the most profitable, with an NPV of up to US$6,400 per hectare. Stone pine cropping will provide local and export markets with high quality, high-value, healthy, and potentially equitably produced pine nuts to help meet the growing global demand. This emergent crop can contribute to transitioning towards a bioeconomy by favouring sustainable and inclusive rural development with economic (annual significant income generation), social (jobs creation, recreation) and environmental benefits (carbon sequestration, erosion control). Providing incentives and fostering stakeholder involvement to reach a critical production area and volumes, supported by science-based technological innovation, will facilitate the transition to a bioeconomy.

Sustainable deficit irrigation to enhance establishment of young, grafted plants of Pinus edulis, a potential nut-tree crop

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

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Abstract: A growing number of consumers across the world want access to locally produced, healthy food, but also highly value sustainable food production, including the cultivation of low-water-use crops. Producing pine nuts from the regionally native, drought-tolerant two-needle pinyon pine (*Pinus edulis*), which currently is not cultivated, offers an opportunity to produce a sustainable, long-lived tree crop on tribal and non-tribal lands. We have developed a highly effective grafting protocol, using the side-wedge graft, for the propagation of superior pinyon genotypes, which we have collected from across its native range in the southwestern United States. Prior to widespread adoption of pinyon pine as a nut-tree crop, however, we need to determine the minimum amount of irrigation water needed to successfully establish young, grafted pinyon pines in typical orchard conditions in semi-arid environments. As such, we applied four irrigation treatments (50, 75, and 100% drip-irrigation plus a wick-based irrigation technique (Groasis Waterboxx)) to 1-year-old grafted pinyon pines (*Pinus edulis* scions on *Pinus edulis* seedling rootstocks) in orchard in central Utah, USA. We found that pinyons drip-irrigated at 75% the amount of the positive control had comparable growth rates with those in the control. However, those growing in the Waterboxxes exhibited similar end-of-season growth compared to those in the control treatment. Our research suggests that deficit-irrigating young, grafted pinyon pines leads to an appreciable amount of successful establishment. Future work needs to determine long-term establishment and growth of grafted pinyon pines under suboptimal conditions.

Sustainable forest management for progressive bioeconomies

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

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Abstract: Despite being essential to forest health and resilience, and supporting the food security, nutrition, and wellbeing of billions of people, non-timber forest products (NTFPs) have been largely overlooked within traditional forest management planning and implementation strategies. Historically, forest management has aimed at harnessing diverse and complex ecosystems with single-goal production models, evolving with changing demand for raw materials. As sustainable forest management moves towards modern and more inclusive models, an innovative paradigm is needed, in line with bioeconomy principles. The focus of this presentation is management of forest resources and derivative products that make up a forest-based bioeconomy. A bioeconomy ostensibly includes production, utilisation, conservation, and regeneration of biological resources, incorporating related knowledge, science, technology, and innovation, to provide sustainable solutions across all economic sectors. Transition to a forest-based bioeconomy depends on moving from "single-objective" management to multiple-objective sustainable forest management (SFM). Contemporary SFM principles recognise forests as more complex ecosystems, incorporating provisioning of food, water, materials, and cultural amenities; regulating effects of climate, floods, disease and water quality; and supporting services such as soil formation, photosynthesis, and nutrient cycling. SFM also considers the provisioning ecosystem services of goods other than wood, although it has not yet fully integrated the production and extraction of NTFPs. This presentation explores and integrates the concepts of forest management that consider NTFPs relative to the principles of a bioeconomy, focusing on possibilities and challenges that support or impede the integration of NTFPs into SFM. We examine relevant aspects of NTFPs that may be influenced by forest management and discuss how silvicultural and forest management practices can be adjusted for the sustainable production of multiple goods. Finally, we discuss challenges and factors that may encourage a transition to SFM including NTFPs within a functioning bioeconomy.

Utilizing Artificial Intelligence for Discrimination of Pollen in Taiwan Forests: A Preliminary Case Study of Dimocarpus longan and Litchi chinensis

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

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Abstract: Bees play a critical role as pollinators in the ecological world, and bee honey is a significant global product. In recent years, Taiwan's forestry policies have actively promoted beekeeping in forested areas. Understanding the species composition of honey is crucial for determining bee preferences as food sources and assessing the botanical composition of honey. However, with the diverse range of plant species in Taiwan's forests, distinguishing between them becomes challenging. This study focuses on two popular varieties, *Dimocarpus longan* and *Litchi chinensis*, which are important economic trees in Taiwan and exhibit very similar pollen morphology. The primary objective is to investigate the dominant species ratio of *Dimocarpus longan* and *Litchi chinensis* in honey products, with the potential to expand the identification to other forest tree species.

To achieve this, pollen was extracted from flower buds of both species, and optical microscopy was employed for species identification. Subsequently, an AI technology utilizing the Mask R-CNN deep learning model was developed to train and identify pollen samples specifically from *Dimocarpus longan* and *Litchi chinensis*.

Our results indicate that after ten training cycles, the model exhibited significantly improved precision with a value of 0.94, while the recall rate was moderate at 0.50, indicating a higher type 2 error during the training process. The mean average precision (mAP) value achieved was 0.91. In comparison, three training cycles yielded lower precision (0.7), recall rate (0.44), and mAP (0.59). However, it is important to note certain limitations, including a limited dataset, uneven pollen sample sizes, and deformations during the preprocessing stage, which may have influenced the training and recognition capabilities of the model. Additionally, factors such as bubbles and impurities on pollen slides, as well as variations in focal lengths in the photos, could introduce errors in the model.

Future work will involve further calibration and expansion of the pollen species database to automate the identification process, particularly for species in forested areas. This approach will enable the determination of forest honey species composition and reduce the time and labor costs associated with manual identification.

Yield and quality of Ugni molinae fruits from natural forests, in response to silvicultural interventions to optimize its sustainable production

T2.25 Silviculture for food and medicine in a forest-based bioeconomy

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Abstract: Murta (*Ugni molinae* Turcz), a native understory shrub that grows wildly in central and southern Chile, used by native people who attributed beneficial properties to its fruits and its leaves. It is the species fruit is an edible berry, which it is considered a super fruit due to its high level of secondary metabolites. Currently there is information about murta management focused on agricultural cultivation with little or no information on the state of conservation and sustainable management in native forest conditions.

In a stand of Roble-Raulí-Peumo, (*Nothofagus obliqua, Nothofagus alpina and Cryptocarya alba*) belonging to the Roble-Raulí-Coihue (*Nothofagus dombeyi*) forest type, subtype Degraded Forests, located in Biobío region, eastern slope of the Nahuelbuta Mountain Range, a study was established aimed at designing and evaluating methods of silvicultural management in native forest formations with the presence of *Ugni molinae*, with the objective of increasing yield and quality. The experimental trial involves 24 plots of 25 m2, with a factorial design in randomized blocks. Treatments were release cutting, increasing light on plants; thinning of murta and elimination of other competing shrub species; and pruning. In total eight treatments and three repetitions. Preliminary results indicate a superior fruit weight in the thinned plots without release, which presents significant differences with the plots without release or thinning. The size registers statistically significant higher values in the treatments without release, with thinning and pruning. Finally, fruits harvested in the control plots presented significantly lower weight and size. We conclude that optimal solar radiation favors the increase in the size and weight of the fruits of murta fruits, and that with the high level of thinning of plants of murta, and of all direct competing shrub species, in the coming years, a positive response of the remaining murta to the greater arrival of light, temperature and release of nutrients would affect fruit productivity.

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

BEYOND BLIGHT: SILVICULTURE AND POLICY CONSIDERATIONS FOR AMERICAN CHESTNUT RESTORATION

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: American chestnut (*Castanea dentata*) was functionally extirpated from eastern US forests by chestnut blight. As efforts to produce blight-resistant American chestnut germplasm advance, approaches to reintroduce chestnut throughout its former range are being developed. Over the past twenty years, I have collaborated with many colleagues to better understand how reintroduced chestnut may perform across the landscape. We have parameterized chestnut ecophysiology, responses to silviculture, seed dispersal and establishment, and carbon storage / decay; and then used these findings to conduct modeling experiments. We have published several key findings related to this work. First, American chestnut is very fast growing, competitive, relatively long-lived, and resistant to decay. Nevertheless, aggressive restoration efforts are needed to ensure that chestnut will become a significant and stable component of the forest within a century under current or future conditions (i.e., introduced pests, climate change). Additionally, despite its fast growing and long-lived nature, chestnut will produce only modest increases in carbon storage, mainly through slow decay of its wood. Second, analysis of non-structural carbohydrate (NSC) pools in different organs of American chestnut trees found that coarse roots were a remarkably important storage site, suggesting that chestnut may thrive under disturbance-based management. Third, the pathogen *Phytophthora cinnamomi*, which causes a root rot disease, generally reduced chestnut biomass on the landscape even when modeled using the highest levels of resistance to root rot infection that are incorporated into current breeding efforts. As root rot is expected to increase in virulence and migrate north in response to climate change, we suggest the need to further increase root rot resistance through biotechnology, as well as to target reintroduction to sites where root rot is not expected to be present well into the future. Finally, although remarkable progress has been made in developing blight-resistant chestnut, we suggest that successful reintroduction will ultimately depend on regulatory policy, informed by science and with public support.

Biodiversity in sweet chestnut forests: effects of coppicing and of the spread of black locust

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: Sweet chestnut (*Castanea sativa* Mill.) dominated forests are commonly shaped and maintained by silvicultural practices. Coppice systems are frequently applied; however, in many European landscapes over-aged stands are developing because of the lack of silvicultural interventions. Furthermore, these forests are frequently considered a habitat type of community interest and it is a widely spread forest type in several Natura 2000 sites. This contribution builds on the results of a recent study (https://doi.org/10.1016/j.foreco.2023.120907) that compared the effects of different management regime intensities on sweet chestnut forests as well as on the differences with forests dominated by the invasive non-native tree black locust (*Robinia pseudoacacia* L.) in north-eastern Italy (Veneto region). The main results on plant composition, soil Ammonia-oxidising archaea abundance and stand structure was used to understand the implications of forest management as well as the spread of an invasive non-native tree. This discussion helps proposing conservation measures, mainly forest management indications, aiming at a good conservation condition for sweet chestnut (*Castanea sativa*) forests.

Blight-tolerant Darling™ transgenic American chestnuts

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: The American chestnut was once one of the most abundant trees in the eastern US. It was considered a keystone species for wildlife and provided significant economic benefits due to the delicious nuts it produced and valuable rot-resistant timber. The chestnut blight fungus, *Cryphonectria parasitica,* killed over 3 billion American chestnuts in the 20th century, leaving the species functionally extinct. We developed transgenic American chestnut trees called Darling™, with enhanced blight tolerance. This trait was achieved by inserting a single gene from wheat, oxalate oxidase (OxO), which encodes for an enzyme that detoxifies oxalic acid produced by the fungus, preventing necrosis of chestnut tissues that can lead to fatal cankers. This trait is inherited throughout generations (classical Mendelian inheritance) and has already been a valuable tool to rescue surviving remnant American chestnut trees. We are continuing these crosses with diverse wild-type trees for multiple generations to ultimately produce a resilient and diverse population suitable for restoration. Extensive research on Darling, their offspring and other OxO-expressing events has been ongoing for several years. Inoculations of seedlings and young trees have shown a substantial reduction of canker size and severity on the transgenic trees compared to the closely related non-transgenic controls. Multiple non-target studies (e.g., mycorrhizal colonization of roots, insect herbivory of leaves, and wood frog tadpoles feeding on leaf litter) and nutritional comparisons confirm that the transgenic and wild-type trees are essentially equivalent apart from blight tolerance. The comprehensive characterization of Darling trees and environmental tests were required for ongoing governmental regulatory review, which we expect to conclude this year, allowing the first public distribution of transgenic disease-tolerant chestnut trees. The tree's scientific path, project status, and regulatory updates will be discussed during this presentation.

Chestnut technique, physiology and legislation: an emblematic paradox. The Amiata experience

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: The origin of stand coppice in forestry, as we understand it and study it nowadays, has very deep and varied roots, often influenced by the rural habits of the territory [Zanzi Sulli and Di Pasquale 1993]. To the classic objectives that can be found in all the basic forestry texts it is in fact necessary to add the multiple possibilities motivations that were widespread in the Apennine environment.

This reasoning is difficult to apply to the Amiata chestnut groves, in fact these statements find little foundation in an environment as peculiar as it is replicable. Since the past centuries, the people of Amiata were accustomed to grafting, and therefore cultivating chestnuts, with the many local varieties selected over time to satisfy their own uses. Therefore, since the past, fruit chestnut groves were clearly distinguished from those aimed at wood production, all woods that were in the courtyard of small inhabited areas in which squeegees and carpenters alternated.

Going even further into the silvicultural peculiarities of chestnut, and more precisely into its biological characteristics, we realize even more that the concept of stand coppice in this specie groves leaves room for many perplexities. The production of chestnuts for the rejuvenation of the stumps is very little required since it shows surprising longevity of these apparatuses, and for this requirement the seed production that the suckers guarantee from the very first years following the utilization. The site conditions and the objective fertility of the local soils guarantee maximum vigor of the young shoots. Research conducted in the municipality of Abbadia S.S. (SI) show that in simple coppices (without the release of stand) the re-explosion and the state of health of the young shoots is at least as good as that observed in the stand coppice. Thus the experience and the state of the forest of this surprising species suggests a radical re-evaluation of the Italian legislation that governs it, as happens moreover in many European countries where they have (for some time) become aware of the disadvantages due to the release of stand in chestnut coppices (Switzerland, France, Spain, Portugal).

Continued Chestnut Biotechnology Development at SUNY-ESF

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: Our research team at SUNY-ESF in Syracuse, NY, USA has developed an innovative biotechnology pipeline for the American chestnut (*Castanea dentata*) . Transgenic lines such as Darling 58 contain an oxalate oxidase (OxO) gene from wheat, which enhances tolerance to the necrotrophic blight pathogen *Cryphonectria parasitica*. These have undergone rigorous safety reviews to attain required US government regulatory approvals, which are anticipated this year. However, research toward improved disease resistance in American chestnut will not end with regulatory approval of Darling 58. New transgenic lines are currently in development for enhanced and refined resistance to *C. parasitica,* as well as *Phytophthora cinnamomi*, the causal pathogen of root rot disease in chestnut. The 'DarWin' chestnut line contains the same OxO gene as Darling 58, but with expression controlled under a pathogen-inducible promoter from poplar instead of a constitutive promoter. A putative *Phytophthora* resistance gene from Japanese chestnut is also being assessed in American chestnut lines, which could enable restoration to the Southern portion of the American chestnut range. In addition, RNAi Host Induced Gene Silencing (HIGS) is being researched as an additional source of resistance to both *C. parasitica* and *P. cinnamomi*, and possibly others pests and pathogens as well. Continued improvement in American chestnut genetics and resistance to multiple diseases will be critical for success of future restored populations.

Keywords:

Castanea dentata; Cryphonectria parasitica; Phytophthora cinnamomi; biotechnology

Coppices are not the same anymore: evolution of the radial increment in young chestnut coppices

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: We evaluated the radial increment in the young stage (up to 10 years old) of dominant sprouts in chestnut (*Castanea sativa*) stands coppiced in two different epochs (before 1980 and between 1990 and 2000) but before the arrival of the Asian chestnut gallwasp (*Dryocosmus kuriphilus*). The study sites were located in in Ticino (Switzerland), Veneto, Piedmont, and Tuscany (Italy). The analyzed data highlighted a significant higher increment rate in shoots from post-1990 coppicing. Possible explanatory factors are the management techniques, the increasing temperatures, the atmospheric CO2 enrichment and the increased soil nitrification due to the anthropogenic-induced N-depositions.

Conversely, in sites located at the edges of the climatic optimum for the chestnut tree, frequent summer droughts observed from 2003 on seem to have caused a decline in the woody increments of the species.

Development of blight-tolerant Castanea ozarkensis

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: We have engineered transgenic American chestnuts to express oxalate oxidase (OxO), which counters the main virulence factor produced by the chestnut blight fungus, *Cryphonectria parasitica.* These blight-tolerant trees have been extensively studied and are currently under governmental regulatory review. The present work focuses on applying the knowledge used to develop the transgenic American chestnuts to the Ozark chinquapin, a closely related North American species also severely impacted by chestnut blight. *C. parasitica* reached the Ozark chinquapin native range (U.S. Interior Highlands) after 1950, killing mature trees that used to reach up to 20 m tall. Their population substantially decreased, and currently surviving individuals are heavily suppressed subcanopy trees or grow as small resprouting bushes. We are using two biotechnological approaches to develop blight-tolerant Ozark chinquapins: a backcross breeding program with transgenic American chestnuts and direct genetic transformation of Ozark chinquapin. Pollen from the transgenic American chestnuts is being used as source of blight tolerance to introgress the OxO gene into Ozark chinquapin mother trees. Transgene inheritance has been confirmed in F1 hybrids, which are currently under high-light treatments to induce pollen production, which is typically achievable in less than a year. This transgenic hybrid pollen will be backcrossed to full Ozark chinquapin mother trees to start the process of recovering the species' phenotype. We are also performing genetic transformations of Ozark chinquapin somatic embryos using the American chestnut's *Agrobacterium*-mediated transformation protocol. We first confirmed this technique by transforming Ozark chinquapin somatic embryos with a reporter gene, and subsequently obtained multiple transformed events with OxO and other candidate genes for blight resistance (e.g. laccase from *C. mollissima*). These results show great promise for meeting the challenge of developing a blight-tolerant Ozark chinquapin and potentially addressing related threats in other species.

Integrating Diversity, Ramping Up Capacity, and Transforming Nursery Capacity for Threatened Native Tree Species Restoration

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: As wildfires ravage forested landscapes, native species' habitats are being altered and constricted due to climate change, and non-native pests and pathogens extirpate native tree species from their range, the need for tree seedlings is estimated to be double the current capacity across the US. The American chestnut was one of the first native tree species in the United States extirpated due to the importation of non-native pathogens, taking place sometime in the years between 1850 – 1950. Since that time, globalization and trade have introduced a multitude of new pests, pathogens, and invasive vegetation which threaten the sustainability of US forested ecosystems.

While the American chestnut was one of the first to become functionally extinct in its native range, it is also poised to be one of the first to be restored. Over the past 40 years, The American Chestnut Foundation (TACF), working with hundreds of partners, stands ready to deploy a diversified population of disease-resistant American chestnuts. In order to restore a species across millions of acres, millions of tree seedlings will be needed. Tree planting, especially that with hardwood trees, is expensive and laborious. Forest landowners will need access to high quality and low-cost tree seedlings, not only of American chestnut, but other native tree species which can facilitate large-scale ecosystem sustainability.

This decades-long project will involve hundreds of private landowners, academic institutions, federal and state agencies, and NGOs. The work ahead relies on timely installation and implementation of seed orchards and which exponentially ramp up seed production for the subsequent distribution of tree seedlings to be planted across the eastern United States.

Mid-last century, many states had multiple agency tree seedling nurseries; most of those have been mothballed or entirely closed. Working with limited budgets, aging infrastructure, and limited personnel, these state nurseries need infusions of funding to be able to meet increased capacity goals. Using the American chestnut as a test case for introduction of a new species into nursery production pipelines, TACF seeks to re-invigorate the use of seed orchards and to install new processes and efficiencies in private and state agency nursery seedling production.

Micro-collective approach to establish a mixed forest with Castanea sativa and Quercus petraea after two years from plantation

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: We present the preliminary findings of a forest restoration project involving micro-collectives of a mixed plantation comprising European chestnut (*Castanea sativa* Mill.) and sessile oak (*Quercus petraea* Matt. Liebl.), replacing a degraded pure stand of exotic Pinus strobus L. The indigenous species, better adapted to the site compared to pine, can offer improved climate change mitigation, enhanced biodiversity, and increased economic value through wood and non-wood products. The study site, located in Tuscany, Italy, provides favorable soil and climatic conditions for both species, with chestnut particularly well-suited.

The micro-collectives were designed to emulate a natural and irregular distribution pattern, with five 1-year-old chestnut seedlings as the primary species and oak as the secondary species, spaced 10 meters apart. Planting took place in early spring 2022. Approximately half of the area was fenced to protect against wildlife damage and browsing. Chestnut seedlings were sourced from three local stands with varying altitudes and exposures. Our research aimed to address three key questions: a) Is the micro-collective approach more effective than natural regeneration? b) What is the influence of wildlife on the regeneration process? c) How do provenance and seedling size affect chestnut field performance?

Destructive analysis was conducted on nursery seedlings from each provenance to assess their morphological characteristics and their relation to field performance. Field monitoring encompassed the assessment of survival, growth, stem structure, viability, and phytosanitary conditions of all planted seedlings, both within and outside the fenced area. Additionally, 30 subplots with a 2-meter radius were established to evaluate natural regeneration capacity in the presence or absence of wildlife.

Initial results from the first two years of monitoring indicate higher survival rates in chestnut compared to oak within the micro-collectives. Indigenous species from surrounding stands displayed encouraging levels of natural regeneration. The impact of fencing and the influence of climatic patterns on the observed outcomes are also presented.

These findings contribute to our understanding of early-stage dynamics in mixed plantations and highlight the challenges and opportunities associated with introducing diverse tree species in reforestation initiatives.

More than trees: how fungal community ecology can inform and improve success of Castanea outplanting performance and disease outcomes

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: American chestnut (*Castanea dentata*) is a historically important species in the eastern United States that has become functionally extinct due to major pathogen stressors, including the causal agent of chestnut blight (*Cryphonectria parasitica*). Backcross hybrids of American chestnut have been developed with the goal of increasing disease resistance for reforestation efforts. Further, outplanting success may be affected when co-planting with naturally co-occurring Fagaceae trees such as white oak (*Quercus alba*). Here, we explore the role fungal community ecology can play in improving success of reforestation efforts and informing future management options. Outplanting of American chestnut, Chinese Chestnut (*C. mollissima*), five families of third generation backcross hybrids and white oak was established in southern North Carolina (USA). Soils were collected at time of planting and at 3- and 6-years post planting. Secondary roots and leaves were collected at year 6 to examine rhizosphere and root and leave endophytic communities. Additionally, metabolites from chestnut leaves at year 6 were queried using nuclear magnetic resonance (NMR) to explore functional differences between plant families and as associated with foliar fungal communities. We find that soil fungal communities associated with chestnuts and oaks shift in similar ways over the first three years of plant growth and that key fungal taxa might be able to be used to predict tree performance and/or chestnut blight occurrence. We also provide strong evidence of shared ectomycorrhizal communities across Fagaceae species, and persistent nursery-bed fungal taxa that may play an unappreciated role in plant performance. Ongoing work is expected to demonstrate chestnut family differences in 6-year rhizospheric soils and endophytes, particularly with pathogens. We also expect to see broad metabolic profile differences among chestnut families and to identify key metabolite groups associated with foliar fungi. Taken together, these analyses demonstrate the utility of integrating fungal ecology into chestnut reforestation efforts as an additional tool to inform silvicultural decisions and to improve plant performance.

Multifunctionality of chestnut coppices and future prospects in timber production and ecosystem services.

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: The chestnut coppice management has been perpetuated for millennia thanks to the unlimited resprouting capacity of the stool, which results in a high number of fast-growing shoots. In Europe, first written historical evidence of applying a coppice management to the sweet chestnut (*Castanea sativa*) date back to Theophrastus (~370 B.C.–287 B.C.). The widespread diffusion of *C. sativa* for wood production, well beyond its natural range, has pushed the diffusion in Europe up to the current 1.78 million hectares of which 79% is managed as coppice.

Over time, the biological and economic sustainability of the chestnut coppice have been usefully included into the traditional small farm management, since a wide range of wood assortments can be obtained (poles, beams, sawn wood, wood-based panels, tannins, biomass for energy) in monospecific, coeval, and even-structured forest stands.

Regular coppice management of chestnut carried out on small plots has always represented a guarantee both in terms of production continuity and ecosystem services (biodiversity conservation, landscape structuring and protection against natural hazards).

However, in the last century, profound economic and social changes have caused a general abandonment of the coppice management with the consequent loss of ecosystem products and services, including the replacement of the chestnut with other tree species.

Recently, there has been a renewed interest in chestnut coppice products and services such as sustainability of timber but also non-timber products, ecological function and biodiversity, slope protection, carbon sequestration and educational and tourist recreational activities.

Where possible (sites with good fertility, reduced presence of aggressive pathogens), the main practice proposed in chestnut coppices is the extension of the rotation time accompanied by the application of adequate silvicultural practices. In this way, larger quality assortments can be obtained with additionally benefits for the diversity of the vascular flora, the stand stability and for the general vulnerability of the chestnut forest to fire. This results in social benefits for local communities (employment, reduction of timber imports).

In this perspective, innovative silvicultural systems (e.g., tree-oriented silviculture) have been introduced recently, while others have been implemented for improving the tradition of coppice management options (e.g., stand-silviculture).

Naturalized sweet chestnut (Castanea sativa Mill.) in the rural landscape

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: Sweet chestnut is widely naturalized in allochthonous environments, derived from the long history of cultivation of this tree for chestnut production, that have been traded since Roman times with relevant socioeconomic benefits. Furthermore, a wide range of timber products is also valuable. The species characteristics allow for different management options (coppicing, high-forests, mixed plantations, agroforestry), depending on environmental, economic and/or social conditions. The species was introduced outside its native range in South America (mostly in Argentina, Chile and Uruguay), Australia and New Zealand as early as the 19-century for nut and timber production. Management of the species is appealing to small and medium-size landowners because since it may provide yearly chestnuts along with timber at the end of the rotation. In Chile, *C. sativa* is considered naturalized, and it has been planted both in pure and mixed plantations with conifers and broadleaves. Furthermore, ring shake, a timber defect causing important economic losses in the species native range, is not present in Chile. An inventory of plantations was performed, recording tree growth variables and plantation characteristics. The presentation includes information on tree growth and management schemes in naturalized environments, explores the expected impact of climate change on the species performance, and presents possible tools to deal with these challenges, including genetic breeding, assisted migration and management adjustments to foster its adaptation.

Optimizing American Chestnut Restoration Efforts Through Habitat Suitability Modeling

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: American chestnut (AMC) (*Castanea dentata*), a once widely abundant tree species in the eastern US has functionally been lost from much of its natural range due to the introduced fungal pathogen, *Cryphonectria parasitica*. Restoration efforts have since focused largely on the development of disease-resistant chestnuts, while the restoration strategic plan has little or no information on the effect of changing climate on suitable habitats as well as changes in this species' range over the last century. Our research centers on utilizing improved models to forecast appropriate habitats in the eastern United States, predict changes in habitat ranges, and identify factors influencing the habitat suitability of the AMC within the region. The aim is to support the ongoing restoration efforts of AMC by employing an ensemble model that combines different species distribution modeling (SDM) methods. Additionally, our study extends the predictions until 2100 to account for the impact of climate change. We gathered 1,806 occurrence records from various sources, including the United States Department of Agriculture (USDA) Forest Service, iNaturalist, and TreeSnap. The application of SDM techniques yielded highly accurate models with true skill statistics (TSS) and Area-Under-the-Curve (AUC) values exceeding 0.8 and 0.90, respectively, which were assembled. A comparison between the historically suitable habitat of AMC and the present habitat suitability prediction in the US revealed a significant decline in suitable habitat. The primary variables influencing the distribution of the American chestnut in the US were identified as the mean temperature of the warmest quarter, precipitation seasonality, and temperature seasonality. The future projection indicates a potential reduction of up to 61.1% and 100.0% in suitable habitats by the end of the century under high emissions as well as stable and high precipitation conditions, respectively, with a northeast range shift spanning approximately 43.2 and 476.9 km which translates to 4.3 and 47.7 km per year. It is crucial to model the habitat suitability of the AMC for a successful restoration program, and these findings underscore the importance of increased conservation efforts and the utilization of southern genotypes.

Promoting species diversity: understanding Sweet chestnut within regeneration of Scots pine stands

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: Pine forests show a natural gradual transition to mixed plantations where, with the progression of ecological succession, hardwoods such as Sweet chestnut (*Castanea sativa* Mill.) and oaks begin to progressively settle. However, the persistence of chestnut in conifer stands remains poorly studied and appears to be strongly influenced by the surrounding areas where the species is cultivated and light availability. In this case study conducted in Serra da Nogueira, Portugal, which is characterized by a mosaic of habitats resulting from mountain agriculture, including extensive Pyrenean oak forests and stands of other hardwoods and conifers, such as Scots pine (Pinus sylvestris L.), it was observed that chestnut persisted in the natural regeneration of these stands primarily due to the presence of nearby chestnut forests and agroforestry stands. The presence of advanced regeneration in the understory of Scots pine stands suggests that chestnut can persist in the natural regeneration dynamics, leading to the formation of mixed stands more resilient and biodiverse. Therefore, the regeneration status of two Scots pine stands covering a 12-hectare area in Serra da Nogueira (41°45'34"N, 6°54'53"W, altitude 980 m) was assessed. A systematic sampling approach was applied. A semi-permanent circular plot device was installed, following a concentric system with a fixed radius. Natural regeneration ($d<10$ cm) was divided into two height strata: up to 2 m and > 2 m. Concentric circular plots of 100 and 200 m^2 were used to study each height stratum. Abundance and diversity were evaluated using modified Shannon and Simpson indices, the inverse of the Berger-Parker index, and species richness. Generalized linear models (GLM) and generalized additive models (GAM) were employed to explore the influence of potential explanatory variables related to stand structure, crown cover, and degree of shrub cover (SC) on the abundance of the main species contributing to natural regeneration. The results indicate that basal area (G) significantly affects the abundance of natural regeneration. Additionally, it was found that the percentage of SC also had an influence. Basal areas close to 40 $m^2\ ha^{-1}$ promote the regeneration of Scots pine while lower G favors the establishment of hardwoods, particularly chestnut.

Synergies between the American and Sweet chestnuts could impact the rural bioeconomy

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: Sweet chestnut (*Castanea sativa*) and American chestnut (*C. dentata*) have been explicitly linked to historical and contemporary cultures and have played important roles in rural bioeconomies. These species also have been important for enhancing ecological services, such as mast production, soil stabilization, and high water use efficiency. Threats to these species are unprecedented and additive, including global climate change, nonnative pests and pathogens, land use changes, and lack of scientific knowledge and technologies. We will provide a synthesis of traditional and novel silvicultural systems for chestnut, focusing on timber and non-timber forest products that enhance the forest bioeconomy. Sweet and American chestnuts require divergent management strategies to sustain their conservation values, and both species require active forest management to maintain or restore populations in native or naturalized habitats. Even-aged regeneration systems are the preferred silvicultural practice for both species. Coppicing is commonly implemented for sweet chestnut and provides a potential future strategy for American chestnut once disease-resistant material is available. *Cryphonectria parasitica* causes chestnut blight and may limit long-rotation timber production of American chestnut making coppice systems more attractive for managers. High forests of sweet chestnuts are managed primarily for timber production in single or mixed species plantations and naturalized stands, although ecosystem services are being increasingly considered in value estimations for this species. American chestnut will probably be reintroduced to achieve ecological restoration goals that can be considered in determining values to the bioeconomy. Traditional and emerging markets for sweet chestnut, such as biomass or carbon, may help inform future opportunities around American chestnut, particularly for tribal and rural communities. Climate change and other threats call for synergistic partnerships and knowledge sharing to maintain or restore sweet and American chestnuts as part of the global ecosystem.

The Management of Agroforestry for Japanese Chestnut (Castanea crenata) in Taiwan.

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: Japanese chestnut (*Castanea crenata* Sieb. & Zucc.) was introduced into Taiwan in 1910 for the purpose of harvesting its edible nuts. However, due to the difficulties in cultivation and the influence of the local warmer climate, Japanese chestnut grows slowly in Taiwan. Currently, the primary chestnut orchard covers about 25 hectares in Jhongpu Township, Chiayi County.

This study addresses two major issues. Firstly, the research applied in-depth interviews to conduct 6 landowners in 2018. We collected their management information and experience regarding orchard maintenance operations, harvesting practices, production status, and the challenges of management. At the same time, agricultural statistics data from 1997 to 2021 were also collected and analyzed the trends in annual yield and marketing status of the chestnuts in Taiwan. The results showed that chestnuts are vulnerable to the Formosan rock-monkey (*Macaca cyclopis*). Additionally, the cost of labor and process equipment is high, and the harvest period coincides with the typhoon season, making nuts production unstable and susceptible to damage from natural disasters or climate variations.

With regard to the second issue of the study, the research team aims to develop an agroforestry management model by integrating beekeeping businesses into the orchard operations. Starting in 2020, beehives were placed in the designated area to collect chestnut honey. The blooming season of Japanese chestnut typically occurs from late of April to mid-May. Based on the harvest data from 2020 to 2022, the average honey yield per beehive is about 1060±597g. However, the yield varies significantly due to fluctuations in rainfall and temperature. This research will continue to collect Japanese chestnut honey and expect to establish an agroforestry model. It is not only to increase the benefit for landowners but also to provide valuable information to landowners and management agencies, enhancing their recognition of the value of the ecosystem services provided by bee populations.

The potentials of chestnut forests for supporting a forest-based bioeconomy

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: Chestnut forests are multifunctional ecosystems. They can be managed under different management approaches (coppice, coppice with standards, highforests) and rotation periods for one specialized product or, more frequently, for a set of different ones: biomass for energy, biomass for tanning and other chemicals, small poles, transmission poles, construction wood, high quality timber for the construction sector (also through Engineered Wood Products) or for the furniture one. Additional marketable products from chestnut forests include nuts (with some valuable varieties like "*maroni*"), honey, and the collection of wild forest products, like mushrooms, which might be associated to recreational and cultural activities with relevant social impacts in local rural economies. Finally, chestnut forests are able to provide non-priced ecosystem services like carbon sequestration (including in durable wood products), such as biodiversity protection and water-cycle regulation for erosion control. For some of these services, such as carbon and biodiversity, new voluntary markets are likely be created based on credit systems or on donations associated to environmental claims made by sponsoring organizations.

This paper will discuss the financial and economic benefits related to various investments in chestnut forests through traditional indicators like the Net Present Value, Internal Rate of Investments and Land Expectation value. The research targets Piedmont Region (NW Italy) as a case study area. This is a region where chestnut forests traditionally play a relevant role in the local economy and for the quality of the landscape (with associated positive impacts on tourism). The region has some elements of relevant interest in the value chain organization: chestnut orchards for the production of nuts (some of them of certified origin) and derived products (like the *marron glacé*), chestnut wood for the chemical industry (Silvateam, one of world's largest producer of tannin and other chemicals, is based in Piedmont), poles (both in vineyards producing Piedmont famous wines and for communication poles, under the new ideas connected to bioeconomy), timber for the building and the furniture sectors. The above-mentioned financial indicators associated to these activities will be integrated by estimated values for non-market services that have been recently subject to payment mechanisms in the area.

Unlocking the Potential of Sweet Chestnut Stands: Sustainable Management, Carbon Sequestration and Revenue Generation

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: The sweet chestnut (Castanea sativa Mill.), a species common in European forest ecosystems, provides numerous ecosystem services including landscape diversity, supporting biodiversity and enhance resilience to forest wildfires in Mediterranean regions. While climate change poses challenges to this species, it also presents opportunities to leverage its ecosystem services that have been overlooked in the potential incomes on chestnut management. Carbon sequestration is one such service that can revitalize chestnut areas. By exploring carbon storage as a passive income stream, profitability in chestnut areas can be enhanced beyond traditional revenue sources like timber and nuts. A comparative analysis is carried out to assess the potential of carbon sequestration in diverse cultural systems of chestnut stands during the juvenile phase (up to 24 years). The analysis is based on data of field permanent plots used to estimate biomass and carbon levels. The estimation of carbon value is based on EU Carbon Permits. To effectively mitigate greenhouse gas emissions, it is crucial to strike a balance between carbon sequestration and the duration of carbon retention in wood products. By emphasizing the production of high-quality wood and incorporating it into long-lived products, significant environmental benefits can be achieved by storing carbon outside the atmosphere for extended periods of time. Furthermore, the silviculture practices related to this innovative approach are also discussed. By transferring the significant value of Carbon Permits for carbon ecosystem services, we can demonstrate the potential impact of carbon sequestration as a compelling factor for revitalizing the chestnut forests. The most carbon-sequestering chestnut forest areas are productive sites, including high forest stands and coppices. These areas exhibit an average annual CO_2 sequestration ranging from 12.7 to 13.6 Mg ha^{-1} $year^{-1}$ over a period of 23-24 years, with carbon values exceeding €900.00 per hectare per year and possibly reaching €1,150.00 per hectare per year. When combined with the quality and durability of wood products and the opportunity to substitute alternative materials like plastics and steel in construction, the environmental and economic benefits become even more pronounced. This presentation highlights the potential of chestnut in mitigating climate change, generating revenue and fostering sustainability.

What new frontiers for the socio-economic revival of the Italian chestnut sector?

T2.26 Silviculture for the Bioeconomy and Ecosystem Services in Castanea Forests

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Abstract: Natural resource governance cannot disregard participatory decision-making processes including different stakeholders, both public and private, and citizens. In this work, an attempt was made to actively involve at a regional scale the various stakeholders related to the chestnut wood resource. The aim is to investigate what factors should be involved to revitalise and valorise a resource that has strongly characterised European mountains. The same resource that today, at least in Italy, is now subject to abandonment or sub-management, apart from the market niches of the fruit and tannin production chains. The A'WOT methodology used is part of the multi-criteria analysis family and consists of the qualitative SWOT method combined with the quantitative analytic hierarchy process (AHP) method. Starting from a SWOT analysis, 20 factors - 6 for strengths and weaknesses and 4 for opportunities and threats, respectively - were selected to create the pairwise comparison questionnaire required for the AHP. The sampling technique used was the snowball technique, and the questionnaire was administered in two different periods, between 2021 and 2022, involving 36 chestnut resource experts. A total of 20 were collected and validated (55% response rate). The results showed a strong propensity of respondents to leverage factors external to the resource, for which they have no control, as opposed to internal factors that they could manage. Specifically, the opportunity to increase awareness of the role and importance of ecosystem services, the implementation of projects targeting the chestnut tree, and the need to reduce and reverse the trend of depopulation of mountainous areas appear to be the priority factors on which to act. The results of the work point to the potential for expansion and replicability of our analysis to larger spatial scales, while also highlighting some limitations that future studies should address, such as the inherent limits of AHP depending on the objective and the need, therefore, to combine it with other multi-criteria analysis techniques and the need to stimulate stakeholders motivation to participate in such decision-making processes from the outset, otherwise there is a risk of poor adherence.

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

A comprehensive analysis of the most relevant uptake factors for agroforestry systems

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Agroforestry systems (AFS) offer various socio-economic and ecological benefits but can hardly outcompete monocultural approaches in practice. Despite their key role for climate change mitigation, and adaptation, AFS adoption, diffusion, and scaling have not kept pace with the urgency of the global problems they may help address. AFS are even disappearing in the European Union mainly due to agricultural intensification and unfavorable policies. Although the literature on AFS adoption is rich and extensive, it remains somewhat scattered, disciplinarily siloed and therefore inconclusive as to fully understand exactly when, why, how, and by whom AFS are taken up in practice. For instance, several studies put emphasis on farmers' agency, while others highlight mainly environmental constraints or structural issues including market access and policy frameworks. Overall, many existing studies remain conceptually limited within their specific disciplines, or disproportionately focus only on specific regions, like Asia and Africa, undermining to gain a more complete understanding of technology appropriation at scale. To address the pertaining knowledge derangement, we conducted a configurative review of AFS adoption arguments from different disciplines and world regions, aiming at understanding and ordering the key factors behind what makes AFS desirable, practicable, and applicable in different contexts. Our narrative and iterative approach to synthesizing the state of knowledge goes well beyond classical meta-analytical approaches to literature review. Our reflexive configurative review explicitly draws on expert and stakeholder perspectives as well as empirical case studies when collecting and re-organizing the key conceptual arguments and supportive evidence on AFS adoption from various disciplines and research traditions. This way our configurative approach helps to identify and differentiate broader narratives and their shared, but also contradictory, arguments, while embracing the complexity and diversity in the AFS adoption literature. When exposing and mapping out the diversity and tensions among different traditions, our review contributes to gaining a more holistic but likewise less tendentious picture of the problem that offers a nuanced knowledge basis for decision-making in policy and practice.

Agroforestry across geographies: seeking "Options by context" that work

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Agroforestry systems (AFS) summarize a collective of land-uses, combining forest and agricultural species, providing long-term economic and ecological benefits. They offer a timely and readily available approach to addressing climate change, ensuring food security, and promoting sustainable rural development in much more (land) efficient ways than intensive monoculture farming. However, policies and rural development programs prioritize and promote supposedly economically more viable monoculture approaches to agricultural commodity production, limiting the spread of more integrated systems. Despite limited policy support, innovative AFS approaches have emerged and, at least at small scales and in niches, demonstrated ecological, social and economic benefits. Apparently. the process of technology uptake in agriculture is far more complex and nonlinear and rests in more factors than just supportive policies. Better understanding what makes farmers adopt a niche technology – against all odds – can therefore be highly authoritative for designing better policies for widespread adoption. Existing theories and single-focused approaches of what determines AFS adoption often fall short of providing a comprehensive and holistic understanding of when and why smallholders (or farmers more generally) adopt (or not) agroforestry within their distinct situations. To capture the heterogeneity of farmers' responses across different geographical contexts, this study employs the "Options by Context" conceptual framework. Integrating the theory of affordance and the innovation system, the framework helps us getting a more comprehensive understanding of the socio-economic, political, and household contexts, in which AFS interventions emerge, resist, adapt, or transform. Data from two distinct case studies (Eastern Amazon in Brazil and Upper Rhine region across Germany, France and Switzerland) help us empirically substantiate and ground-truth the varied driving forces behind technology appropriation (i.e., adoption, non-adoption, mal-adaptation, diffusion) at farm level in different contexts. By delving into diverse contexts, in which AFS adoption occurs, we seek to get a more complete understanding of the complex decision-making processes and of what exactly motivates (or not) farmers to adopt AFS vis-à-vis specific contextual factors, like subsidies or legal frameworks. This way the paper provides key insights needed for re-designing those very context-specific policies in a way that they may promote rather than hinder widespread AFS adoption.

Agroforestry as a climate-resilient development path

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: In most parts of Africa, Asia and tropical America, agroforestry is not new. There are traditional agroforestry practices spanning centuries. Examples include the Moringa-based agroforestry system in Ethiopia, the parkland systems of the Sahel, the Gedo home garden cultural landscapes in Ethiopia, coffee agroforestry systems, *Faidherbia albida*-based cropping system in Malawi, , rotational woodlots in Kenya, multistory home gardens in Mt. Kilimanjaro, cocoa systems in Cameroon, Cocoa agroforestry sysetems inCôte d'Ivoire and farmer-managed natural regeneration in the Sahel. Agroforestry is also gaining ground in the global North.

As a result of their diversity, agroforestry systems are more resilient to environmental shocks and the effects of climate change than conventional agriculture. Trees serve as safety nets in times of emergency such as natural disasters (e.g., floods and droughts). Trees substantially cool cities. Agroforestry provides a range of other benefits – food and nutrition security, improved health and well-being, and livelihoods. In addition, homestead agroforestry empowers women and youth. Agroforestry connects habitats and provides corridors for vulnerable species. Depending on the system and local conditions, agroforestry can enhance biodiversity, restore wildlife habitats, it guarantees the balance of ecosystems.

Despite its multiple benefits, the adoption of agroforestry has not been widespread in many parts of Africa. Nevertheless, some general principles for their wider adoption, from lessons learned so far, in Africa and research needs to better understand the challenges and opportunities at the local and global level will be presented and discussed.

Key words: Climate change, adaptation, mitigation, biodiversity, one health, gender

Agroforestry as a Resilient Land Use Strategy in Central Asia: Exploring Sustainable Management of Apricot Orchards in Kyrgyzstan

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Central Asia, a region highly vulnerable to climate change impacts, presents an urgent need for adaptive land practices. This study focuses on the existing sustainable management of apricot orchards in the arid Kyrgyz border region of Batken, combining trees with crops, specifically alfalfa, to address these challenges. Agroforestry systems offer a promising solution by integrating ecological resilience with agricultural productivity. Understanding the management principles and carbon cycling within such systems is essential for achieving sustainable livelihoods and a healthy environment.

By evaluating the interactions between apricot trees and alfalfa crops, considering site-specific characteristics, we aim to identify resilient practices of withstanding climate change while conserving biodiversity, soil health, and water resources. Additionally, we investigate the carbon cycle within the agroforestry system to assess its contribution to climate change mitigation and the potential for carbon sequestration.

Our findings emphasize the role of agroforestry as an effective climate change adaptation strategy in Central Asia, specifically in the context of apricot orchards integrated with arable crops. These systems not only enhance ecosystem services but also maintain agricultural production, provide economic opportunities, supporting rural employment from nursery management to product processing and marketing. By sharing design and management principles, innovative technologies, and local insights, we can maximize the full potential of agroforestry systems and contribute to a more sustainable future.

Agroforestry systems and their function as islands of biodiversity in human dominated environments

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Given their ability to harmonize productivity with environmental functions, agroforestry systems (AFS) are an important strategy for conservation within human managed landscapes. AFS are heterogeneous in their design, management, and species composition, with consequences for their restoration, conservation, and productivity functions. AFS can function as biodiversity islands (BI) or areas of land with greater diversity than surrounding areas, where plant and animal species can thrive without major interference from human activity. More complex multistrata AFS such as many indigenous land use systems, homegardens, successional agroforestry and intensive silvopastoral systems hold higher conservation values than more simplified AFS and may constitute BIs themselves. Other less complex AFS may be part of a BI, or form part of a buffer zone of different categories of protected areas. In all cases, the inclusion of AFS within a human dominated landscape provides greater biodiversity than conventional agriculture or degraded areas. However, the positive role of AFS on biodiversity should not justify land use change from natural forest. Rather, AFS can be integrated into landscapes already dedicated to agriculture, afforestation, and other productive land uses.

This presentation provides an overview of the various ecological, social, and economic benefits of the main types of AFS and their applications as and within BI, expanding on their role in providing critical ecosystem services. Moreover, it discusses the use of incentives such as Payments for Ecosystem Services (PES), credits, international funding and government programs to support and promote AFS, safeguarding the contributions they provide to landscape biodiversity and rural communities. Finally, the role of government initiatives in supporting agroecological transitions from conventional agriculture is described, with updates from the USA and Latin America. These programs support the role of AFS and climate-smart agroecology over conventional agriculture, reinforcing the contributions of AFS to the consecution of the Sustainable Development Goals (SDG) and the conservation of biodiversity in agricultural landscapes.

Assessing Environmental Impacts and Carbon Stocks in Temperate Agroforestry Systems with Sheep and Cattle: A Systematic Map

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: The escalating challenges of climate change and biodiversity loss necessitate innovative approaches in agricultural land management, specifically, in temperate ruminant livestock farming. Current farming practices contribute to greenhouse gas emissions (GHGEs), air pollution, increased flood hazard, reduced water quality, and enhanced soil erosion. This study presents a systematic map exploring the potential of agroforestry - the re-integration of trees and farming systems - as a strategy to alleviate these environmental impacts, while maintaining productivity and economic viability. Building upon an existing systematic map, this systematic evidence map focuses specifically on the environmental impacts and carbon stocks in temperate agroforestry systems with sheep and cattle. This evidence map follows best practice guidance to search for, select, and synthesise pertinent studies on the environmental impacts and carbon stock implications of integrating trees into temperate ruminant production systems. An interactive online map is presented, which is free to use and encompasses multiple filters based on topics and time slices. Links are provided to the included studies (full-text if open access, or bibliographic information only, where articles are in journals requiring subscriptions). The systematic evidence map of relevant studies offers a valuable tool to guide decision-making by land managers, academics, and policymakers across temperate regions, highlighting knowledge gaps and potential areas for future research.

Certified community forestry in endemic Boswellia species conservation - case study from Socotra Island

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Globally, frankincense trees (Burseraceae: *Boswellia*) are increasingly under threat due to habitat deterioration, climate impacts and the olibanum trade. Despite harbouring nearly half of the species in the genus, up-to-date insights are lacking for the insular frankincense trees of the Socotra Archipelago UNESCO World Heritage Site (Yemen). We present an overview of key conservation data for all eleven endemic *Boswellia* taxa occurring in the Socotra Archipelago. We discuss the current distribution in detail and evaluate threats based on new on-the-ground surveys in 2020-2022. Our field data support that the Socotran frankincense trees are endangered by fragmentation and overgrazing resulting in a lack of natural regeneration, in combination with effects of climate change some species´ populations are near to extinction. We suggest the certified community agroforestry silvo-pastoral system to manage the woodlands with Boswellia spp. populations in sustainable way. Involvement of local communities in Boswellia trees conservation is only possible way how to save these unique trees from extinction.

Chlorophyll Content of nine selected Crops at Different Temperature and Light conditions

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Shifting cultivation is still a major form of agriculture pracictice in Liberia, which is a concern for forest conservation in Liberia and way to increase production for smallholder farmers. Understanding the role played by temperature and light intensity on chlorophyll content of plants remains a minor priority for farmers and many researchers in Liberia that could help reducesd the need for shifting cultivation. A lab experiment was conducted in the Plant and Soil Science Laboratory of the Department of Plant and Soil Science (PSS) on nine selected crops of different taxonomical classes, crop type, growth type, temperature and light requirements grown in the Upper Highland Tropical Forest Agro-Ecological Zone (UHTF AEZ) of the Suakoko District, Bong County from November 2022-March 2023. The aim of this study was to assess the effect of temperature and light intensity on chlorophyll content of the selected crops at CASD. Results of the study show that among all the nine crops, pepper has the most significant chlorophyll content while corn recorded the least chlorophyll content. Temperature and light intensity have significant effect on Chlorophyll content and growth and development of plant. Results of the study also show that chlorophyll contents were higher in higher temperature and light conditions with corresponding higher yields. The null hypothesis of the study was therefore rejected while the alternative hypothesis was accepted as temperature and light intensity had significant effect on Chlorophyll content and plant growth and development.

Complex agroforestry systems for promoted ecosystem services

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Soil erosion, droughts, nutrient leaching, and biodiversity loss pose significant challenges for agriculture. Agroforestry systems, integrating woody plants into agricultural land, offer potential solutions. These systems have been found to positively influence microclimate, soil erosion, water availability, and biodiversity. By using multiple tree species on the same land, ecosystem services like biodiversity and carbon sequestration can be further enhanced. However, there is a lack of practical examples and research on agroforestry systems in temperate regions.

At Gladbacherhof, a teaching and experimental farm of the Justus-Liebig-University Gießen in Germany, three alley cropping systems were established to reduce erosion on arable land and provide shade for pasture animals. These systems cover around 15 hectares and comprise different tree strip planting schemes. The tree strips, 3-4 meters wide, alternate with 18-meter-wide arable strips. The tree use types include fruit, valuable timber, and biomass trees organized in simple and complex tree strip planting schemes. Simple strips consist of a single tree use type, based on well-known agroforestry systems like orchard, short-rotation coppice, and valuable timber. Complex strips combine multiple tree use types, aiming for a multi-layered structure with high-pruned valuable timber trees, apple trees, and elderberry shrubs. Biomass trees in the complex strips are removed and serve as mulch after the initial years, following the concept of successional agroforestry.

These long-term field trials at Gladbacherhof serve as practical examples for land managers and others. The accompanying scientific research focuses on management factors, ecological services (including soil fertility, water availability and biodiversity), and developing recommendations for agricultural subsidies. This contribution presents the design, research, experiences in planning and maintenance, and initial results on ecosystem services.

Does Shade Impact Coffee Yield, Tree Trunk, and Soil Moisture on Coffea canephora Plantations in Mondulkiri, Cambodia?

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Coffee crops are highly sensitive to climate change, whereas robusta is more adaptable than arabica and able to thrive in warmer and lower land conditions. For these reasons, knowledge of the impact of shading on the yield of robusta coffee is extremely important as decreasing yield is one of the reasons why farmers do not grow coffee within the agroforestry system. The necessity to determine the effects of shade on the yield of *Coffea canephora* and on the soil water availability is obvious. Three coffee plantations in the province of Mondulkiri, were selected to evaluate the effect of shade on *Coffea canephora* yields, coffee trunk changes, and soil moisture. Shade-grown coffee has the same yields in terms of coffee bean weight or size, the total weight of coffee fruits per coffee shrub and the total weight of 100 fruits (fresh and dry) as coffee grown without shading. Additionally, fruit ripeness was not influenced by shade in terms of variability neither in terms of delay in ripening. Soil moisture was higher throughout shaded sites. These results show that the plants were not affected by the lower soil moisture in sunny sites or higher soil moisture in shaded sites, which may indicate that competition for water did not occur between coffee tree and shade tree roots in the studied plantations. In our study, in the morning the trunk of the coffee tree shrinks and, after 12 p.m., it grows again. The changes in coffee trunk diameter are visibly connected (especially in the dry season) with the curves of air humidity and temperature on studied localities. These daily changes were more pronounced on sunny sites. Our findings indicate that planting robusta coffee in agroforestry systems will not cause losses in yield for individual coffee plants. Considering the ecological attributes and ecosystem service benefits of agroforestry, such as increased biodiversity and landscape diversity, providing soil protection, increasing the carbon stock, and providing sources of fuel wood and construction material, we suggest maintaining and planting *Coffea canephora* in agroforestry shade-based systems, as coffee producers transition away from monoculture plantations.

Enhancing landscape connectivity through agroforests: The case of Gedeo's agroforests in Ethiopia

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: *The Gedeo agroforested cultural landscape in Ethiopia is recognized as a leading example of sustainable agroforestry practices. It mimics and resembles with natural forest. The agroforest is characterized by vertically and horizontally diverse composition, structure, and functionality, which contribute to on-farm conservation, environmental well-being, and livelihood support systems. Numerous studies have highlighted the positive impacts of agroforests in the landscape on circa situm biodiversity conservation, implicating conservation of biodiversity through utilization. The agroforest provides additional habitats for species that are sensitive to disturbance, conserve gene pools of native tree species, enhance microbial, avian, and faunal diversities. They also act as a buffer against forest degradation and deforestation in the surrounding natural habitat, while connecting fragmented habitats for floral and faunal species through the creation of corridors and stepping stones. Agroforests in the Gedeo landscape serve as important havens for preserving high levels of diversity. The smallholder agroforests play a crucial role in conserving tropical woody plant species as circa situm reservoirs of biodiversity in agricultural environments. Previous studies have shown that with a diverse species composition the agroforest contributes significantly to biomass and carbon storage, which in turn helps mitigate climate change. For the Gedeo people, agroforestry is not just a supplementary livelihood activity but a mainstay. Therefore the Gedeo agroforests have a great role in enhancing the landscape connectivity and hence, contributing to the integrity and sustainability of the system. However, the Gedeo agroforests face challenges such as land degradation, land fragmentation, emergency of lucrative monocropping cash crops, climate change, and limited market access, as well as lack of financial resources, and insufficient technical knowledge and training*.

Key words: Agroforest, landscape connectivity, circa situm conservation, Gedeo landscape

Evaluating Melientha suavis Agroforestry Systems for Climate Resilience

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Evaluating *Melientha suavis* Agroforestry Systems for Climate Resilience

Agroforestry, the practice of integrating trees with crops, is beneficial for farmers due to its multifaceted returns. This study focuses on *Melientha suavis*, a Thai tree crop known for its edible shoots, as the main element in an agroforestry system. Intercropping M. *suavis* with various companion tree species not only fosters suitable microclimatic conditions for M. *suavis* shoot production but also offers additional income through fruit or timber, promotes soil conservation, and unlocks the potential for financial gains from carbon credits. The study compared two M. *suavis* agroforestry systems in terms of productivity, carbon sequestration potential, and co-benefits, particularly when intercropped with fruit trees and native timber trees. Data were collected through on-field measurements of M. *suavis* and companion trees across six farms over three seasons, complemented by farmer interviews. The variables measured included productivity, carbon storage, microclimate, and soil conditions, with farmer interviews used to understand farm management practices and socio-economic benefits. Our findings show that farm microclimate variations significantly impact the growth of M. *suavis* and its associated tree species. Native timber trees were found to optimize microclimate and soil conditions, thereby improving M. *suavis* productivity. The system that saw M. *suavis* intercropped with fruit trees demonstrated the highest carbon storage—29.17 tCO_2/rai over 24 years, but this was offset by high input requirements and unstable market prices. In contrast, M. *suavis* intercropped with various timber tree species showed lower carbon storage (21.02 tCO_2/rai over 22 years). However, due to its more stable income and market conditions, this system presents a viable alternative. In light of increasing drought risks, the study concludes that agroforestry practices - especially those involving the cultivation of M. *suavis* - can enhance climate resilience and contribute to sustainable carbon sequestration efforts.

Impacts of Climate Changes and Adaptation Measures of Local People in Central Highlands of Viet Nam

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Central Highlands is located in the central part of Viet Nam where is the home of difference ethnic minorities groups and have a lot of traditional customs on the agriculture production and society. This is also famous for many perennial crops which contribute to local and national economy and generate income for local communities. There are several major crops including Coffee, black Pepper and Rubber, cultivated in the Central Highlands. These crops have contributed to the economic development of the region but have also created problems and challenges for local communities and authorities as well, including (add challenges – conflict over land? Land degradation?).

In recent years, the impact of climate change is becoming clear in the region: There are more and stronger rains in the rainy season, which cause a lot of landslides and flooding. On the other hand, the longer dry season and stronger winds lead to water scarcity, which has an impact on crop irrigation and has caused more and bigger forest fires.

In response to these changes, local communities have started to apply different measures for adapting to the changes in weather and its impacts. This includes: planting more multipurpose trees (for shade, timber and non-timber products) in the coffee plantation, with the aim to reduce water evaporation under strong sun light, and avoid the soil erosion. Tropenbos Vietnam, through its Green Livelihoods Alliance Programme, has supported in capacity building of farmer associations and communities in these agroforestry practices, and supported the development of demonstration models. We have also organised exchange visits, for farmers from different parts of the landscape to learn from each other, and facilitated the local government in the development of new policies for climate change adaptation.

The presentation will not only address the technical solutions but also talk about the governance and monitoring aspects in the climate change adaptation process in the landscape

Integrated approaches for food, energy and environment: lessons from Asia, Africa and Europe

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: The demand for woody biomass for energy and biomaterial is increasing rapidly in line with the rise in global populations and changing consumption patterns for sustainable resources. Central to meeting this demand is answering the question of how woody biomass and biofuel production and use can be reconciled with food production, biodiversity protection, climate-change resilience and mitigation, and inclusive prosperity for local communities. In many cases, policy and development interventions tend to address these issues in isolation whereas they are interconnected.

CIFOR-ICRAF and partners propose — and are demonstrating — integrated approaches to food and energy security that focus on bioeconomy opportunities and are based on agroecological principles. Such opportunities are identified with a view of value chains for diverse bioeconomic products, such as food crops, woody biomass for energy, and non-timber forest products. In terms of agroecological principles, emphasis is on measures to increase soil fertility and the diversity of plant and animal species and on improving control of pests and diseases, management of water and promotion of a combination of multi-structured land uses.

This talk highlights such approaches with examples from across diverse geographies and settings. In Southeast Asia, integrated approaches to climate-smart agroforestry produce a variety of food, energy and biomaterial while restoring degraded landscapes. In Sub-Saharan Africa, a balanced agroforestry approach considers demand and supply dynamics in wood-energy value chains, food production, recovery of waste bioresources for energy, and the use of improved kilns and stoves, with a significant impact on improving smallholders' livelihoods and reducing pressure on forests. In the Western Balkans, the combination of short-rotation plantations of fast-growing tree species (willow, poplar), agroforestry borders and permanent tree areas enhances energy security, income generation and biodiversity in landscapes otherwise dominated by the production of wheat, maize and sunflowers while at the same time contributing to the urgently needed energy transition away from coal.

Our findings indicate integrated approaches to bioeconomy based on agroecological principles are an often-overlooked pathway to producing healthy foods, providing sustainable energy, reducing greenhouse gas emissions, creating equitable jobs and prosperity, and conserving biodiversity at global scale.

Minimum support price of farm-grown wood: How relevant will it be?

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Agroforestry is widely recognised as a tool to increase farm productivity and diversify income sources of farmers while providing various environmental services. Agroforestry is an age-old practice which has traditionally been used by farmers to meet their domestic requirements. It has been considerably refined through research during the last four decades and is now being adopted by farmers on commercial lines with a more conscious selection of species and intensive management. Agroforestry has been supported by the government through need-based policy changes during this journey. As the prices of agricultural produce vary frequently, fluctuations are witnessed in prices of wood as well. The fluctuation is quite marked in prices of *Populus deltoides* wood.

The government of India provides minimum support price (MSP) to many agricultural crops. MSP is fixed by the government of India and markets operated by the government are encouraged to buy produce at or above the MSP. MSP is usually fixed around one-and-a-half times the cost of production incurred by the farmers. The MSP is announced in the beginning of the sowing season of crops and protects the farmers in case of excessive fall in price during bumper production years. Crops which receive a more steep increase in MSP at the beginning of a sowing season are able to attract more growers during that season. This intervention helps the government indirectly regulate the extent of area under different crops.

Trees are long-gestation crops and it is not possible foresee the price scenario at time of harvest. They are subject to longer period of uncertainties on account of changing weather, pests and diseases. An assurance about minimum price would go a long way in encouraging the farmers about threshold price in the market. Farmers have been demanding a system of providing MSP for farm-grown wood for long time, especially for poplars. A critical analysis has been done by the author which showed that MSP would not be able to solve the problem for growers of poplar and possibly other species too.

Potential of agroforestry as win-win solution to enhance livelihood and biodiversity of the degraded Sal forest in Bangladesh

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Agroforestry in the degraded forestland has gained enormous attention from traditional to people-oriented forest management approaches in Bangladesh. Various types of tree-crop combinations of agroforestry practices in the degraded forestland support the basic needs, increase species richness and alleviate the poverty of millions of small-scale farmers. Thus, the study tried to identify the impacts of agroforestry practices on the livelihood improvement of forest-dependent people and biodiversity conservation of Sal forests in Bangladesh. The study was conducted in the Madhupur Sal forest of Bangladesh, which is considered an economically and ecologically important moist deciduous Sal (*Shorea robusta*) forest in Bangladesh. The study used mixed-methods data collection techniques such as interviews with 100 farmers for livelihood analysis and quadrat (20m × 20m) sampling techniques for biodiversity measurements from 2020 to 2022. The results found that the most common features of the agroforestry practices were the contribution of financial income and improvements to the physical and natural assets of the forest dependent farmers. Farmer training programs were sufficiently developed to increase 82% of farmers' capacity on how to cultivate profitable tree-crop based agroforestry practices on their farms; however, their social asset development faced some constraints and difficulties. At the same time, agroforestry practices restored 34 plant species to the depleted Sal forest. The fast-growing tree species, mainly *Acacia spp*., in association with pineapple, ginger, aroid and turmeric crops, were the most dominant species in the degraded Madhupur Sal forest. The study also revealed that agroforestry serves as a wildlife corridor and attracts birds for breeding and feeding. Despite its limitations on the development of farmers' social assets, agroforestry is a viable land-use practice to improve farmers livelihoods and biodiversity conservation in degraded Sal forest in Bangladesh. Therefore, the study recommended implementing high yielding agroforestry models under the direct patronage of the local government and involving all stakeholders in a more sustainable way.

Sustainable Agro-forestry Practices for Climate Adaptation and Mitigation: A case study of Kerala

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Agroforestry shows promise for co-delivery of adaptation to and mitigation of climate change. Agrisilvicultural, silvopastoral, and agrosilvopastoral systems constitute the dominant agroforestry types of Kerala. Examples are numerous: tropical homegardens, plantation crop - food crop combinations, jackfruit tree and palm-based food production systems, integrated agriculture-aquaculture systems—agrosilvofishery systems, small holder livestock production systems and so on. Home gardens are physiognomically similar to evergreen forests because they are composed of a variety of different trees and plants and are arranged in a multi-tiered, intimately interconnected pattern. Dominant trees include the coconut (*Cocos nucifera*), arecanut (*Areca catechu*), and para-rubber (*Hevea brasiliensis*); in addition to a large number of multipurpose trees (MPTs), including mango (*Mangifera indica*), jack (*Artocarpus heterophyllus*), teak (*Tectona grandis*), cashew (*Anacardium occidentale*). In this present paper, we focus on the prevalent agroforestry practices and commodities as well as its significant social, economical and environmental benefits to the society. We also discuss in detail social and technical barriers that limit the implementation of adaptation and mitigation practices in agroforestry. We will propose comprehensive alternative solutions to agroforestry and consider rational and sound changes for regulations and encourage farmer adoption. We will come to the conclusion that agroforestry is one of the finest land-use techniques for promoting food security while also reducing environmental deterioration in the case of state of Kerala, India.
Keywords: Agroforestry, Agroecology, Home Gardens, Food security, Climate Resilience

Unleashing Payments for Ecosystem Services applied to agroforestry: state of research and policy implications

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: Both Payments for ecosystem services (PES) and agroforestry have been increasingly attracting the attention of policy-makers and scholars alike, which has led to an increasing amount of literature in these research fields. Accordingly, syntheses on the state-of-art and performance of those payments have been performed both cross-sectoral and sector-specific, such as for water services or forest-related services. However, no such synthesis has been performed yet on payments for ecosystem services applied to agroforestry or, broadly spoken, to trees and carbon removals in agriculture. Therefore, this synthesis aims to provide an overview of the current state of research on this topic including policy implications. We examine a wide range of relevant literature from various disciplines, including environmental science, economics and policy analysis. We identify payment types, explores the effectiveness of payment schemes in achieving carbon sequestration and other environmental objectives and identify factors explaining the effectiveness of those schemes. The review also discusses key policy considerations for designing and implementing effective payment schemes such as the role of public-private partnerships and monitoring and verification mechanisms. Overall, the review highlights the potential for payments for ecosystem services and carbon removal to contribute to sustainable agricultural development and climate change mitigation, and identifies key areas for future research and policy development.

Valuing under-utilized green manure of available agroforestry species: Potential organic input sources in humid highland and semi-arid areas

T2.27 SMART (Sustainable Modern Acceptable Resilient Technological) Agroforestry Practices for Sustainable Livelihood and healthy environment

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Abstract: In Rwanda, land degradation is a major challenge threatening food production, and soil and water conservation measures are insufficient. Building the resilience of food systems requires urgent action to prevent and reverse land degradation and restore soil health. Green manure from agroforestry trees can increase soil nutrient inputs via litter decomposition and hence contribute to replenishing soil fertility and enhancing food security. Even though agroforestry is widely promoted in Rwanda, native agroforestry tree species are undervalued and under-utilized as potential sources of nutrients. The aim of this study was to investigate litter decomposition rates and nutrient release patterns from six agroforestry tree species grouped into three categories: Exotic N-fixing species (*Alnus acuminata* and *Calliandra calothyrsus*), farmer-preferred species (*Eucalyptus globulus* and *Grevillea robusta*) and native species (*Markhamia lutea* and *Croton megalocarpus*). We conducted a litterbag field experiment in two regions of Rwanda during the wet and dry seasons. Changes in litter mass loss and chemical composition (C, N, P, K, lignin and polyphenol) were determined. Our results highlight the importance of revisiting native and exotic N-fixing tree species that deliver higher green manure quality than the most prevalent agroforestry tree species. While native species have been largely overlooked in agroforestry, our findings show they offer great potential as sources of high-quality green manure. We hope these results will contribute to guiding ongoing tree-based restoration efforts in Rwanda and across the region for enhanced food security and biodiversity.

Key-words: Green manure, leaf litter decomposition, soil fertility, tree-based restoration, agroforestry.

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

Assessing the sustainability of harvesting practices in the southeastern US to meet European renewable energy goals: a review

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: The transition towards renewable energy sources over the last decade has generated a surge in demand for sustainable alternatives, notably woody biomass. In Europe, this demand is driven by the creation of legislation, such as the Renewable Energy Directive passed by the European Union (EU) member states, which determines biomass utilization and practices. As a result of the heightened demand, biomass production in the southeastern United States (US) has expanded, giving rise to concerns regarding the intensified removal of residual material, distribution and spatial allocation of residues, and potential ramifications for site nutrients, erosion rates, and water quality. Due to the relatively recent market developments, there is limited literature evaluating biomass market effects on forest management practices and site sustainability. With the continued growth and utilization of woody material as a source of bioenergy it is important to further our understanding of wood pellet harvesting practices and evaluate the sustainability of accelerated removal of forest residuals. Therefore, the primary objective of this study was to evaluate the status of knowledge related to biomass harvesting in order to provide a baseline for future policy, practice, and implementation. Environmental, social, and governance impacts from biomass harvesting practices were categorized to gauge a full scope of sustainable harvest practices. Three key themes were outlined: international bioenergy demand interactions, public perception, and harvest characteristics. Our survey of existing literature revealed that there is a lack of research evaluating residual retention across the southeastern US. There are minimal field studies assessing biomass harvesting, and effectively no studies assessing wood pellet operations. These markets are growing at an expedited rate, and it is important to characterize these operations to better understand regional resource utilization, changes in forested land allocation, and the quality of post-harvest features.

Biomass expansion factors for commercial and restoration forest plantations in Brazil: developing specific factors for tropical regions

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Carbon sequestration by forest plantations, for commercial or restoration purposes, is a nature-based solution to mitigate the impacts of climate change. One of the methodologies suggested by IPCC to quantify carbon sequestration in biomass by forest plantations is to use biomass expansion factors. These factors derive aboveground (BEF) and belowground biomass (R) and carbon information from merchantable bole volume, based on regular inventory of diameter at breast height (DBH) and total height measurements. Currently, most of the IPCC default BEF and R values are based on data from studies in the northern hemisphere and might not be accurately applied to forest plantations in Brazil. Few studies have been carried out to determine BEF and R factors for Brazilian forest plantations due to the high cost of sampling. Therefore, we integrated a dataset of thousands of destructively sampled trees under field conditions, from *Eucalyptus*, *Pinus* and Brazilian native tree species at contrasting climatic regions and at different stocking and ages over the rotation.

The objectives were to calculate the BEF and R for Brazilian forest plantations and compare those with the factors suggested by IPCC to explore the potential impacts on carbon sequestration calculations for Brazilian forest plantations.

The average values of R in our dataset were higher than those proposed by the IPCC for *Eucalyptus*, *Pinus* and native trees. However, some BEF factors were lower than IPCC values. Despite these average numbers, the distribution range of these factors was large and responsive to climate, stocking and age of the trees.

These results suggest that there are significant differences between Brazilian BEF and R factors and IPCC recommendations and instead of focusing only on average numbers, using other statistical

metrics that explore the distribution of values would be important. Additionally, understanding the relation of BEF and R to climate, soils and age is key to better represent carbon sequestration in living biomass of commercial and restoration forest plantations in Brazil.

Early stand management using an unmanned aerial vehicle to locate trees and measure survival, height, and competing vegetation

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: At an operational scale, early stand management presents difficulties given the large areas under management and limited resources to manage that area. Early survival data is typically generated from a few small plots and, consequently, may not adequately capture survival in the entire stand. Similarly, assessments of competing vegetation will also represent smaller areas with in a stand. Unmanned aerial vehicles (UAV) can be used to generate survival and competing vegetation coverage for the entire stand or a larger sample than normally captured with ground measurements. Additionally, three-dimensional point clouds derived from UAV photographs permit height estimation. We tested a system to locate and measure individual trees in a pine plantation using an UAV to fly over the area while taking multiple photographs on a rectangular grid pattern. Flights were planned and managed using readily available applications (i.e. PIX4D, Drone Deploy Flight) to fly a DJI Phantom 4 with a 12.4 megapixel camera. Images were processed using WebODM to generate a point cloud. We tested different UAV flying altitudes and identified the optimum flying altitude (66 m), which produced the best height estimates with a reasonable flight time for trees 0.4 to 5.0 m tall. UAV height measurements were well correlated with field measurements. UAV tree locations were well matched with locations acquired using a sub centimeter global positioning system. We determined competing vegetation coverage area and height from the same flight used for the tree location and measurements. Flight time for a four hectare stand was ~25 minutes. Post flight processing to generate point clouds, orthophotos, and digital surface and terrain models was automated and only required image uploading. Additional metrics could be extracted from the data including crown size (estimating leaf area index), growth over time with repeated flights, and identification of underperforming areas within a stand that may require additional treatment. The combination of precise geolocation and the ability to generate metrics of tree size, location, and competing vegetation presence, provides an opportunity to characterize stand establishment performance, and the possibility of creating a system based on multidimensional spatially explicit records to help explain future stand performance.

Economic analysis of mixed forest plantations in the Southeastern US

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: The importance of forest plantations has increased rapidly in recent decades. Although they occupy 3% of the world's forest area forest plantations supply 33% of the global roundwood output. Due to their high profitability easy management, and straightforward ecological relationships, most plantations are managed as pure forest stands. However, a growing number of researchers have indicated the disadvantages of this type of stand structure maintained for the production of timber only. They suggest that pure forest plantations are particularly susceptible to insect outbreaks, pests and forest fires, provide low levels of biodiversity and reduce the range of ecosystem services provided.

Study of mixed forest plantations is necessary to improve the sustainability of forestry, under the assumption that mixed forest plantations are more productive, reduce natural risks, positively impact biodiversity and provide additional ecosystem services in a better way than pure plantations. Obviously, a gap exists between the pure forest plantation management applied in practice and the desired introduction of mixed forest plantations. The aim behind the research presented in this paper is to address some of this gap. The focus of this paper is on the economic analysis of the profitability of mixed forest plantations in the southeastern US.

We compared the economic performance, in terms of land expectation value (LEV), of loblolly pine mixed in various ratios with either white oak or sweetgum, the two commercially important hardwood species of the southeastern United States. The reference for comparison were pure stands with 100% loblolly pine. When considering only timber production, our finding that mixed plantations of loblolly pine and hardwoods are more profitable than pure loblolly pine plantations. The optimal mixture consisted of 1500 trees per hectare at a ratio 75% loblolly pine and 25% sweetgum. The density effect between the loblolly pine trees within the mixed plantation of loblolly pines and sweetgums was the main factor driving the higher profitability of mixed plantations in comparison to the pure plantations. With payments for carbon credits, the most profitable mixture consisted of 2000 trees per hectare in stands consisting of 75% to 100% hardwoods.

Evaluating Pinus taeda L. crown morphology development and its impact upon stem volume through UAV laser scanning derived datasets

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Individual tree growth is associated with the size, shape and efficiency of its crown, which represents an expression of resource acquisition. Many existing tree crown models are based on simple symmetric three-dimensional shapes, which often do not accurately represent crown shape. Remote sensing data could overcome this limitation and provide information over large areas. We used high-pulse density airborne laser scanning (ALS), from unoccupied aerial vehicles, to classify individual tree crowns (ITC) for two dates (four years apart) in loblolly pine (*Pinus taeda*) forest. The study included six genotypes, each exhibiting different crown architecture, comprising 1337 trees. We classified potions of the pointcloud for each ITC as part of the tree stem to represent tree center. We approximated 3D ITC exterior using a 3D alphashape. The horizontal distance of the alphashape exterior from the stem at multiple heights was calculated, and the largest distance assessed using circular statistics. The genotypes exhibited significant ($p < 0.05$) preferred direction and difference between the two dates. We used mixed-effect-models (MEM) to evaluate the effects of genotype and 3D alphashape, as represented by the orientation patch count rotated (OPCR) index on stem volume growth. ITC OPCR was significantly related to stem growth. Significant interactions between OPCR and genotype were observed. The effect of direction of ITC crown volume growth in a horizontal direction was evaluated by calculating 3D ITC change in 45° segments from stem center using MEM. Significant main effects and interactions were observed among volume, direction and genotype. Our results provide evidence that ALS can evaluate change within ITCs. This includes determining if there is any preferred direction of expansion and the responsiveness of specific genotypes in utilizing available growing space. Accounting for within tree variability and available 3D growth space could improve our estimates of tree growth over large areas.

Modeling dominant height with USGS 3DEP LiDAR to determine site index in even-aged loblolly pine (Pinus taeda L.) plantations in the southeastern US

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Accurate quantification and mapping of forest productivity are critical to understanding and managing forest ecosystems. LiDAR- or photogrammetry-derived point clouds have been used to obtain reliable estimates of canopy heights, yet most of the models rely on expensive data acquisitions. In this context, the use of publicly available data would provide invaluable information for managers and policymakers. We developed models of dominant height using United States Geological Survey (USGS) free LiDAR data with the goal to map site index across loblolly pine (*Pinus taeda* L.) plantations in the southeastern US. We used the 2017 – 2020 national USGS 3D Elevation Program LiDAR acquisitions and explored how different height percentiles, grid output resolutions, time difference between LiDAR acquisitions and ground measurements, tree size, and dominant height definition affected the proposed model. We built the model using 1,301 ground plots from timber industry inventories. The final regression model was constructed with the 95th percentile of the height distribution of the first returns above ground and had a high accuracy in dominant height estimation (R2 = 0.88; RMSE = 1.55 m; RRMSE = 7.65%) at a 20-m pixel basis, yet all the percentile-resolution combinations were found acceptable. Little evidence of effect was found due to time difference when the flight was less than 4 months in advance or after the ground measurement, and it was also found independent of pulse density when this variable was lower than 9.5 pulses m^{-2}. Finally, we assessed the error propagation when translating dominant height to site index, in two commonly used site index models, and found a relative RMSE lower than 10% in both. We found that USGS LiDAR acquisitions can be reliably used to map dominant height as a proxy for forest productivity, adding value to a tool proven widely applicable in time and space. That offers a great opportunity for stakeholders in different fields to use.

Modeling Wood Product Carbon Flows in Southern U.S. Pine Plantations: Implications for Carbon Storage

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Wood products continue to store carbon sequestered in forests after harvest and therefore play an important role in the total carbon storage associated with the forest sector. Trade-offs between carbon sequestration/storage in wood product pools and managed forest systems exist, and in order for forest sector carbon modeling to be meaningful, it must link wood product carbon with the specific forest system from which the products originate and have the ability to incorporate *in situ* and *ex situ* carbon synchronously over time. This study uses elements of a life cycle assessment approach, tracing carbon from US southern pine timber harvests to emission, to create a decision support tool that practitioners can use to inform policy design around land- and bioproduct-based mitigation strategies. We estimate that wood products from annual loblolly and shortleaf pine timber harvests across the southern US store 29.7 MtC in the year they enter the market, and 11.4 MtC remain stored after 120 years. We estimate fossil fuel emissions from the procurement, transportation, and manufacturing of these wood products to be 43.3 $MtCO_2e$ $year^{-1}$. We found that composite logs, used to manufacture oriented strand board (OSB), were the most efficient log type for storing carbon, storing around 1.8 times as much carbon as saw logs per tonne of log over 120 years. Results from our analysis suggest that adjusting rotation length based on individual site productivity, reducing methane emissions from landfills, and extending the storage of carbon in key products, such as corrugated boxes, through longer lifespans, higher recycling rates, and less landfill decomposition could result in significant carbon gains. Our results also highlight the benefits of high site productivity to store more carbon in both *in situ* and *ex situ* pools and suggest that shorter rotations could be used to optimize carbon storage on sites when productivity is high.

Precision thinning: Using light detection and ranging to inform row removal selection

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Remote sensing technologies are facilitating sub-stand treatments in forests. Near-complete inventory data from LiDAR in loblolly pine (*Pinus taeda* L.) plantations facilitated a case study testing the effect of selecting removal rows in a mechanical thinning operation. Two treatments were implemented on the 64-row, 3.5-hectare study area. One 32-row block used a fourth-row removal scenario which removed the least amount of volume while the other 32-row block used a scenario which removed the most volume. Such deliberate selection of take-rows resulted in a significantly greater volume removed in take-rows and a greater removal of stems ≥ 25 cm in diameter across the high volume removal treatment. Post-thinning LiDAR data were capable of being matched with pre-thinning LiDAR data indicating that monitoring of operator-select removals is possible as is estimating localized thinning effects on individual tree growth post-thinning.

Site-specific silvicultural practices enhance productivity of pine plantations in Brazil

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Pine plantations in Brazil cover approximately 2 million hectares, mainly in the southern part of the country, in a subtropical climate. Currently the average productivity is reaching 30 m^3 ha^{-1} $year^{-1}$, after decades of investment in research and optimization of field operations. Despite the high productivity, there is room for improvement by adjustments of silvicultural practices to site-specific conditions. The variability in climatic and edaphic characteristics of the planting region requires specific recommendation of silvicultural practices, focusing on optimal soil management, demand for fertilization, frequency and intensity of competing vegetation control, and stocking for specific genotypes.

This study is an integration of three experiments with trials in five locations covering different varieties of pine at different planting spacings, under contrasting levels of soil preparation, competing vegetation control and fertilization. To evaluate the effects of these silvicultural practices, survival, growth, and carbon stocks were frequently measured from planting up to 10 years of age, depending on the trial design and objectives.

Differences in pine varieties resulted in significant differences in productivity, up to 20% within the site, and they respond disproportionately to changes in stocking according to their level of improvement. Overall, more intensive silviculture increased productivity across sites. Competing vegetation control was the most important factor for all sites, and soil preparation was only significant on sites with higher soil clay content. Fertilization seemed to be significant during early years, with marginal (or inexistent) gains over the years.

Pine plantations in Brazil demand site-specific silvicultural recommendations to maximize gains in wood productivity. General silvicultural practices recommendation should be avoided. This network of trials will be monitored for a full rotation (~14 years in Brazil) to evaluate the long-term effects of applying intensive silviculture to pine plantations in Brazil.

Soil Classification for Loblolly Pine (Pinus taeda L.) Productivity and Management

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Forest productivity and response to silvicultural treatments are dependent on inherent site resource availability and limitations. As trees have deeper rooting profiles than agronomic crops, evaluating the impacts of soils, geology, and physiographic province on forest productivity can help guide silvicultural management decisions in southern pine plantations. In this study, we use a series of "Regionwide" trials that go back decades to assess the variable importance of the new Forest Productivity Cooperative forest soils classification system that includes texture, depth to increase in clay content, drainage class, soil modifiers, geologic formations, and physiographic province on site index and fertilizer response. We also included variables such as climate and year of plantation establishment. We then used a remotely sensed layer that identifies managed loblolly pine across the southeast (approximately 14 million ha within its native range). The variable importance results from random forest modeling showed geology to be one of the top-ranking variables to explain site productivity. Plantation year was the most important variable, showing an increase of 16 cm per year since 1970. Because the Regionwide trial soils represent 72 out of over 10,000 unique soil site codes and approximately one million ha or about 7% of all soils identified as supporting management loblolly pine, we created a predictive model to extrapolate site productivity results outside of the unique soil & geologic conditions empirically represented. This model will be improved by additional observations across more soils. Overall, this system will allow managers to assess their current site productivity and assess the likelihood of fertilization response due to inherent site resources.

The Genetics-Genomics, Management-Modelling, Protection-Products experimental network: opportunities for gains in Eucalyptus productivity in Brazil

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: The Genetics-Genomics, Management-Modelling, Protection-Products (G2M2P2) experimental network consists of 71 experiments of five themes (C = clonal-protection, P = soil preparation, N = nutrition, E = spacing and M = weed -competition) installed in 2016-2017 in 18 places of edaphoclimatic representativeness of Suzano SA.

In the “C” tests, a total of 200 clones were tested, evaluating the incidence of pests and diseases. For the “P” tests, minimal to intensive preparations were used to verify the influence on growth. In the “N” tests, the omission of nutrients was used to map the deficiencies that still occur in soils under silviculture. In trials “E”, densities of 600 to 2,500 arv/ha were used to assess survival, growth and impact on harvest. For the “M” trials, the effects of weed communities and the period of interference-coexistence were evaluated.

The six years-old rotation results show that an experimental network that samples different climates and soils is essential to understand the different “non-linear” behaviors of Eucalyptus clones. It also shows that the correct clonal deployment can provide productivity gains for Brazil, as long as pest and disease monitoring is active.

For site preparation, fertilization, spacing and weed recommendations, there are possibilities for optimizing the use of machines and fertilizers and herbicides.

In summary, the G2M2P2 network is capable and crucial to better calibrate hybrid production - ecophysiological models for eucalyptus cultivation incorporating site-specific constraints.

The role of ectomycorrhizal fungi in the long-term management of Pinus taeda phosphorus fertility in intensive silviculture

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Loblolly pine (*Pinus taeda* L.) is one of the most intensively managed tree species for timber production globally, especially in the southeastern United States. Phosphorus (P) fertilization has been shown to improve productivity and can lead to growth responses of 20 years or more, but little is known about the carryover effect of P fertilization from one rotation to the next. Long-term P availability depends on complex interactions among abiotic and biotic factors. Ectomycorrhizal (ECM) fungi are perhaps the most important biotic factor influencing pine nutrient acquisition, as they provide nutrients and water to roots in exchange for sugars from tree photosynthesis. ECM fungi mycelial scavenging can produce enzymes and organic acids that facilitate mobilization and uptake of fixed soil P from organic, mineral, and surface-sorbed sources. Fungal community composition has been shown to respond to additions of P fertilizer, but the long-term effects on the composition of ECM communities in subsequent plantings is poorly understood. A long-term, regionwide experiment is being conducted on sites that were fertilized with increasing P rates during the previous rotation, and with or without P additions in the current rotation. ECM fungal community composition following harvest and re-planting are examined by DNA extraction from rhizosphere soil and buried P-baited mesh ingrowth bags that capture fungal hyphae beyond the root zone. Preliminary results show ECM community structure responses to P fertilization and soil type, and dominant ECM species were identified as possible biological indicators of P fertility. To further understand the role of ECM communities in pine P nutrition, field observations are being coupled with analogous laboratory experiments that utilize culturable fungi and field soil in multi-compartment systems to assess the capacity of important loblolly-associated ECM fungal symbionts to transport P to pine roots from various labile and non-labile P sources. This research aims to provide a more robust understanding of the role of ECM fungi in long-term P-cycling processes in intensively managed pine plantations and determine the suitability of ECM fungal community assays as indicators that may improve predictive models to optimize P fertilizer use in loblolly pine production.

Tropical Eucalyptus plantations yields depends on topographic features that influences water availability on sandstone derived landscapes

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Eucalyptus growth driver has been deeply studied and associated with species/clones, soil type, fertilization regime, spacing, weed control, temperature, and rainfall over the years. In parallel a lot of effort has been carried out to understand eucalypt root system, and at spot trials, proved to be important to fully describe Eucalyptus growth in deep profile soils (Oxisols and Quartzpsaments) and its relationship on with the traditional tropical monsoon climate in Brazil, Australia, and South Africa.

Based on that review and in broad field mortality observation we hypothesized that the water table depth (WTD) and root dynamics would play a strong role in tree growth. In this study an extensive spatial (270 km x 270 km range) and temporal scale inventory network was put together and related with a water table algorithm based on most recent geo-information data available in a 30 m x 30 m resolution for the forestry part of the Brazilian state of Mato Grosso do Sul. We used the HAND terrain descriptor (Height Above Nearest Drainage) as a surrogate for the WTD on the watershed scale. Approximately 113,000 plots of the permanent forest inventory of Suzano's commercial Eucalyptus plantations, spread over dozens of thousands of hectares for the last 10 years, were made available for this study. The forest dataset included planted stands from 2005 to 2018 and tree measurements from 2008 to 2021.

Our study identifies physiography (position in the local relief) as the factor that controls the availability of water, and indirectly nutrients, to the Eucalyptus forests on sandstone derived landscapes in the Mato Grosso do Sul. The results obtained will allow the classification of the region into physiographic zones, which explain productivity by the effect of local drainage and water deficit, opening opportunities for clonal adequacy, management, operational activities, increasing tree survival and the productivity. Genetic and silvicultural prescriptions as variety and spacing recommendations have already been implemented, and further ones as fertilization rates, weed control and site preparation and conservation are being considered.

Using Spectral Vegetation Indices to estimate mid-term responses to soil preparation intensity and weed control timing for Pinus radiata plantations

T2.28 Strategies and challenges for improving commercial forest plantations productivity and sustainability in North and South America

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Abstract: Leaf area index (LAI) is a key parameter in forestry research due to its association with many ecological processes such as photosynthesis, evapotranspiration, carbon sequestration and growth of forest stands. Given this, the use of remote sensing in the study of forest productivity has been of great importance due to the relationship between spectral vegetation indices (SVI) with LAI and its potential to monitor forest management. Silvicultural treatments, such as soil preparation and weed control, are key to improve commercial forest stands and the use of remote sensing provides an excellent tool to estimate responses to treatments. Our objective was to quantify the effects of soil preparation intensity and weed control on young radiata pine plantation growth and model these effects on stand productivity using SVI. The investigation utilized two field trials established with a split-plot design examining cultivation treatments as main plots (shovel, subsoiling to 80 cm, disking to 30 cm depth) and weed control as subplots (none, pre+post 2 years after planting, and only post 2 years after planting). Trees were planted in 2013 and measured in diameter and height annually. Sentinel-2 images were acquired (converting digital numbers to radiance and then to reflectance) to estimate SVIs. At both sites, nine years after establishment, soil preparation treatments with weed control applied pre+post planting showed the best accumulated volume, with responses ranging from 83 to 85 $m^3 ha^{-1}$ over no weed control for both sites. Volume responses to soil preparation did not show differences between disking and subsoiling ($p>0.05$), but they did show differences compared to shovel only. A significant correlation was observed ($p<0.001$, with $r^2=0.77$ to 0.79) between the current annual increment (CAI) and the simple ratio (SR, the ratio between the spectral NIR and Red bands). At both sites, a linear model between CAI with SR showed weed control pre+post planting had a higher slope than no weed control or only post-planting weed control.

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

Development of smallholder teak plantations in Vietnam

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak has been introduced to Vietnam in the early 20th century. Although it performed well adapted to a wide range of climatic conditions in Vietnam with a yield of 7-16 m^3/ha/year for 20-25 years rotation, its extent of areas is still very limited in comparison with about 2.5 million hectares of *Acacia* and *Eucalyptus*. In Vietnam, about 70% of the plantation lands are owned by the households and the major constraint for teak development is that the rotation length is about four times that of acacia (4-7 years), even though the economic return from Teak (converted to annual basis) is much higher than Acacia. The ITTO Teak in Mekong Project (PP-A/54-331) implemented during 2019-2022 has supported Vietnam teak planting households in several communities in capacity building, selection of quality seed sources, development of silviculture demonstration plots, and identification of teak value chain, those initially support the smallholders in development and sustainable management of the teak plantation.

The demand for high-quality timber including teak in Vietnam for the furniture industry has been increasing steadily during the last 15 years, mainly for export with exporting value increased 15% annually to reach 15.7 billion USD in 2022. Teak promises to be a valuable and suitable tree species for the large-dimension timber plantation regime in Vietnam, which is recently encouraged by the government. Finding solutions for smallholders to invest in long-rotation plantations, particularly for teak, is crucial. Recommendations from findings in the ITTO Teak in Mekong project, including (1) boosting teak growth by improvement of germplasm and silviculture technology, (2) diversifying income regime based on teak-based agroforestry, (3) improvement of the value chain and marketing, (4) promotion of linkage between wood processing company and teak smallholders for sustainable material supply chain, and (5) micro-finance mechanism for long-term investment, are promising solutions. This presentation will discuss those issues with the aim to support smallholder teak plantations in Vietnam and the livelihood enhancement of the people employed in the sustainable teakwood industry sector.

Effect of Topographic Conditions on Teak Heartwood Quality in Mountainous Area

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak is a globally commercial hardwood tree species. Teakwood exhibits a high timber quality, owing to unique properties such as lightness with strength, stability, durability, malleability, resistance to termites and fungi, and high adaptability to environmental variations. Hence, it is widely used to build outdoor and indoor furniture, ships, decorative veneers, paneling, doors, and windows. High-quality teakwood has been obtained from tree dimension, wood quality (e.g., heartwood content, wood properties, wood characteristics, and defects). The heartwood factor is a crucial component that alters to log yield, grading, and price, directly affecting wooden productivity and profitability. In Lao PDR, there is little research on teakwood quality. Despite this, wood quality is vital for the Lao wood industry sector. This study has specific criteria, according to commenced harvest year of ≥ 10 years along with optimum site elevation of <900 m.a.s.l and without evidence of damage in heartwood. Forty-nine sample plots in total were selected from target plantations, having 147 short log samples obtained from the felled tree (three trees per plot) using for heartwood quality assessment. This study found that the heartwood content of the basal area mainly increases with tree size. However, it had slightly affected by topographic conditions. Heartwood content of commercial volume increases with tree age, having a greater proportion in the middle to upper slope. Lower tangential shrinkage and radial shrinkage with higher basic density mean better wood properties. Therefore, the analysis results suggest that teak's heartwood properties; basic density and tangential shrinkage have an increasing quality with tree age, slope gradient, and elevation, while radial shrinkage showed a good value with larger stem diameter at gentle concave slope along where an area of lower elevation, while tangential shrinkage had a better value at steep land where an area of higher elevation might be affected by soil condition factors. Teak heartwood color; L^* has a darker color associated with the southwest-facing gentle slope in lower elevation. The redder color showed a relationship with the southeast-facing straight slope, while yellow has a higher value at lower stand density whereas southwest facing slope in lower elevation.

Global Teak Resources and Market Assessment 2023

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak (*Tectona grandis*) is one of the most valuable tropical hardwoods of the world and is grown in nearly 70 tropical countries. Besides timber, teak is also considered an important livelihood option for dependent communities in the tropical region. Myanmar, India and Indonesia hold more than 75% of the world's teak planted area. The global teak 'heavyweights' namely India, Myanmar and Indonesia have teak planted areas of 1.667 million ha (38% of total teak planted area globally), 1.269 million ha (29% of total teak planted area globally) and 0.39 million ha (9% of total teak planted area globally). Since 1990's, teak plantations had expanded rapidly in Africa with large tracts of land in Benin, Côte d'Ivoire, Ghana, Nigeria, and Tanzania. Realizing the potential of teak in the international market, commercial teak plantations were established in the South and Central American countries like Brazil, Columbia, Costa Rica, Ecuador, El Salvador, Guatemala, Nicaragua and Panama. However, reports show that the timber output from planted teak forests in West Africa would have declined in recent years due exhaustive felling and non - replanting of old plantations. A comprehensive outlook on the teak sector was published by FAO in 2010 in its global assessment of teak resources and estimated planted teak forests from 38 countries at 4.35 million ha. However, there has been no attempt to assess the changes in the global teak resources and trade since this study in 2010. Hence, there exists a huge data gap in the status of these resources and trade. The Teak Resources and Market Assessment 2022, a joint project by TEAKNET, IUFRO and FAO, fills this data gap and presents a detailed assessment the world's teak resource, its distribution at country, regional and global levels, ownership ship status of the plantations, productivity aspects, trade and major markets and the ways in which these teak sectors have changed over the years.

Heartwood production and density of 22-year-old teakwood from fast-growth plantations: a comparative study across three locations in Brazil

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: In Brazil, there are approximately 100,000 hectares of teak plantations, with 65% of them located in the state of Mato Grosso, which has an extensive territorial area and diverse soil and climate conditions. These plantations are typically established by private investors and managed with short rotations, with the final harvest taking place between 20 and 25 years. The objective of this study was to compare the diameter, heartwood percentage in the first commercial log, and radial apparent density of 22-year-old trees from three planting locations. The plantations are situated in Santo Antônio do Leverger (L1), Nova Maringá (L2), and Alta Floresta (L3) in Mato Grosso, Brazil. The average temperature varies from 26 to 27°C, and the annual rainfall is 1360 mm (L1), 1700 mm (L2), and 2250 mm (L3). Five trees were sampled from each location, and a disk was taken at a height of 2.3 m (end of the first commercial log) to determine the total diameter, heartwood diameter, and apparent density in the heartwood, transition, and sapwood regions. The average total diameter was 22.35 cm (L1), 32.10 cm (L2), and 28.91 cm (L3). The heartwood diameter followed the same trend as the total diameter, with average values of 17.64 cm (L1), 25.34 cm (L2), and 21.86 cm (L3). The heartwood percentages were above 50%, from 57% (L1) to 62% (L2 and L3). For L1 and L2, the average apparent density (at 12% moisture content) was 608 kg/cm³ and increased from pith to bark. In L3, where the wood density was higher at 643 kg/cm³, the sapwood presented a lower average density compared to the heartwood. Teakwood from these fast-growth plantations is classified as medium density. While there was no observed relationship between growth and wood density, the planting location does affect both the growth of teak trees and the properties of the wood. It should be emphasized that wood from fast-growth plantations has potential for common uses of teak wood. However, further in-depth studies on the characteristics of teakwood from the final harvest in fast-growth plantations are necessary to fully explore its potential and better understand its properties.

Intensely managed teak plantations – Quality of teakwood & common grading rules for teak logs

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak is a valuable species, predominant in the Central India especially in the state of Maharashtra. The Forest Development Corporation of Maharashtra (FDCM) focuses on intensely managing the teak plantations which are raised by clearing the irregular forests & converting them into a uniform system with supplemental artificial regeneration of genetically superior stock. This is a form of clear felling system but leaving out 20 trees per ha which are middle aged fruit bearing trees and 20 trees/ha which are superior miscellaneous species which are teak associates.

The intensely managed teak plantations begin from the nursery practice of soil & fertility analysis, green manure (sun hemp) supplements in bed preparation. The planting stock management includes weeding, culling, application of fertilizer, sprinkler irrigation, pest management (from white grub attack). This is followed by preparation of teak stumps which are uprooted just at the beginning of first showers in monsoon season. Once the plantation is in place , the casuality replacement of inferior/dead/diseased growths are replaced with root trainers which are raised in potting media which consists of neem cake, borax powder, posphates and sulphates. This is complimented with vermi compost as a means to minimize the impact of chemical fertilzers and to reverse its effects on soil.

Once the plantation is established, silvicultural thinning (growing stock manipulation) ensures that there is no overstocked plantation which affects the reproduction of teak, since it is a heavy light demander. This regulates the distribution of growing space for the advantage of the existing crop. The thinning cycle starts from the 10th year and is carried out every 5 years till the final felling in the 80th year.

The timber extracted during the thinning process as well as final felling is graded once it is transported to the sales depot. The grading rules depend on the length, girth, bends, buttresses, surface cracks, splits & shakes, twists, hollows & rots, knots, wound and taper. The grading rules standardization is important interms of bringing uniformity in measuring units & volume of log dimensions especially in timber exports.

Keywords
Supplemental artificial regeneration of genetically superior stock, planting stock management, silvicultural thinning, grading rules.

On-farm thinning trials in smallholder woodlots of teak: intensive early thinning improves productivity

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak woodlots in northern Lao PDR are a dominant component of the landscape in many districts of Luang Prabang Province. Smallholder famers planted teak into their upland crops, which after usually 2 years of cropping, were allowed to continue to grow with limited management until such time as some trees had achieved the minimum merchantable size and the owners required cash to meet household needs (e.g. schooling, medical, wedding or other expenses). Initial stocking rates were typically much greater than 1100 t/ha (e.g. 3 x 3 m), sometimes exceeding 3000 t/ha. Smallholder valued their woodlots based on the number of trees on the plot, and viewed 'thinning' only as thinning from above where the best/largest (i.e. dominant) trees are sold for cash usually to middle men acting for a sawmill. Extract is usually manual, with 2 or 3 men carrying short logs (2.3 m) to the roadside; however, while elephants can be used to extract larger logs, extraction methods and woodlot location do limit maximum log size. The results of thinning trials established in collaboration with a network of smallholders, as part of a series of ACIAR projects in Luang Prabang Province of northern Lao PDR commencing in 2009, are described. Due to the relatively small size of teak woodlots in northern Laos, and variability of the terrain, only two plots were established in each woodlot: a thinned plot and an un-thinned control plot. Initially, farmers were reluctant to be involved in the project, and so woodlots of disparate age were recruited into the trail, and thinning intensities were relatively low. In a second phase of the ACIAR project, new thinning trials were established within target age of 5-9 years and selected trial sites were retained, and thinning regimes involving removal of approximately one half of the trees (equating around one third of the standing basal area) were implemented. Trials were measured annually through to 2019 when the project ended. This network of thinning trials can continue to provide valuable long-term information on the growth and productivity of teak in north Laos.

Promoting Legal and Sustainable Supply Chains for Sustainable Global Teak Markets

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: The global teak market faces challenges in establishing transparent and sustainable supply chains due to the complex nature of roundwood products and the need to verify the legality of raw materials. Industrialized countries have implemented regulations to prevent the import of timber from unknown sources, requiring importers to demonstrate the legality of their supplies through due diligence (e.g. the Lacey Act, USA; the EU-FLEGT Timber Regulation; the Japanese Clean Wood Act, the Australian Illegal Logging Prohibition Act). India stands as a key player in the global teak trade, consuming nearly 95 percent of teak wood from teak plantations in three tropical regions. While a niche market for luxury yachts also exists, the bulk of the teak wood is used to support India's economy, provide employment opportunities, and cater to the demands of discerning Indian consumers. To address the challenge of illegal logging, it is imperative to establish cost-effective certification systems that facilitate the production of legal teak wood. By implementing such measures, the origin and legality of teak supply chains can be ensured, mitigating the risks associated with trading in illegal wood. Sustainability in teak production is crucial for the long-term viability of this valuable resource. Establishing and managing teak plantations using environmentally responsible forest management practices are key. Encouraging certification schemes and standards incentivizes sustainable teak production and provides assurance to consumers regarding the origin and sustainable management of teak products. Fostering collaboration among stakeholders is vital for building sustainable teak supply chains. Engaging with local communities, indigenous groups, governments, and industry actors is essential to address social issues and ensure the inclusion of diverse perspectives. Robust monitoring systems, sustainable management practices, and transparent communication channels can facilitate cooperation and contribute to the establishment of sustainable global teak trade.

Reducing initial stocking rates in smallholder teak woodlots: results of a Nelder wheel experiment in Northern Lao PDR after 15 growing seasons

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak has been planted in the upland areas of northern Laos for more that 50 years, resulting in an estimated 15,000 ha of teak, established as a patchwork of small woodlots distributed across the landscape. There were varying reasons underpinning the adoption of teak planting by smallholder famers in northern Lao PDR, from securing land tenure, to providing a mechanism for long-term investment (i.e., a green bank). Typically, teak woodlots were established at high initial stocking rates, and were then thinned by progressively removing the largest trees once they obtain a marketable size. This strategy has returned significant benefits to households that have retained ownership of their woodlots until maturity. However, the timeframes are long (often 15 or more years to first harvest) and repeated thinning from above results in a residual stand dominated by poorly formed, suppressed trees that grow very slowly, with limited value. Here we present the results of a Nelder Wheel experiment planted in 2008 under an ACIAR project and remeasured after 15 growing seasons during 2023. The results demonstrate the potential for teak to be grown under shorter rotations, by either planting at around 625 t/ha or adopting early pre-commercial thinning to reduce stocking levels to 500-600 t/ha. This approach can allow intercropping with the developing teak for longer periods, greatly increase diameter increments, thereby reducing time to first commercial harvest and increasing profitability. Woodlots can then be commercially thinned (from below) at 12-15 years of age, or potentially clear-cut at 15 years, and the coppice managed to regenerate the woodlot, providing long-term, sustainable timber production, with limited management requirements.

STRENGTHENING SMALLHOLDER COMMUNITY-BASED TEAK PLANTATIONS IN THAILAND

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Thailand's 20-year National Strategy (2018-2037) targeted at increasing the forest cover up to 40% of the country's land area. In addition, the National Forest Strategy and Action Plan for Extension of Integrated Economic Trees aims at increasing economic plantations of 4.1 million ha to meet future wood demand and the economic forests of 15% out of 40% target by motivating people to plant more trees for economic benefits. Teak (*Tectona grandis*) is promoted as one of the top priority species for plantations, which was exempted from the list of restricted species and recognized as commercial timber species in the amended Forest Act of 2019. Although teak plantations were established more than 100 years ago and the first world teak orchard was initiated in Thailand in 1965, most of the existing teak plantations are of poor quality and from unknown genetic origin. Furthermore, teak smallholders lack of sustainable financing mechanisms and gain limited short- and medium terms income from the plantations. The ITTO Teak Project Phase I "Enhancing Conservation and Sustainable Management of Teak Forests and Legal and Sustainable Wood Supply Chains in the Greater Mekong Sub-region was implemented during 2019-2022 by ITTO with the participation of five countries, namely Cambodia, Lao PDR, Myanmar, Thailand and Vietnam as well as with the support of the Kasetsart University of Thailand. Although the COVID-19 pandemic caused disruptions in the global trade of tropical timber products, significant achievements could be made. Trainees became trainers to share knowledge with their colleagues. Fourteen demonstration plots were established in the five participating countries to support community-based smallholder teak forests. Plus trees were identified, and several clonal tests and seed production areas were established. Subsequently, good quality seedlings were distributed to teak smallholders. These outputs are bridging to project phase II. This presentation will focus on the strategies to strengthen smallholder community-based teak plantations in the Mekong and other countries in the tropics. In addition, support for the livelihood enhancement of the people employed in the sustainable teakwood industry sector will be discussed.

Keywords: smallholder teak, demonstration plots, plus trees, sustainable teakwood industry, *Tectona grandis*

Sustainable Development of the Global Teak Sector: Adapting to Future Markets and Environments

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak has a world-wide reputation as high-quality tropical timber. In recent years, teak has attracted the commercial interest of investors and small land holders, especially, in developing short rotation teak plantations across the globe. The rapid expansion of planted teak forests risks compromising the excellent reputation of naturally-grown teakwood in the global markets due to the wide discrepancy of wood quality in plantation grown timber. The reduction in wood quality has a significant impact on the timber prices. This is aggravated by the absence of an approved international market intelligence, log grading rule or pricing mechanism. Recent years have also brought to the fore a plethora of challenges in the teak sector such as climate change induced growth constraints, erosion of the gene pool, emergence of new pests and diseases, difficulties in maintaining legal supply chains and disruptions in the markets through the COVID -19 pandemic. Though research and development has produced important results in recent years in all aspects of teak farming and markets, there exist serious gaps in knowledge management and dissemination to the stakeholders, as well as professional networking among the teak growing regions. Properly managed planted teak forests can produce financial benefits and offer opportunities to support the global environmental initiatives on Forest Landscape Restoration, carbon sequestration and livelihood enhancement of rural communities. Teak growers must ensure the proper management of planted teak forests using best forestry practices by producing highest possible quality wood. This includes proper species-site matching, using good genetic planting material, employing optimal rotation cycles and appropriate silvicultural techniques.

Sustainable teak harvesting and regeneration practices: Pivotal in attaining the economic, social and environmental gains

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: The teak forest which is spread over the eastern Vidarbha landscape in Maharashtra are renowned for producing superior quality teakwood with distinguished color, natural durability and mechanical properties. The teakwood is harvested, following the principle of 'Critical Crop Girth'- a concept which has been scientifically established on the basis of systematic studies on mean annual increment in the crop stand. The Critical Crop Girth is unique for every site quality and crop composition. This assures the maintenance of stock density in the forest at levels which will produce optimum productivity with desirable traits.

The management of teak forests through scientific harvesting principles followed by regeneration with genetically superior teak seedlings ensures continuous timber supply to meet the growing demand in the market. Certified seeds from Candidate plus Trees (CPT) are used to raise high quality teak saplings for artificial regeneration in the felled areas to ensure viable teak stand. In addition, systematic grading rules for harvested teak logs are established in consonance with market requirements to obtain best price. The system of grading is an age-old practice and the grade chart varies from Grade 1 to Grade 6 (superior to inferior). The logging as per the market needs and introduction of e-auction creates a demand driven competitive environment, fetching best prices.

Sustainable management of teak forests through scientific harvesting methods followed by artificial regeneration eventually leads to continued supply of teak for export and domestic markets and also delivers a range of environmental and social benefits thereby leading to community transformations by providing employment opportunities to local populace, forest landscape restoration with increased carbon sequestration.

Keywords: Candidate Plus Trees (CPT), critical crop girth, Grade chart.

Teak plantations in mixture with native species in tropical Latin America: growth, management, economics and carbon sequestration

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak is the dominating tree species in plantation forestry of many tropical Latin American countries, e.g. Costa Rica and Panama. Timber production and economic return are usually the main objectives in teak plantation forestry, but there is globally a growing interest in biodiversity protection and carbon sequestration. Mixing teak with native species has been suggested a promising strategy to increase the plantation's value for biodiversity protection while maintaining high economic return. Additionally, due to higher productivity, mixed-species reforestations have been suggested for carbon plantings. Here, we show how mixed species plantations of teak and natives perform in terms of growth, economic return and carbon sequestration under optimal forest management. We analyzed this by calibrating the mixture version of the process-based forest growth model *3-PG* (*3PGmix*) for four Neotropical native species and teak. We then coupled the forest growth model with a detailed economic model and using a simulation-optimization approach, we compared the economic and carbon sequestration performance of commercial mixed-species stands and monocultures in Costa Rica. Mixed species plantations showed good growth and economic performance (~ 3000 – 4000 USD/ha at 8 % discount rate). The best mixed species plantations outperformed conventional teak monoculture plantations with regard to carbon sequestration and economic return. Carbon storage and economic advantages of mixed species plantations increased with increasing carbon prices. The results suggest that mixed species plantations can be a competitive alternative to monocultures, especially if uncertainties are high, such as species-specific site suitability or when considering climate change scenarios.

The future is genomic: rapid clone selection for teak productivity and value

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak is integral to countless tropical landscapes, contributing to society as a high-value commercial timber crop and a key component of smallholders' livelihoods. Genetic improvement has great potential to increase the value of teak in such diverse systems, especially by deployment of well selected clones. Genomic prediction is now a well-tested technology for rapid evaluation of untested clones and revealing unknown relationships. Therefore, we aimed to develop genomic resources suitable for predictive modeling in teak. We demonstrate the approach using a small set of clones.

GENFORES is a Costa Rican based tree improvement cooperative with active breeding programs in 6 Latin American countries. This genomic project started in 2019 with cooperation of North Carolina State University. Thirty-three elite teak genotypes from 9 independent breeding programs were sequenced using a reduced representation approach. This resulted in 10,812 polymorphic SNP markers with MAF>0.05 and 93% realized accuracy. Of the genotyped clones, 26 were accompanied by their genetic ranking values from field tests of DBH, commercial volume, wood specific gravity, heartwood percentage, heartwood color, and stem quality (form). Genomic information revealed previously unknown relationships amongst 18 of the clones, consistent with 7 small full-sib families. Bayes ridge regression (BRR) was found to be superior to Bayes A, B, C, or Lasso prediction models. Leave-one-out cross-validation of BRR models resulted in predictive ability of 0.66 for DBH, 0.60 for volume, 0.59 for specific gravity, and 0.40 each for heartwood percentage and stem quality. A genome-wide association study discovered 7 significant SNP markers for DBH, 8 each for Volume and Specific Gravity, 4 for Stem Quality, and 5 for Heartwood Color. These results compare favorably with published reports from other tree species. We conclude that genomic prediction for early clone selection in teak is a feasible and highly valuable approach.

Future work will focus on increasing the number of genotyped clones and test environments, and the functional annotation of significant markers. We expect that genomic evaluation will become standard in advanced teak improvement programs, particularly for pedigree reconstruction, rapid prediction for untested clones, and genetic connection of separate breeding populations.

Thinning of Teak Forests – A key to a productive , sustainable and profitable forest

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Teak is a valuable species, predominant in the Central Indian forests especially in the state of Maharashtra. The Forest Development Corporation of Maharashtra(FDCM) focuses on making the teak forests/plantations of Maharashtra a productive, sustainable & thereby a profitable forest through periodic silvicultural thinning (growing stock manipulation), thereby ensuring that there is no overstocked forest which affects the reproduction of teak, since it is a heavy light demander. The idea is to maintain the growing stock per hectare at such levels which produces optimum annual increment in volume and the annual increment so produced is deposited on the main stem of the selected individuals. This regulates the distribution of growing space for the advantage of the existing crop.

India is a country of rich heritage in terms of forest conservation & known for having strict forest legislations. This makes plantations of valuable timber all the more important & relevant to meet the ever increasing demand of solid wood like teakwood. The first thinning in teak plantation is carried out in the 10th year only (Rotation of Teak crop is fixed at 80years). Prior to first thinning, only silvicultural operations like cleaning, singling, tending etc are carried out. Thinning at regular intervals ensures sustained yield of teak growing stock.This facilitaties teakwook supplychains and trade in perpetuity to meet the demand of teakwood.

This scientific intervention helps in increasing the total yield, redistribution of growing space to the advantage of teak , engaging the local people & tribals in meaningful employment, reduces fire incidences, increases the mobility of wild fauna, increases biodiversity of the forest (by retaining the fruit tress, mahua, tendu etc). The sustainably extracted timber by FDCM, through online auction fetches best market prices , generating revenue for the government as well as the employees (incentives). Most importantly, the FDCM increases the annual increment of the growing stock & accrual of timber thereby increasing the biomass, carbon sink & sequestration , a step towards a sustainable world.

Keywords:

Teak, productive, thinning, growing stock manipulation, light demander, meaningful employment, mobility of wild fauna, biodiversity, carbon sink & sequestration, sustainable.

Trends of trade and market access of tropical timber and timber products

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: Competitiveness of tropical hardwoods is in continuing loss compared to wood products produced in temperate forests. In the current situation, the availability and quality of large-diameter tropical hardwood logs of primary wood species are declining. Changes in the global trading environment for tropical timbers, including teak, are occurring at a rapid pace. This requires a longer-term view to enable tropical timber industry policy decisions to be effective. Degraded forests have a reduced capacity to supply local, national and global markets with essential forest products. Yet demand for harvested timber and other products are increasing. Demand for tropical primary and secondary wood products is a derived demand, driven by residential, non-residential and public construction activity and by consumer wealth and spending. Global housing and construction trends are therefore important indicators of tropical wood products demand. Commodities produced in tropical countries are not always viewed in a positive light as they are associated with deforestation, forest degradation, illegality, etc. Increasing degraded forests have reduced their capacity to supply local, national and global market with essential forest products. The COVID-19 crisis has affected tropical timber and timber product trade and amplified the economic slow down in its both producer and consumer countries. Tropical timber producer countries need to regularly assess the situation of competitiveness of their products in international markets to ensure continued maintenance of production and trade of sustainably managed tropical timber products. Ensuring sustainable tropical timber trade requires optimizing the utilization and improving productivity of production forests, which will, in turn, benefit conservation and protected forests, in terms of reducing pressures and disturbances. A key requirement of sustainability is compliance with all relevant legal frameworks.

X-ray densitometry and tree-rings applied in growth reconstruction of Tectona grandis

T2.29 Strengthening Teak Forest Management for Sustainable Teakwood Supply Chains and Trade

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Abstract: In view of the increase in the global demand for wood, it is necessary to know the dynamics of growth, productivity and wood quality in short and medium cycle forests in different environmental conditions. Thus, our objective was the reconstruction in diameter and height of planted forests of the Tectona grandis species in four locations in Brazil, Porto Esperidião – MT (L1), Glória D'Oeste – MT (L2), Rosário D'Oeste – MT (L3) and Angatuba – SP (L4), in addition to the analysis of the microdensity profile in the pith-bark direction. For this, disks were collected from five trees in each location and at different heights of the stem (every 1.30 meters in height). The forests were 9 to 18 years old, and the growth rings were measured in the different disks and the height was reconstructed through trunk analysis. The Faxitron X-Ray equipment was used to determine the apparent density (12%). In L1 at 14 years old, the trees had an average diameter of 24.88cm and 15.66m in height. In L2 and L4, both 9-year-old plantations, the diameters were 18.32cm and 21.39cm, and the heights were 13.50m and 6.75m, respectively. In L3, the longest planting (18 years), the diameter reached 33.25 cm and height 15.39 m. With dendrochronological analyses, it was possible to carry out the annual reconstruction both in diameter and in height. The apparent microdensity profile data point to an increasing trend in the base-to-top direction, on average the values were 0.65, 0.68, 0.68 and 0.63 (L1, L2, L3 and L4, respectively), being that the values are related to implantation variables, management, age of the trees and edafo-climatic characteristics. Information on growth and wood properties are basic for assessing the forest suitability of the site, as well as for defining silvicultural techniques, planning, forecasting the wood stock and estimating carbon sequestration in forest formations.

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

2016

Battery-powered chainsaws in forest operations: a sustainability assessment with a special focus on ergonomics

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: The use of chainsaws in forest operations is still largely widespread. In fact, the use of this tool, in comparison with big machines, guarantees some pros related with reduced costs, good efficiency and versatility. Operating within the Sustainable Forest Operations should guarantee environmentally friendly, convenient, high-quality and fair productions. In this context, the use of chainsaws may be critical in terms of health and safety of forest operators, being the use of this tool very dangerous, as the direct or indirect cause of many accidents and the cause of several work-related diseases. Moreover, it has a limited but evident role in greenhouse gases emission. In this context, a forest operator with chainsaw is subject to exhaust fumes, noise, and vibrations exposure. In the last years, thanks to a rapid evolution of battery technology, new generations of chainsaws are available on the market. These battery chainsaws are professional tools with declared power and performances comparable with the modern petrol-powered chainsaws, but with many advantages in terms of emissions; no exhaust fumes and reduced noise and vibrations. For this reason, the use of battery chainsaws in forest operations instead of petrol ones would be a good solution to reduce the risks in terms of health and safety. The aim of this work is to show the results of several studies aimed at understanding the differences between petrol and battery chainsaws in terms of performance, i.e. productivity and noise and vibrations emission, assessing also the differences in logistics needed by the two types of chainsaw. These evaluations have been carried out during real forest operations and on different wood species. The results showed very good performance of battery chainsaw, but also some critical points that does not allow its current use in real forest operations. In particular, considering that battery duration is almost the same of a full tank in petrol-chainsaw, recharging process in forestry is a key-task to be solved. In conclusion, the use of battery chainsaws in forest operation has a very high positive potential especially in terms of risks reduction, but it needs further technological developments to be really implemented.

Birch among forestry measures to adapt to climate change

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: Authorities and actors in the Swedish forest sector advocate an increase in management of broad-lead tree species. Increased abundance of broad-leaved tree species would benefit biological diversity as well as adaptation to climate change. The major broad-leaved tree species in Sweden is birch, with 10% of the standing volume. The dominating use of birch is in pulp production and for energy purposes. For forest owners they represent low-value products and from a climate perspective they are products with short life and thereby short carbon storage time. Instead, sawn wood would benefit forest owners and the climate. However, the production of sawn birch is in Sweden on a very low level, only 2-3% of the annually felled volume of birch is processed in sawmills compared to more than 50% of the softwood volume.

The study investigates the potential for the sawmill industry in southern Sweden to extract and process birch. Current silviculture as well as silvicultural methods promoting birch are studied. The quality of trees for sawmilling is a critical parameter; data from new trials are used to illuminate this aspect. To explore the conditions that need to be fulfilled from a supply and demand perspective to increase the share of birch processed in sawmills, the forest sector model (FSM), SweFor, is used. The FSM contains a forest module (forest management options and simulation of forest owner behaviour), industry process models (transformation of logs and residues to outputs including costs), and market demand for semi-finished forest products. Results show what combinations of tree quality requirements and sawmill technology will yield adequate volumes for a viable industry. Since quality and volume is dependent on silviculture, this will also show what will be required in terms of forest management. The dependence of birch sawmilling on demand for other uses is demonstrated.

Challenges and Opportunities in Forest Operations: Case study from South Africa

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: The global industrial roundwood production in 2021 was just over 2 billion m^3. 4% of the total volume came from Africa with South Africa producing around 16 million m^3. Forest operations is an integral part of the timber product value chain, supporting livelihoods of people through employment, energy production, value addition and enabling food security. However, the sustainability of forest management activities in forest operations is dependent on managing risks and exploring opportunities within various forestry environments. The aim of this study is to highlight the key difficulties and opportunities in forest operations by focusing on South Africa as a case study.

Forest operations in South Africa are currently facing several challenges which are inhibiting the industry's growth. Forest operations are dependent on a large proportion of unskilled labour to meet timber volume production requirements. Labour intensive operations pose a challenge because of increasing labour costs, significant risks to health and safety, high labour turnover and anticipated labour shortages. The poor governance of state-owned entities over several years has led to the deterioration of rail infrastructure used to efficiently transport timber to the markets, a surge in criminal activities (e.g., theft of harvesting equipment, timber and materials like fuel) and a lack of reliable energy supply to various timber processing facilities has led to significant decreases in volumes produced and increased costs.

Existing opportunities in forest operations include the adoption of technologies to optimally harvest and recover timber in high-risk and difficult conditions where manual labour is not suited (e.g. integrating traction and cable assist technologies). The deregulation of the logistics industry by creating opportunities for privatisation of rail transport services will encourage more efficient, reliable and cost-effective rail systems to operate. Furthermore, road timber transportation can be optimised by using more advanced performance-based standard (PBS) trucks which carry larger payloads (e.g., 30.5 m long trucks; payload = 79 tonnes), reducing delivered cost, total vehicles, road damage, accidents and CO^2 emissions. The collection, processing and transport of biomass material (residues) presents an opportunity for renewable energy generation thereby reducing the dependence on non-renewables, generating employment, and revitalizing rural economies.

Compatibility of an increased machine operating trail distance with SFO

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: More and more German forest owners, especially state forestry departments, increase the distance between machine operating trails from 20 to 40 or more meters, which is in accordance to the current German Forest Stewardship Council-certification standard. Inevitably, with the current forestry machine equipment (e.g. 10 m boom reach of harvesters), this increase in distance leads to a machine operating trail system with midfields. Still, increasing the distance between the machine operating trails is fully in line with Sustainable Development Goals (SDG) 12, 13 and 15 as more productive forest area is available and, hence more carbon can be stored in both forests (soil and biomass) and in timber products.

In response to this, the mechanized forestry equipment and/or the forest operation systems need to be adapted. An example of adapted forestry equipment is an increase in harvester size, resulting in 18 m operational boom reach. An example for an adapted forest operation system is motor-manual felling and mechanized winching of the midfield tress to the machine operating trail with subsequent mechanized processing. Our research is about the impacts of equipment and operation system adapted to an increase of machine operating trail distance on the main pillars of the Sustainable Forest Operations (SFO) concept: Environment, Economics, Ergonomics, People & Society and Quality Optimization.

The results of this research provide decision support for practitioners in accordance to the pillars of the SFO concept. Work metabolism related strain using spiroergometry (Ergonomics), productivities and costs using time studies (Economics), environmental impacts using life cycle assessments (Environment), residual stand damage (Quality Optimization) and work safety as well as available (wo)manpower (People & Society) were analyzed.

As a result, adapted equipment or operation systems seems to be more in line with SDG's compared to fully mechanized systems with 20m spacings (reference) because of increased carbon stocks (SDG 13 & 15), higher timber production (SDG 12 & 13) and a higher recreational value (SDG 15). However, the analyzed forest operations systems showed weaknesses compared to the reference as well, such as lower work safety or higher cost.

Criteria for assessing the sustainability of forest operations - a systematic review

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: The comprehensive assessment of forest operations through the consideration of the three pillars of sustainability (Economic, Social and Environmental) has not received much attention. The use of criteria and indicators can significantly improve impact assessment. Therefore, the objective of this contribution was to analyze the most commonly used criteria and indicators for each dimension of sustainability in timber and fuelwood harvesting over the last six years. It is intended to provide an overview of these criteria for different harvesting machines, geographical areas, slope classes, time periods, types of research, and silvicultural treatments. Another important aspect was to analyze how these criteria are connected to the UN Sustainable Development Goals (SDGs) and targets.

The environmental pillar (46%) was the most studied, followed by the economic pillar (38%). However, productivity was the most investigated criterion. On the one hand, productivity is linked to the environmental and social pillars, as it is related to the level of greenhouse gas emissions, energy consumption and the employment rate. However, productivity is mainly used as a criterion of financial interest, as it is most often studied in combination with costs. In addition to productivity (15%), the most frequently examined criteria were costs (10%), soil nutrients (9.5%), and soil compaction (9%). The social dimension was the least studied with 16%. This may be due to a more complex understanding and lack of knowledge of social sustainability issues in this area. Seven SDG targets have been identified to have a connection to the criteria of sustainable forest operations, whereas the most important are 8.2 (45% of all investigated studies), 15.2 (41%), 8.8 (19%), 3.4 (18%), and 12.2 (8%).

Sustainability is achieved when all three dimensions of sustainability are balanced. The results of a review of scientific publications of the last six years showed an imbalance, with economic and environmental aspects being weighted more heavily than social aspects. Balancing all three dimensions normally require an assessment of trade-offs This contribution provides a comprehensive summary of the criteria that have been studied to date and can be used as a checklist and guideline for future sustainability assessments of forest operations.

Developing and testing sensor systems for the detection of people in danger zones of forest work

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: Few workplaces pose as great a challenge as the forest. Demanding terrain and harsh environmental conditions coupled with a multitude of hazards result in a high level of occupational accidents. Especially the large danger zones are highly problematic. They must be monitored by the forestry worker throughout the process in order to not endanger people. However, especially in difficult terrain covered with trees and bushes, this is often almost impossible. For this reason, smart sensor systems are needed to support forestry workers and protect other people involved in the work as well as forest visitors. To protect this wide spectrum of individuals the aim of this study is to use technologies that can use tags as well as devices most individuals already carry with them – smartphones. After a literature research the two most promising technologies Ultra Wideband (UWB) and Bluetooth (BLE) were selected for the prototype development. A field test was conducted in steep and hilly terrain, monitoring typical danger zones of 30, 50, 70 and 90 m.

Evaluated by reference measurements of all tested distances the **UWB** system showed, with a mean deviation of -0.44 m and a RMSE of 1.52 m, accuracy and precision which are more than sufficient for the use in forestry. The detection performance for the 30 m (mean detection distance: 28.4 m RMSE: 3.56 m) and 50 m (mean detection distance: 43.9 m RMSE: 7.92 m) danger zones showed, that the system is suited for the use in motor manual timber harvesting. Even though the implementation of smartphones into the system was possible, the required performance wasn´t achieved. However, due to the rapid development of UWB technology in the smartphone sector, we expect a continuing improvement. The current **BLE** prototype only allowed a presence detection, but monitored, with a mean detection distance of 83.66 m (sd: 13.26 m), larger danger zones. Also, the implementation of smartphones was possible when using BLE.

Particularly the UWB system consisting of a sensor and several tags showed promising results and is therefore tested, as a second step, during forestry work to assess detection performance, practical applicability and limitations.

Effects of passive exoskeletons for the lower back on forest workers conducting two different planting procedures

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: Forest work is physically demanding and can lead to joint and intervertebral disc problems. Manual planting methods, which involve repetitive tasks with monotonous bending movements, particularly strain the lower back. With significant deforestation caused by wind throw, drought, and bark beetle infestations in Germany since 2018, reforestation will be a crucial task in the coming decade, involving a significant degree of manual planting. The use of passive exoskeletons for lower back support has shown to reduce muscle activity in the erector spinae by up to 75 %, depending on the design of the exoskeleton and the specific task and could therefore be a device to reduce strain on the lower back during manual planting tasks. However, these exoskeletons were designed and tested for industrial work tasks like lifting and carrying heavy loads, which rely on a limited set of simple movement patterns in a clean and level work environment. In order to investigate the effects of a passive exoskeleton on forest workers during different planting procedures, field studies were conducted under typical conditions in forestry.

The studies involved two forest workers, one using a hollow spade on even terrain and another one using a Harzian plant hoe on steep slopes. Each planting method was executed for three days in eight to twelve sessions of at least 45 minutes duration, plus half a day for several electromyographic (EMG) and motion capture measurements. For half of the measuring sessions the forest workers were equipped with the individually fitted passive exoskeleton PAEXO Back, manufactured by Ottobock, to provide back support. The effect of the exoskeleton on productivity was measured through a time study, while motion capturing techniques were employed to examine changes in movement patterns resulting from restricted mobility. Additionally, EMG measurements were conducted to assess muscle activity in the supported muscles throughout the planting. In parallel, a spiroergometric device was utilized to measure whole body strain by analysing breathing gas, volume, and rate, complemented by heart rate measurement using a chest belt.

Final results will be presented at the conference.

Ergonomic assessment of motor-manual forest operations: a comparison among different work complexity conditions

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: Motor-manual tree felling is still a widely adopted harvesting system in Europe, especially in difficult terrain where the deployment of modern harvesting machinery is limited. Motor-manual operations are exhausting, ergonomically adverse and tend to expose forest workers to potentially critical working conditions. Furthermore, an increased occurrence of hazardous situations, as well as a worsening of ergonomic and safety conditions, may be observed in the next future due to the increasing frequency of more complex work circumstances, such as salvage logging operations in steep terrain. Few studies investigate the relationship between the ergonomic conditions of forest operators and the complexity of the worksites. The following study aimed to assess the physiological workload and risk of work-related musculoskeletal disorders (WMSDs) of operators carrying out motor-manual tree felling and processing in different working conditions. 17 workers were heart rate monitored in tandem with a time study to analyse the workload experienced per productive working task. In addition, short videoclips were realized with action camera to capture the workers motions during felling and processing operations. Workload analysis was following developed by applying the relative heart rate at work (%HRR), ratio of working heart rate to resting heart rate (HRw/HRr) and 50% level of heart rate reserve (50% Level) indices, respectively. The risk of musculoskeletal disorders was evaluated through the procedure proposed by the Owako Working Posture Analysis System (OWAS). Heart rate was deeply explored to investigate the relationship among forest operator's workload and working conditions according to four complexity categories of the workplace.

Our results showed that regardless of working conditions, forest workers tend to assume higher risk postures while performing tree felling operation (RI = 195.4) compared to tree processing task (RI = 165.8). Conversely, the physiological workload analysis revealed that severe working conditions lead to a substantial increase in the workload of forest workers, such as in salvage logging operations carried out in steep terrain ($p = 9.18e-07$). Moreover, an increasing of potential risk situations and hazard events was observed for salvage logging worksites rather than ordinary harvesting activity.

Forest value chain resilience from a local perspective in five European countries: analysis of co-drivers and predictors

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: Climate change has severe environmental, social, and economic consequences on forests and the related forest value chain (FVC). One adaptation avenue relies on increasing the resilience of the forest systems. To ensure a stable supply of timber and products, forests and their value chains must be managed in a climate-adapted, sustainable, and carbon-neutral manner. However, the information about how to boost forest system adaptation capacities and deal with FVC irregularities resulting from disturbances and stressors is limited. Hence its operationalization is needed. Based on the Operational Resilience Framework (ORF) developed within the RESONATE project, this study aimed to identify and analyze the associations between predictors and co-drivers that affect forest value chain resilience from a local perspective in five European countries (Czechia, Germany, Croatia, Finland and Spain). The data on forest harvesting technologies, logistics, and forest stand-specific variables related to the timber supply was evaluated on an enterprise scale over 20 years (2001-2021). Our analysis indicated that larger forest holdings could offset disturbance effects to a certain extent and demonstrate more resilience by having more control over the value chain, such as managing their own sawmill or having more networking partners. Moreover, the results suggested that the efficiency of harvesting operations might improve resilience on a local level. Depending on their local suitability, the tree species used also influenced the resilience of the value chain through increased resilience of forests to disturbances.

Improving Forestry Supply Chain Resilience by Ensuring Steady Supply for Wood Processors

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: New Zealand is the largest softwood log exporter in the world, and its' sawmills productivity is excellent, but the domestic wood processing and added value are not increasing; contrarily, middle-size sawmills are closing due to supply uncertainty. Volatile log prices and short-term supply contracts erode job security and investors' confidence. At the same time, the unprocessed logs' export causes an unnecessary environmental burden due to the transported waste (water in logs and bark) and overseas transport fumigation requirements (CFC gases are used in the process). Log quality is also deteriorating while the wood is prepared for transportation due to blue stain fungi. Therefore, onshoring processing reduces negative environmental impacts, improves social and economic outcomes, and prevents log quality issues. Authors consulted with the literature, stakeholders and experts to identify potential solutions to ensure a steady wood supply that benefits growers, processors and society. Improvement opportunities were identified (compulsory registration of wood traders and consultants, long-term contracts with price adjustment formulas, cooperatives, business model changes, etc.). The potential solutions were investigated in detail by using a regional supply case study (Steady Northland Wood Supply), using three sawmills' 20 years of historical supply and sales data, and by stochastic models. The potential impacts on the economy, environment, jobs, and other effects were identified and discussed by stakeholder groups. The research triggered a new forest and wood industry legislation and contributed to New Zealand's Wood Industry Transformation Plan. Beyond the original research, the authors report the progress in implementation and compare the outcomes to the planned.

Keywords

Forestry Supply Chains, Resilience, Social, Environmental and Economic Impacts, Implementation

Improving values from harvest to market - An automation approach to sustainable and integrated forest operations in New Zealand

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: New Zealand is experiencing an increased public concern around how forests are managed, particularly regarding the suitability of plantation harvesting and roading operations in light of extreme weather events, with the need to afforest land for carbon sequestration and future timber production. Forest operations that are future-focussed require innovative responses to regulatory changes, community and market pressure, and societal scrutiny. In 2020, an online survey outlined perceptions of the New Zealand public towards three elements of forestry operations – harvesting on steep slopes; species change in plantations; and the use of chemical sprays for forest establishment and pest management. These highlighted an increased level of perceived societal risk particularly for steep slope harvesting, which was regionally concentrated, and effects the level of trust in the forest industry and its social licence.

Through incorporating technology adoption with a care for the environment, forest workers and the surrounding communities, more sustainable and integrated forest operations can be conducted. A targeted research programme “Te Mahi Ngahere i te Ao Hurihuri – Forestry Work in the Modern Age” has three major aims: to create value, improve profitability and enhance sustainability across the forestry value chain through automation. It aims to do this by exploring a new integrated forestry value chain from harvest to market, incorporating new technologies that will promote both industry and Government interests.

This presentation will outline the New Zealand context for improvements needed in forest operations, highlighting both public perceptions towards forest operations, and how new technologies are assisting the forest industry to meet Sustainable Development Goals. We highlight public attitudes towards harvesting, forest health and visual amenity, while introducing crosscutting science undertaken to address and improve operational management of forests. Particular emphasis will look at newer harvesting and roading technologies and the systems being investigated that seek to overcome steep slope forestry risks from environmental, economic, ergonomic and workforce perspectives.

Perspective on improving road networks including public roads through forested areas in Japan for sustainable forest management and wood supply chain

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: The mature stock of plantation forests planted in the 1950s to 1970s has reached the age for final harvesting in Japan. The relatively low current price of logs compared to that of the plantation age requires an improvement in the logistics of the wood supply chain. Recently, with regard to the situation, the Japanese forest road standard has been renovated to include 20-ton class semitrailers in the design vehicles in addition to 10-ton class log trucks and 4-ton class trucks. However, it is said that there are a number of public roads in steep mountainous forest areas in Japan that can only accommodate trucks with a lower load capacity. To confirm this situation, we investigated the suitability of six routes for access by 10-ton class logging trucks in a rural forest management area in Kochi Prefecture, which is located in the southeastern part of Japan and has steep mountainous forest areas. The width of the roads, measured in the field, was compared with images recorded on a drive recorder. The radii of road curves were estimated using interpolation algorithms available in a geographic information system (GIS) application. The required road widening was calculated as the difference between the actual road width and the width of the Type II Class 2 forest road (3.0 m), plus the amount of widening required for the curve radius. One of the existing routes, which was found to be unsuitable for 10-ton class trucks, was found to require significantly less road width expansion, indicating that it was originally designed for lighter 4-ton class vehicles. The other routes surveyed, including a specially constructed forest road and a forest road upgraded to a prefectural road, were found to be sufficiently wide to accommodate 10-ton trucks, although some sections were significantly narrow in residential areas. Based on the results, several options for improving the road network, including public roads over forested areas in Japan, are suggested for sustainable forest management and wood supply chain.

Pulled Three Ways: The Trilemma of Sustainable Northern Forest Operations

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: Forestry in the Nordic Baltic region and elsewhere faces a 'trilemma' of societal demands. Forest management and forest operations are expected to (i) increase wood production to substitute raw fossil materials, (ii) increase forest carbon sequestration and storage capacity, and (iii) improve forest biodiversity and other ecosystem services.

In this presentation, we approach the trilemma with a focus on how it can be visualized through the lens of the UN Sustainable Development Goals (SDGs). Balancing trilemma goals can have both positive and negative effects on sustainability. Increasing wood production can contribute to achieving SDGs 9 (industry, innovation and infrastructure); 11 (sustainable cities and communities);12 (responsible consumption and production) and 15 (life on land) while increasing forest carbon sequestration and storage helps to meet SDG 13 (climate action). However, actions which increase wood production and forest carbon storage must be met with caution, since they can have adverse effects on achieving SDG 14 (life below water) through negative impacts on biodiversity and other ecosystem services, especially those related to clean water and SDG 6 (clean water and sanitation).

Successful, and sustainable, forest operations and management must not only meet the needs of the forest sector but must support sustainable societies. To be successful we need somehow to balance between these different goals and acknowledge that they sometimes counteract each other. By framing the trilemma in an SDG context, we can build a dialogue based upon an existing and relatively accepted global framework, and its connection with society. However, it is critical to emphasize that there is an intrinsic "conflict of interest" within the SDGs themselves to achieve sustainability. Achieving one goal, without considering other goals, may not constitute sustainability of all goals on the agenda.

Theory-of-Change Development for Chainsaw Operators' Safety Improvement from Natural Forests in Indonesia

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

Hermudananto Hermudananto

Abstract: Tree felling with chainsaws is a dangerous occupation rendered even more so when workers do not utilize the recommended personal protective equipment (PPE). Despite regulations in Indonesia that require fellers to use PPEs, workers often do not comply, even in forests certified for sustainable forest management standards. This study analyses the impediments to using PPEs (i.e., safety boots, felling chaps, reflective vests, gloves, helmets, and eye and ear protection) and develops a Theory-of-Change (ToC) to improve worker safety. I observed a total of 11 Indonesian natural forest management units (10 in Kalimantan and 1 in Papua) in 2020-2022 to interview chainsaw operators and discuss with supervisors and forest managers related to PPE use. At least five potential interventions were revealed that could be adopted from the most to the least recommended. Frequent supervisor control to monitor chainsaw operators is the most recommended way to remind workers to use appropriate PPE during work. Not necessarily a formal command from top to bottom, but casual talks during leisure time in the forest camp might be worked. Another least popular option is a monetary incentive or award to the workers. However, its intervention might not be performed for some types of PPE, such as ear protection. Workers claimed that wearing that PPE risks their lives because they can't hear when a tree falls during harvesting. For the success of proposed ToC implementation, all possible assumptions, indicators, and metrics that were captured should be implemented for each ToC stage, including short- or long-term outcomes and final impacts. Worker safety improvement is not only about compliance against regulations or standards but rather a development of a good safety culture.

Work-related injury and chronic health issues among logging workers in the northeast United States

T2.30 Sustainable Forest Operations (SFO): Challenges and opportunities towards a resilient wood supply chain and worker's well-being

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Abstract: Introduction: Despite dramatic improvements in safety and mechanization, logging remains one of the most dangerous industries in the United States. The purpose of this research was to explore injury trends and health issues among Maine logging workers.

Methods: Loggers participated in seven quarterly surveys and a one-time physical health assessment. Data exported from REDCap into SAS 9.4, Excel, and NVivo. We compared endpoints between the sub-group who completed a health screening versus those who did not using the Wilcoxon rank-sum test. Comparisons between groups with more than two levels were made using one-way analysis of variance (ANOVA) or the Kruskal-Wallis ANOVA. Categorical variables, such as gender, were compared using chi-square or Fisher's exact test, as dictated by assumptions. Time to injury was modeled using two different approaches: 1) time to the occurrence of first injury modeled by proportional hazard regression and 2) an intensity model for injury frequency. Two research team members also analyzed qualitative data using a content analysis approach.

Results: During the study, 204 injuries were reported. Of the 154 participants, 93 (60.4%) reported musculoskeletal pain on at least one survey. The majority of injuries were traumatic, including fractures, sprains, and strains. Lack of health insurance was found to be related to increased risk of first injury [HR=1.41, 95% CI=0.97-2.04, p=.069]. Health assessments were completed for 75 loggers. Nearly half of those screened (45.9%) had blood pressure at the level of stage II hypertension. Seeking medical attention for injury was not a priority for this cohort, and narratives revealed a trend for self-assessment.

Discussion: We found that loggers still experience serious, and sometimes disabling, injuries associated with their work. In addition, chronic health issues such as hypertension is a concern for for this cohort. The most frequent injuries were due to slips, trips, and falls along with contact with logging equipment and trees/logs. Entrenched values that prioritized independence, traditional masculinity, and financial considerations were consistently cited as a barrier to adequate care.

Conclusion: There is a continued need to address occupational health and safety in the logging industry.

T2.31 *merged with session T2.30

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

[Cancelled] - Garcinia kola: diversity, domestication and future perspectives in Cameroon

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: *Garcinia kola* Heckel (Clusiaceae) is one of West and Central Africa's most popular agroforestry tree species. Despite its local significance, most of the current research focuses on *G. kola* therapeutic effects, omitting topics which could lead to the species' advancement in domestication. Therefore, our study aimed to provide a comprehensive understanding of *G. kola* phenotypical and genetic variation, its chemical potential as well as utilisation and management by local communities. In total, 122 farmers were interviewed, and 227 trees, along with 1,040 leaves, 1,727 fruits and 4,559 seeds, were evaluated in Cameroon's Southwest, Central, and South regions. Major regional differences in the utilisation, management and commercialisation of *G. kola* products were discovered. Even though fruit collection was harmless to the tree, bark and root harvesting was found to be invasive, threatening the species' existence in wild stands. Kolaviron, the most investigated chemical compound, appeared to be overrated regarding its therapeutic impact. Most of the elite trees originated in the South region, which exhibited higher genetic diversity than the rest of the study sites. However, no significant differences in genotype or phenotype were found between wild and cultivated trees, suggesting that the domestication of *G. kola* is still in its early stages. Promoting the species' therapeutic potential among farmers could be a successful strategy for shifting their focus from the bark to the seeds. Field trials recognising the Participatory Domestication Approach must first be established to test, monitor, and propagate possible cultivars of elite trees and ideotypes.

Agroforestry in Finland: case study of innovations in agroforestry farms in Finland

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Agroforestry is among non-mainstream land use practices in Finland. However, those farmers, forest owners and landowners who practice it in Finland carry information that is not available in conventional agricultural and forestry advisory systems. The traditional knowledge that agroforestry farmers use and pass on in their agroforestry practices is largely silent information for conventional agriculture and forestry advisors as well as to conventional farmers. In the Agroforestry Business Model Innovation Network project (AF4EU) innovative agroforestry farm business models will be analyzed. A multi-actor regional agroforestry innovation network in Finland is used for identifying innovative agroforestry farms in Finland. In this presentation we will explore the identified innovative agroforestry farm business models in Finland by exploring three farm cases from economic, environmental and social sustainability perspectives. The data is collected through interviews and surveys of farmers involved in the identified innovative agroforestry farm cases. Besides the innovative agroforestry farm cases, we explore the associated value chains. The results of this study give new insights particularly for farmers, advisors and policy makers on agroforestry in Northern Europe, a region not typically included in global discussions on advancement of different agroforestry systems.

Commercializing of traditional non-timber forest products in the plateau region: A case study of Matsutake in Shangri-La, Yunnan Province

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Commercialization of non-timber forest products is one of the important strategies to alleviate rural poverty and forest degradation. In recent years, China has explored this strategy to get sustainable ecological products, and the commercialization of Matsutake in Yunnan Province is one of these typical cases of transition from traditional gathering to economic activity. This study conducted a qualitative approach combined with commodity chain analysis to show the interrelationship of different participants along the wild mushroom commodity process in the southwest plateau of China. Taking Matsutake as an example, our research shows that the upstream and downstream participants in the Matsutake commodity chain are constrained by different types of institutional constraints. Besides, not every actor along the chain has access to the latest market information. Compared with local people, the middleman in the Matsutake transaction process can get a high-profit margin. The protection of natural resources and the formation of a stable market order are impacted by government and non-governmental organization activity to some extent, but the impact is neither substantial nor long-lasting. Our research indicated that to enhance both socio-cultural sustainability and ecological sustainability of the commodity chain of non-timber forest products in the plateau area, it is important to balance the interests of different participants along the commodity chain and utilize local traditional knowledge.

Comparative study of nyamplung and argan oils: positioning strategies in the Korean market for nyamplung oil from Indonesia

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: This research comparatively examined the primary effects, prevalent product variants and market attributes of nyamplung and argan oils to develop an efficient market and establish branding strategies for nyamplung oil (produced from *Calophyllum inophyllum* L) in the South Korean market. Employing a systematic review methodology, we investigated the socioeconomic and environmental advantages of nyamplung-based agroforestry systems and evaluated nyamplung oil's potential as a feasible alternative to other wood-based oils, such as argan oil (produced from *Argania spinosa* L). Our conclusions indicated that nyamplung oil could have significant potential in the Korean market, particularly when positioned as a natural, eco-friendly and fairly-traded product. We propose a three-stage positioning strategy for nyamplung oil: 1) analyzing current position in the market as a cosmetic product; 2) developing a product line extension as a medical product; and 3) considering image creation as a unique tree oil with environmentally valuable features. These approaches could support nyamplung oil's reception in the market by leveraging similarities with argan oil while differentiating itself through emphasis on its special benefits and environmental values. Through these approaches, we argue that nyamplung oil could contribute to the economic, social and environmental well-being of producers in Indonesia while providing Korean consumers with a high-quality, sustainable and effective natural product. For future studies, we recommend to investigate Korean consumers' preferences, establish a chain of custody study for sustainable production, or build a certification strategy for nyamplung oil.

Contribution of Oyster nut Women growers to Household Income in Northern Tanzania

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Oyster nut [*Telfairia pedata* (Smiths ex Sim)] Hook is a native vine that is cultivated in East Africa, it produces nuts which can be consumed raw or cooked and used as cooking oil. They are highly preferred by nursing mothers due to their lactogenic properties, which increase their milk flow. The study was undertaken to examine the contribution to household income by women growers of oyster nuts by using semi-structured questionnaires and ecological survey from a sample of 346 respondents in the districts of Lushoto, Bumbuli, Arumeru, and Same in Northern Tanzania. Factors influencing productivity and market participation among oyster nut growers were examined and those affecting women's participation in oyster nut cultivation are provided. Also the number of women growers, in the traditionally male-dominated communities, who contribute to household income from oyster nuts is less known. The market participation of oyster nut growers varied, depended on factors including gender, marital status, level of education and previous market experience to mention a few. According to the findings, oyster nuts were mainly produced by women (87%) compared to men (13%) and the majority of respondents (21%) used the nuts for cooking with other local staple meals, 18% were used by breastfeeding mothers and the least nine percent claimed to use the nuts for cultural and ritual purposes. The average annual income for women engaged in oyster nut farming in the study area was TZS. 640,000 ($273.50), and delivered 5% of the total household income. Oyster nut women growers' appear to be significantly involved and productive to household income, making it essential for increasing sustainable production, meeting expanding demand, and exploring the crop's potential as an underutilized oilseed crop.

Keywords: *Telfairia pedata, utilization, production factors, market participation*

Ecofeminism to analyze gender in geographical indications for non-timber forest products: the case of Madd of Casamance

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Recognizing a product as a geographical indication (GI) generates positive effects on territorial development. Yet, GIs' labels implemented in many contexts and scales lack gendered conditions, representations and abilities to face environmental and social challenges. Rare studies suggest that GIs generate negative gender effects such as invisibilizing women and their know-how. This communication explores potential effects of the GIs' process on gender, by analyzing a non-timber forest product (NTFP): Madd of Casamance (MOC) in Senegal. We mobilize an ecofeminist framework, which focuses on the relationship between the subordination of women and the degradation of nature stemming from the ethics of care. Our methodology is based on a literature review, documents analyses and interviews with key stakeholders of the MOC value chain. We collect data in all Casamance's subregions. The gender system within the GI of MOC is analyzed and compared to the traditional gender system of Casamance's rural communities. Our results describe the role of women and men within the value chain, while highlighting the work of women and their know-how in the transformation of the Madd. While looking at exploitation levels regarding an emerging market, we, furthermore, analyze, according to gender, the changes affecting the control of Madd resources. We confirm that in this case, the GI registration seems to highlight the work of women and their know-how in the transformation of the Madd. Regarding the control of a market and its resources, our adoption of an ecofeminist framework to describe gender systems in the GIs' labeling process for NTFP gives evidence on the inclusion—or exclusion—of women and their know-how. Our findings can be used to analyze gender systems in other GIs with NTFP.

Effects of socio-ecological determinants on carbon accumulation in traditional agroforestry: A Case of Vhembe Biosphere Reserve, South Africa

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Traditional agroforestry has been explicitly recognised worldwide for its positive contribution to biodiversity conservation, climate change mitigation, sustainable land use and improving socio-economic livelihood. Little has been reported regarding the effects of socio-ecological determinants on the carbon sequestration potential of traditional agroforestry in South Africa, especially in the Vhembe Biosphere Reserve (VBR). The main objective was to quantify the tree carbon stock in the VBR traditional agroforestry landscapes along the distance levels, immediate, intermediate, and far distance from villages to the forest. The data were collected and analysed using Diversity indices, Important value index, Allometric equation, Anova, Generalised linear model and Pearson correlation. The results showed no statistically significant differences in total carbon stocks ($F= 0.888$, $p= 0.413$) between the distance levels, with the same amount of carbon stocks stored in the vegetation at all distance levels. When all socio-ecological determinants were considered together, elevation, density and basal areas were the significant predictors of carbon stock. This study concludes that maintaining and enhancing species diversity in traditional agroforestry landscapes can be an effective strategy to achieve the climate change mitigation goals provided this is finely balanced with the livelihoods needs of the local communities.

Mangrove forest food products as alternative ways for mangrove conservation in Muara Gembong, Bekasi Regency, Indonesia

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Mangrove forests provide diverse ecosystem services, yet, are subjected to anthropogenic threats. In the case of Indonesia, where mangroves are declining due to deforestation, the government has accelerated in promoting mangrove restoration program through the declaration of the national agenda on mangrove rehabilitation. One prominent approach being adapted by Indonesia is through community-based mangrove management, in which locals can be benefited. Among the benefits is through production of Non-Timber Forest Products (NTFP). Our case study presents NTFPs of mangroves in Muara Gembong, Bekasi Regency, West Java Province. The focus group discussion (FGD) revealed that NTFPs of mangroves can be used to promote mangrove conservation, however, strong commitment from the community and support from external organizations such as government and non-government agencies are needed. Results of the FGD further showed the huge potential of NTFPs to encourage more women to part take in mangrove conservation activities, which is currently dominated by men. Overall, there are still remaining challenges of bringing NTFPs for mangrove conservation in Indonesia such as branding and marketing of products. Thus, further understanding of utilizing NTFPs is needed to enhance the existing practices in Muara Gembong, and at the same time identifying potential stakeholders for collaboration.

Native plants-based basketry: a natural, cultural, and bioeconomic forest heritage in Chile

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Traditional basketry, made from different plant materials, is still produced by many people worldwide. In Chile, the temperate forest provides more than 15 plant species used in traditional weavings, mostly for the *mapuche* culture. This study aimed to systematize ecological, cultural, and economic information from three plant species and visualize the plant-based weaving practice as a heritage for conservation. A respectful and participatory method was conducted, considering the help of men and women involved in basketry in the *mapuche* culture. Aside from semi-structured interviews, several harvest stands in the forest were visited, as well as production workshops, and markets to gain first-hand knowledge of the materials and weaving processes. The study species were *Greigia sphacelata* (Bromeliaceae), *Boquila trifoliolata* (Lardizabalaceae) and *Luzuriaga polyphylla* (Alstroemeriaceae).

The main results indicate that the three species are an important natural-cultural heritage from forests and indigenous people for centuries. *G. sphacelata* is a perennial herbal plant growing in the forest understory. Its leaves are used to weave ropes, baskets, fish traps, and a bag as a storage container. The most important group of *mapuche-lafquenche* artisans is located in the Budi Lake Basin in the Araucanía region. *B. trifoliolata* is a common evergreen climber vine. Its flexible stems are used for basketry like baskets, decorative objects, and making ropes. The largest group of *lafquenche* artisans is located in Alepue, a coastal range in Los Ríos region. *L. polyphylla* is a hemiepiphytic climbing plant. Its particularly stable and elastic aerial roots are used by the *huilliche* of the Chiloé Archipelago in Los Lagos region, to make ropes, baskets, and other everyday objects. The three, are moderate light species, which are growing in treefall gaps, secondary forests, and old-growth forests. Although deforestation and private forest property attempt against obtaining weaving material, and traditional knowledge could be at risk, the demand for forest-based basketry is increasing. With the participation of the government, enterprises, and farmers, the weaving products have formed a development model of natural-cultural heritage from the forest, which is the basis for advancing toward a bioeconomy that incorporates basketry.

Social Forestry Capacity Development in Sub-Sahara Africa through Knowledge Co-Creation and Information Sharing

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Many communities in Sub-Saharan African (SSA) countries depend on natural resources for their livelihood and provision of ecosystem services. However, over utilization of forests and woodlands, and unsustainable agricultural practices continue to cause environmental degradation. Recurrent and emerging environmental challenges create a need for knowledge co-creation through comprehensive partnerships and capacity development. Social forestry was therefore identified as an approach that would motivate communities in Africa to invest in sustainable environmental management. To build capacity of stakeholders within SSA in Social forestry, Kenya Forestry Research Institute (KEFRI) in collaboration Japan International Cooperation Agency (JICA) implemented a five-week training course annually in Kenya under the Third Country Training Programme (TCTP). The Programme, which was implemented from 1995 to 2018 evolved in scope to address emerging challenges in Natural Resource Management (NRM) which included: low awareness and adoption of social forestry technologies, and climate change effects. The Programme targeted to train partners from governmental and non-governmental organizations involved in NRM activities. The training curriculum was developed by identifying training needs through; Training Needs Assessment (TNA) and continuous review by applying After Course Evaluation (ACE) feedback by participants. Interactive training methodology comprising of: presentations by various experts drawn from relevant institutions; country reports presentation by participants; group work; discussions; themed field visits to selected farmers or organizations sites; field report writing; and development of implementation action plan. Knowledge co-created through research and development by KEFRI and technical cooperation by JICA provided information for addressing emerging NRM challenges. Paper presentations and discussions informed on concepts and practical application of social forestry technologies. Field visits exposed participants to technologies with high adoptability, while Action Plan development built capacity of participants in activity planning and resource mobilization abilities. Participant's feedback through ACE tool gave important information that was used in identifying; gaps, lessons and emerging challenges; as well as modifying and improving course content to ensure relevance and positive impact of the training. Kenya, having similar environmental conditions with many SSA countries, offered a good learning ground by showcasing practices for addressing environmental degradation and climate change effects.

The Effects of Pollarding on Tree Structure in the Northern Zagros: A Photogrammetric UAV Assessment

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Pollarding is a traditional silvopastoral technique practiced in many parts of the world, including the northern Zagros mountain region in Iran, which is known as an ecologically and culturally significant semi-arid forest area. So far, the effect of pollarding on tree structure - specifically the relationship between Diameter at Breast Height (DBH) and Height (H) - has not been studied, although it is crucial for further analysis on the tree allometries across such fragile forest stands. We combined field inventories of DBH with H coordinates acquired from UAV flights to investigate DBH ~ H relationships. Results showed a linear relationship between UAV-extracted H and maximum DBH of pollarded trees, explaining 56% of the observed variation. More complex non-linear allometries did not significantly differ from the performance of the linear model. The model was consistent across oak species, although the pollarding stage had a significant effect on the DBH ~ H relationship. This research is important for biomass inventory across larger areas of northern Zagros, and for DBH estimations in stands of multi-stem coppice structure in other semi-arid ecosystems.

The influence of social capital on the poverty reduction of rangeland agropastoral communities in the Bamyan province, Afghanistan

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: This study investigates the contribution of social capital to the poverty alleviation of rangeland agropastoral communities that are based on agriculture and the rearing of livestock in the Bamyan province of Afghanistan. We collect data through a field survey from the randomly selected 186 households in three rangeland villages in the Bamyan Province, Afghanistan. The relationship between social capital and household poverty was analyzed using binary logistic regression and correlation analysis. Results of our case study show that social capital has a significant impact on alleviating the poverty of rangeland households in Afghanistan. To address the poverty issue of forest dependents, the local level strategy of community development programs should target rangeland communities to build up their social capital for supporting forest tenures and benefit sharing among marginalized people.

Traditional knowledge as the foundational element for a sustainable pathway to a NTFP-based bioeconomy

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Forest communities have a long history of gathering, producing, and using non-timber forest products through agroforestry practices. They have maintained and transferred traditional knowledge related to non-timber forest products through their networks from generation to generation. Recognizing the diverse values of non-timber forest products, traditional knowledge also gained attention as an important social asset. Focusing on the non-timber forest product industry, traditional knowledge can be identified as a strategic value for revitalizing the non-timber forest product industry. This study has systematically reviewed and analyzed the cases of non-timber forest products and traditional knowledge. It classified the types of using traditional knowledge in producing and consuming non-timber forest products. This research indicates the changes in the values of traditional knowledge in the non-timber forest product industry and the potential of the sustainable pathway to a non-timber forest products-based bioeconomy.

Utilization Status and Conservation Factors of Traditional Knowledge existing in Mountain Villages of Nepal

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: Traditional knowledge continues to be utilized in daily life in Asian developing countries, including mountain villages, although it is rapidly disappearing. In Nepal’s mountain villages, the threat to the preservation of the traditional knowledge is evident. This is primarily due to the shift from subsistence farming to commercialized agriculture driven by the introduction of the new crop varieties aimed at improving livelihoods, as well as the migration of the population from the mountain villages to the cities. However, there are also instances where traditional knowledge is employed to promote regional development through tourism and product innovation. Therefore, in Nepal's mountain villages, there is both a loss of traditional local resources due to changes in social structure, an increase in the utilization of these resources for regional development.

This study aims to elucidate the current status of local knowledge, specifically traditional agriculture practices in Nepal’s mountain villages. It seeks to understand why this knowledge has been preserved and how it is used. The study was conducted in two villages, Bihunkot in Baglung district and Thaprek in Tanahun district. Both of which are considered to have different level of traditional knowledge preservation. In both village, traditional agricultural knowledge related to crops like, wheat, rice, finger millet and orange are maintained.

To ensure the sustainable development of mountain villages and preserve traditional knowledge, we propose the following measures: (1) establishing a comprehensive creation of the conservation system that involves various stakeholders many actors from inside and outside the region. (2) Promoting innovative approaches to utilize local knowledge, such as conservation initiatives with tourism.

Xate leaves (Chamaedorea spp.) and Ramón seeds (Brosimum alicastrum Sw.), a bioeconomy example in the Maya Biosphere Reserve, Guatemala

T2.32 Traditional knowledge, geographical indications and non-timber forest products towards a bioeconomy in community-based agroforestry systems

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Abstract: This work contains a systematization of experiences that show the social construction of a territory: the Community Forest Concessions (CFCs) of the Maya Biosphere Reserve (MBR). Xate leaves (*Chamaedorea spp.*) and Ramón seeds (*Brosimum alicastrum* Sw.) are two non-timber forest products (NTFPs) which have given rise to one of the most successful cases in the world in terms of forest management, halting deforestation and promoting a sustainable and inclusive development for the local communities. These two NTFPs form very important value chains. Both assets have contributed at different stages of the concession process to adding value to the forest, conserving and even restoring it. The community organization at different levels has been able to effectively market the products, find strategic allies, with whom more and more value has been added to the primary products extracted from the forest. A clear and ambitious plan on the part of the CFCs has led to national and international partners investing in the technification and certification of the processes, with which they have been able to enter in more and better markets. Through ethnographic methods and participatory techniques, we found that the CFCs are enterprises with an efficient organization of their finances, with which they have invested in a better knowledge of their management units and therefore in well-structured plans to maintain the supply of products for which there is a stable market, and in the promotion of forest goods without buyers yet. The main outcome of this work are 18 technical and socio-economic bases that made possible the success of these two value chains. The most important bases are local leaderships, cultural identity with the product and land tenure certainty. On the other hand we got the strengths, weaknesses, opportunities and threats with the participation of all the actors who play a role in the chain, trying not to obtain partial views. Finally, the future perspectives allow us to have clear ideas of the key factors to unlock an effective bioeconomy for common goods that, when regulated by a strong community base, are a clear example of effective governance.

T2.33 Transitioning to a Bioeconomy with Non-Timber Forest Products: Leadership from Latin America and the Caribbean

Bases for the sustainable management of a wild species for fruit production: a study case of non-timber forest products in Colombia

T2.33 Transitioning to a Bioeconomy with Non-Timber Forest Products: Leadership from Latin America and the Caribbean

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Abstract: The sustainable use of non-timber forest products in natural forests is a promising activity. It generates additional income for peasant communities inhabiting forests and promotes conservation because it increases the value and importance of forests and reduces their conversion to other uses. However, to promote this activity in Colombia, technical and traditional information about biology, ecology, and management is necessary for correct decision-making related to the sustainable harvest rate.

Considering the necessary information and the parties involved in the correct management of the agraz species (*Vaccinium meridionale*) that inhabits the Colombian high Andean forests, we coordinated a work team with local peasant communities to obtain information about its biology, ecology, and harvesting process to evaluate its current state and plan its sustainable use. We established 41 10x10 m plots on different land covers of high Andean forests in Ráquira (Boyacá, Colombia) to evaluate population abundance and structure of the agraz. All shrubs were tagged, and the diameter of the thickest stem (cm), total height (m), crown diameter, and harvest characteristics were measured. Three local peasants monitored fruit harvest (g) on ten shrubs during February-April 2020, and the harvesting activity was characterized through semi-structured interviews and participant observation among the work team. 1071 individuals were found in the 41 plots and were grouped into 554 seedlings, 393 juveniles, and 124 adults. The average abundance of agraz species was 0.26 shrubs/m^2 (2600 shrubs/ha), and it was similar on different land covers. The population structure followed a negative exponential distribution indicating a relatively stable population unaffected by harvest activity. Each shrub produced, on average, 1.04 kg of fruits, and 0.66 kg (61.1%) were manually harvested by local peasants without causing damage or death to the shrub. The peasant harvesters were organized under the associative model to commercialize their product, which is highly attractive in the market, but their activity lacked promotion and cultural and traditional recognition. Our results suggest that this activity is highly sustainable due to its ecological, economic, and social potential, but it requires the support and promotion of local institutions. Finally, we recommended keeping harvest rates of fruits under 70%.

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

Assessing ecosystem services of tropical forests and peatlands based on multiple restoration project scenarios

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Many international organizations have tried to launch proper conservation and restoration projects, as tropical forests and peatlands in Indonesia are considered to be an important carbon sink globally. Thus, understanding the potential impact of conservation and restoration is required before the decision-making process. In this study, we assessed the value of ecosystem services with the possible restoration project scenarios including remaining current status, expanding agricultural area, and ecosystem restoration. First off, we focused on the assessment at the provincial level within Sumatra Selatan and Jambi provinces. We analyzed land cover changes from 1992 to 2020 and developed various scenarios based on the historical trends of land cover changes. Ecosystem services of carbon storage, habitat quality, water yield, and crop yield were spatially analyzed with InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) model and other assessment approaches. Second, we narrowed down the assessment scope at the local level to design more suitable projects for the local communities. A systematic review, scenario building based on assessing ecosystem services of forests and peatlands status at the local level was conducted in Perigi, Sumatra Selatan and the Londerang, Jambi for in-depth ecosystem services assessment. Each scenario showed different benefits and pitfalls. However, the ecosystem restoration scenario had the strongest benefits on carbon storage and habitat quality. Some anthropogenic pressures, such as agricultural land conversion and urban expansion, negatively affected ecosystem services in numerous scenarios. Through the quantification of scenarios, we found that proper conservation and restoration approaches could be identified in the project development phases. This study may contribute to the future ecosystem services-oriented project management for a wise climate change adaptation and securing global carbon sinks.

Assessment of peat forests disturbances in the Central Congo Basin

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: The Cuvette Centrale in Africa encompasses one of the largest tropical peatland complexes. However, information is yet limited on peatland disturbances in the Cuvette Centrale. We assessed the peat forest disturbances and their drivers occurring between 2019 and 2021 in the Cuvette Centrale, spanning the Republic of Congo (ROC) and the Democratic Republic of Congo (DRC). We utilized Sentinel-1 based RADD alert forest disturbances data for analyzing the spatial-temporal distribution of these disturbances. Further, we employed the monthly planet data from NICFI platforms to investigate the drivers behind these disturbances. We sampled 2000 RADD alert events randomly over the Cuvette Centrale for assessing drivers. The alert events were defined as the individual connected patches in the alert dataset. The preliminary findings revealed that the most of peat forest disturbances occurred in the DRC, with high-intensity disturbances concentrated in the northwest region of the DRC and along the Congo River across both in the DRC and ROC. Between 2019 and 2021, we identified five primary drivers: agriculture, logging, floods, road development, and small settlements. Agriculture was the most prevalent driver, accounting for over 80% of the sampled events, followed by logging at approximately 10%. More than 90% of the agricultural events were located in the DRC. Although logging was also more prevalent in DRC, ROC had a relatively large share of these events (~ 25%). The majority of the drivers corresponded to small events (< 0.5 ha in size). For two prominent drivers - agriculture and logging, around two-thirds and three-quarters of events, respectively, were small. Although large agriculture events comprised only 3% of all events, they cover around 20% area of all events. A great majority of large events (~95%) were agriculture. Notably, agricultural events exhibited a seasonal pattern, occurring more frequently during dry periods. Whereas logging events showed no such pattern indicating they occur regardless of the time of the year. These insights from our study provide valuable information regarding peat forest disturbances and their drivers that would serve as a useful reference for scientists and policymakers involved in the protection and restoration of peat forests in the Cuvette Centrale.

Composition and Structure of Secondary Peat Swamp Forest and Comparative Analysis on Individual Tree Detection using LiDAR for Carbon Measurement

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Although there are few existed applications of airborne laser scanning or LiDAR in terms of the composition and structure of the vegetation in peat swamp forests, the costs of LiDAR are decreasing. With the help of the packages lidR and lidaRtRee from the Rstudio package for Forest carbon monitoring measurement, we try to assess the vegetation and compare it to the lidar tree detection. In six different plots with varying sizes (two 25x25-meter plots, three with five 20x20-meter subplots, and one 100x100-meter plot), we measured the tree composition and DBH above 10 cm. We discovered that *Tetractomia tetrandra* (Rutaceae), *Campnosperma coriaceum* (Anacardiaceae), and *Diospyros areolata* (Ebenaceae) dominate the largest plot, with percentages of Important Value Index of 51.69%, 34.99%, and 22.98%, respectively. The density of each life stage reveals the structure of the vegetation. We discovered 95 individuals per 100 m2 (or 9500 individuals/ha) in seedlings, 459 individuals per 125 m2 (or 6496 individuals/ha) in saplings, and 676 individuals/ha in poles and trees. The method we used for tree detection makes use of the Canopy Height Model (CHM) raster (lidaRtRee) and point cloud base data (li2012, Local Maxima Function (lmf), and fixed window size). We acquire the number of trees in each plot after applying lidR and lidaRtRee to the cloud-based data, which results in the lowest RMSE and MAPE in the 20cm up DBH using LMF Function and lidaRtRee (RMSE=16.79, MAPE= 0.31 and RMSE= 18.75, MAPE=0.38 respectively). We analyze the lidar dataset's crown area and height for the carbon measurement, and then use allometry to determine each tree's diameter. We presumed that each tree's carbon fraction and wood density would be the same. Utilizing the lmf function and employing height information to calculate DBH yields the carbon measurement result that is most accurate to the actual data.

Fires and diversity of tropical peat swamp forests

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Tropical peat swamp forests contain diverse plant communities that support many endangered flora and fauna species. These forests are increasingly threatened by disturbances such as drainage, logging, and subsequent fire, yet little is known about tree species recovery from these threats.

Tree species richness and diversity were measured in peat swamp forests of Central Borneo regenerating naturally after fires from 139 chronosequence plots. Our findings indicated that two to three decades after fire, similar levels of richness and diversity to relatively undisturbed reference forest are reached within sites.

However, when averaged across landscapes our modelling shows that fires of average frequency of 50 years, or even 100 years, can substantially suppress tree species richness and diversity. Thus, even rare fires can reduce the species richness and diversity of tropical peat swamp forests.

Two groups of tree species drove the difference in richness and diversity between disturbed and reference forests: ‘decreasers’, occupying recently burnt forest and declining with fire exclusion, and ‘increasers’, that were only present in less disturbed forests and absent or rare in recently burnt forests. The decreasers were more common than the increasers.

We conclude that peat swamp forests can recover adequately from fires through natural regeneration, and it is possible that artificial planting may speed up this process. Where possible, excluding fire from tropical peat forests will help to maintain the diversity of these threatened ecosystems and promote their recovery.

How to measure Peatland restoration success: Principles, Criteria and Indicators for assessing outcomes

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Preserving and restoring peatlands is critical for climate change mitigation, ecosystem health and community development in many parts of the world. But existing pressures lead to peatlands drainage and conversion to other land uses. These degraded peatlands can be targeted for restoration to reduce the loss of carbon and other important ecological services natural/undrained peatlands provide. Successful restoration of degraded tropical peatlands in Indonesia could mean significant progress towards country’s commitment for reducing emissions and meeting its NDC pledges while ensuring sustainable and equitable growth.

Indonesian peatland restoration follows strategies that target future sustainable land use and management, social justice, livelihoods and governance. These strategies underpin restoration activities such as re-wetting, re-vegetation, revitalization of communities and avoidance of peat fires. But effective long-term restoration must be carefully monitored to adapt designs, strategies and management approaches that can meet specified goals.

Availability of tested standard tools to assess the outcomes of restored ecosystems can help practitioners to determine successes and failures of peatland restoration. Availability of simple, easy to recognize, measurable indicators for monitoring progress over time can be very helpful. We developed robust, reliable, and practical set of criteria and indicators (C and I) to help assess progress and outcomes of peatland restoration through collaboration of relevant govt. institutions, expert consultations, and field verification at actual restoration sites. Using four broad categories (Bio-physical, Economic, Social and Governance) to determine restoration progress, we found identified C and I provide a reliable practical tool that can be used by mangers. This C and I approach can be applied to assess restoration progress at a site over time or to compare different restoration sites. In this presentation, we will share the set of C and I for peatland restoration monitoring and discuss the nuances of our iterative process to formulate these.

Landowners' perceptions of carbon farming and livelihoods' improvement in South Sumatra, Indonesia based on adoption of agrosilvofishery models

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Tropical peatlands in Indonesia have substantial potential to store vast amounts of carbon yet experience extensive degradation caused by conversion for agriculture, logging and mining. This has led to the pursuit of solutions for restoration of peat-ecosystem functions. One of the potential solutions, agroforestry, was recommended as a best practice for peatland restoration by the Indonesian Ministry of Environment and Forestry. This study examined the socio-economic factors influencing adoption of agrosilvofishery practices, which could support both peatland restoration and livelihoods' improvement. A structured questionnaire survey was conducted with landowners and farmers in Central Kalimantan to assess their perceptions of, and willingness to adopt, agrosilvofishery models for carbon farming and livelihoods' improvement. Findings implied that family roles, education level and experience with tree-based livelihoods significantly affected the willingness of farmers to adopt agrosilvofishery practices. On the one hand, some agricultural characteristics and lack of knowledge of technical aspects negatively influenced their adoption. On the other, the perception of potential improved well-being from the agrosilvofishery practices positively influenced farmers' willingness to adopt. This study highlighted the importance of effective communication strategies and teaching methods to address perceived barriers. We anticipate that the adoption of the agrosilvofishery practices by the farmers could be positively increased through strategies that targeted decision-makers, promoted local connections, simplified technical information, emphasized well-being benefits and addressed productivity concerns.

Net CO2-eq Emissions from Rewetted Peatlands and Other Land-Uses

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: There is no silver bullet to reduce greenhouse gas emissions from degraded peat swamp forests (PSF). Rewetting has been proposed to be one of the candidates, but at the same time, CH_4 emissions will be increased. While revegetating the degraded landscape with agroforestry practice, the choice and combination of species are poorly understood. Our five years long measurements (2019-2023) using Ultraportable Greenhouse Gas Analyzer (UGGA) showed that the annual average of total CO_2 emission in the rewetted peat swamp forest (PSF) site was the lowest (10.04 ± 0.4 CO_2 Mg $ha^{-1}ar^{-1}$) followed by undrained PSF (11.3 ± 0.7 CO_2 Mg $ha^{-1}yr^{-1}$) and agroforestry practices on peatland (22.1 ± 1.5 CO_2 Mg $ha^{-1}yr^{-1}$). On the contrary, the annual average of CH_4 emissions was the highest in the undrained site (168.9 ± 6.8 CH_4 Kg $ha^{-1}yr^{-1}$) compared to the rewetted site (74.2 ± 11.4 CH_4 kg $ha^{-1}year^{-1}$), and the agroforestry site (4.9 ± 1.3 CH_4 kg $ha^{-1}yr^{-1}$). Therefore, the net CO_2-eq emissions from re-wetted, undrained, and agroforestry on peatland were 11.9 ± 0.5 Mg $ha^{-1}yr^{-1}$, 15.5 ± 0.7 Mg $ha^{-1}yr^{-1}$, and 22.2 ± 1.5 Mg $ha^{-1}yr^{-1}$ respectively. While it is not entirely new, agroforestry in peatland ecosystems offers opportunities to explore appropriate practices regarding the choice of species from the perspectives of climate and local community agenda.

Keywords: *Peat restoration*; *heterotrophic respiration; GHGs emissions; nature-based solution; peatland agroforestry.*

Net greenhouse gas balance of fibre wood plantation on peat in Indonesia

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Tropical peatlands are important sinks of atmospheric carbon dioxide (CO_2), having accumulated at least 75 gigatonnes of carbon over millennia. However, they are threatened by changes in climate and land-use - particularly those that affect the groundwater level dynamics. When groundwater levels fall below the peat surface, stored carbon decomposes, resulting in CO_2 emissions. Yet, estimates of greenhouse-gas (GHG) exchanges in tropical peatlands have been highly variable owing to a dearth of high-quality contemporary measurements. Given the role of tropical peatlands as nature-based mitigators of climate change, having accurate estimates of contemporary GHG exchanges and their relationship with controlling factors, can improve our understanding of their global climate impact, and support responsible peatland management and optimization of emissions mitigation measures.

Between mid-2016 and mid-2022, we measured GHG exchange in intact forest, degraded forest and *Acacia crassicarpa* plantation (17–22 years after initial plantation establishment) in the same peat landscape of Sumatra, Indonesia. We used the eddy-covariance technique to measure the net exchanges of CO_2 and methane between the ecosystem and atmosphere, and the chamber to measure soil nitrous oxide exchanges. The plantation's CO_2 emissions is calculated as the sum of net ecosystem CO_2 exchange and harvested wood carbon export, conservatively assuming that all harvested wood carbon will be returned to the atmosphere as CO_2. To our knowledge, this study is the first investigation of GHGs in any peatland-based fibre-wood plantation to cover a full plantation-rotation period and to encompass all major GHG flux terms.

The CO_2 emissions from the *Acacia* over a full plantation rotation were half of the current Intergovernmental Panel on Climate Change Tier 1 emission factor for this land-use type. The

conversion of intact forest to *Acacia* plantation results in a long-term net increase in GHG emissions equivalent to 18 tonnes of CO_2 per hectare per year, which is smaller than the increase associated with the degradation of intact forest. Our results confirm that conserving, restoring and sustainably managing peatlands will be important for meeting nationally determined contributions (as defined by the Paris climate agreement) to limit global warming to 1.5 °C above pre-industrial levels.

Peat greenhouse gas emission factors: Concepts, applicability, and research needs

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Over millennia, peatlands have slowly accumulated vast amounts of carbon (C) and nitrogen (N) in their soil. When disturbed through degradation, drainage, fire or land-use conversion, C and N dynamics in peat soils are profoundly altered as are their greenhouse gas (GHG) emission rates. Quantifying accurately peat GHG flux and flux changes resulting from disturbances is essential for appraising the potential of peatlands to mitigate climate change or the high burden caused to atmospheric GHG concentrations, depending on their fate. In its wetland supplement, the IPCC has developed guidelines for reporting national peat GHG emissions/removals and defined general concepts for developing peat GHG emission factors. While peat-rich countries are employing these guidelines and moving towards higher Tier reporting, some scientific barriers remain to fully and accurately report peat GHG emission/removals, especially in the tropics. Furthermore, anthropogenic activities for which default Tier 1 emission factors are available remain incomplete hampering some countries to report their peatlands emissions. This talk will navigate the wetland supplement, present existing default peat emission factors for the tropics, and explain conceptual basis for producing them. It will showcase two countries of the tropics, Indonesia and Peru, which contrast in terms of anthropogenic activity and emission rates and will highlight critical research gaps.

PEAT REWETTING IMPACT ASSESSMENT USING HYDROLOGICAL MODELING IN CENTRAL KALIMANTAN

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Indonesia is one of the world's largest tropical peatland-covered countries with 14.43 million hectares or more than 30% of the global tropical peat area. Peatlands are fragile ecosystems with essential biological and hydrological functions. However, peatland in Indonesia has been managed extensively for agriculture, especially commercial plantations and other urban needs. This land-use change is relatively well advanced where most of the peatland area has been deforested, drained, and converted. This has resulted in not only losses of biodiversity but also emissions of greenhouse gases and loss of carbon from peatland that consequently contribute to climate change. The Government of Indonesia committed to restoring degraded peatlands by implementing rewetting infrastructures with the main objective to raise the peat water table depth (WTD) and keep the peat moist to prevent fires. However, there are still gaps in identifying the impact of rewetting activities. Hydrology modeling seems to be an attractive option for solving this issue and is widely used to predict peatland hydrological processes. This study aims to assess the peat rewetting impact using a deterministic and physically-based model (MIKE SHE) coupled with a fully dynamic and one-dimensional modeling system (MIKE Hydro River). The study was conducted in Kahayan-Sebangau Peat Hydrological Unit (PHU) in Central Kalimantan Province. There were three main steps in conducting the study, including data collection and analysis, followed by hydrological model setup and calibration, and scenario analysis. The model was calibrated by matching simulated peat WTD against observed WTD obtained from the government-owned peatland water monitoring system (SIPALAGA). The calibrated hydrological model then be used to assess the restoration impact. Scenario analysis was performed to simulate the water table rise by comparing peat WTD in degraded peatlands with and without rewetting infrastructures implementation. Results showed that the peat WTD can be predicted using the hydrological model with RMSE, R^2, and NSE range values by 0.15 – 0.37, 0.62 – 0.82, and 0.64 – 0.91, respectively. This study also indicates that the impact of rewetting activities can be scientifically quantified by using hydrological modeling with the percentage of the rewetted area compared to the PHU’s total area was around 3.9 – 6.9%.

Peatland Rewetting in Oil Palm Plantations Reduces CO2 but no impact on CH4 fluxes: A Case Study from West Kalimantan

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Decades after peatland drainage and destruction mostly into oil palm and acacia plantations, at present, there is a growing interest in peatland rewetting for restoring the hydrological system in degraded peatlands in Indonesia. A recent study reported that peatland rewetting is expected to contribute up to 13% of Indonesia's total mitigation potential from natural climate solutions analysis. However, Indonesia's 2nd Forest Reference Emission Level submitted to UNFCCC does not consider peatland rewetting for historical greenhouse gas emissions calculation, causing a loss of the opportunity to claim emission reductions from this critical effort. To our knowledge, no comprehensive assessment has been performed to understand the overall dynamic patterns of annual CO_2 and CH_4 fluxes simultaneously from rewetted Indonesia's peatlands, particularly from oil palm plantations. In this study, our primary objective was to investigate the impacts of peatland rewetting by constructing canal-blocking structures on CO_2 and CH_4 fluxes along with associated soil physicochemical properties and relevant environmental variables. We biweekly monitored carbon fluxes using LiCOR LI-7810 Trace Gas Analyzer from the two sites of secondary forests and oil palm plantations, respectively, located in Mempawah and Kubu Raya regencies, West Kalimantan, Indonesia. Soil carbon fluxes measurements were carried out for over a year, from January to December 2022 until now. ANOVA or Kruskal Wallis test, followed by Tukey's honestly significant difference test, was used to analyze differences in carbon fluxes, environmental variables, and soil physicochemical properties between the treatments. Our results show that peatland rewetting significantly lowered soil CO_2 emissions, and no clear impact of peatland rewetting on CH_4 fluxes in oil palm plantations. Rewetting drained peatlands in oil palm plantations can significantly reduce a third (34%) of heterotrophic emissions and a fifth (20%) of total respiration. Even though the water table depth in secondary forests is deeper than in rewetted oil palm plantations, total soil respiration is still higher in oil palm plantations. This results indicates that rewetting will not reach the reference emission in the secondary forest without revegetation. We translate our results into policy action by prioritizing peat conservation first and then restoration to optimizing climate change mitigation actions.

Peatlands of Amazonia: current knowledge, distribution and threats

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Substantial peat deposits are known to exist across Amazonia. The peatlands of the Pastaza-Marañon Foreland Basin in Northern Peru have received increasing attention from researchers in the past decade, however, peatlands found in other Amazonian countries remain relatively unstudied. Most notably the peatlands of Brazil and Venezuela, which are predicted to cover 260,000 km^2 and 39,000 km^2, respectively. Peatlands are known to be the most carbon dense terrestrial ecosystem, once soil carbon is accounted for, and due to the remote and inaccessible location of many Amazonian peatlands most of them are believed to remain relatively intact. Thus, these ecosystems are likely to harbour large stocks of carbon and unique biodiversity, which need to be protected. We undertook a systematic review to determine the current state of knowledge of Amazonian peatlands. We then used remotely sensed and spatial datasets to assess the potential threats to peatlands from fire, deforestation, oil and gas exploration and hydroelectric dam construction, based on our current understanding of peatland distribution. Our systematic review found 169 studies published about Amazonian peatlands, with 70% of studies published in the last 10 years. Most research was done in Peru (48% of all studies), followed by Venezuela (15%) and Brazil (12%). Analysis of peatland threats found that between 2015 and 2020, 13,400 km^2 of peatlands were burnt and 4000 km^2 of forested peatlands were cleared of tree cover. The greatest threat to peatlands from dam construction and oil and gas production were in Western Amazonia where several large dams are operational and large areas of land are either being exploited or have the potential for oil & gas exploitation. Our analysis highlights that whist research into Amazonian peatlands has increased in the past decade, there are still large gaps in our knowledge and as some areas are under threats of different forms. This analysis allows us to highlight key areas where further research is needed and make recommendations for policy makers, to help improve our knowledge of this important ecosystem.

Peatlands, People and Policy: Analysing the Relationship between Amazonian Indigenous Knowledge and State-Led Conservation in the Imiria Lake, Peru

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Tropical peatlands play a key role in climate change mitigation due to their remarkable carbon density. While the importance of Southeast Asian peatlands as significant carbon reservoirs has been widely acknowledged, the recognition of tropical peatlands in the Amazon region has emerged more recently. Peru ranks second in South America in terms of peatland area, with an estimated area of 75,614 km2, according to the latest Global Peatlands Assessment. Thanks to landscape-scale efforts, the ecological knowledge of Peruvian peatlands has improved in the last two decades. However, there still exists a considerable knowledge gap regarding their boundaries, condition, ecological processes, as well as their social and cultural importance, utilization, management, and preservation by local communities.

This poses a latent problem, potentially excluding marginalized communities from participating in conservation and development programs and decision-making processes. To address this issue, the present research endeavours to bridge the knowledge gap by investigating the relationships with peatlands in the Regional Conservation Area of Irimia, situated in Ucayali, Peru. The study will specifically concentrate on comprehending the socio-economic uses, cultural significance and the relationship with state-led conservation strategies implemented in the area.

Firstly, it aims to identify both direct and indirect socio-economic activities derived from the natural resources of peatlands. Secondly, it strives to explore the cultural values and practices associated with peatlands among both indigenous and non-indigenous communities. Lastly, it identifies the conservation approaches implemented in the area. The findings will contribute to a comprehensive understanding of peatland ecosystems, their role in socioeconomic development, and their potential for effective conservation initiatives. Additionally, this research aims to ensure inclusive decision-making processes that actively involve marginalized communities in peatland conservation and development efforts. Ultimately, this study aims to bridge the existing knowledge gap and promote sustainable management practices that support biodiversity and the well-being of local communities.

Refinement of tropical peat greenhouse gas emission factors with process-based modeling

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Oil palm plantations on peat and associated drainage generate sizeable GHG emissions. Current IPCC default emission factors (EF) for oil palm on organic soil are based on a very limited number of observations from young plantations, thereby resulting in large uncertainties in emissions estimates. To explore the potential of process-based modeling to refine oil palm peat CO_2 and N_2O EFs, we simulated peat GHG emissions and biogeophysical variables over 30 years in plantations of Central Kalimantan, Indonesia. The DNDC model simulated well the magnitude of C inputs (litterfall and root mortality) and dynamics of annual heterotrophic respiration and peat decomposition N_2O fluxes. The modeled peat onsite CO_2-C EF was lower than the IPCC default (11 Mg C ha^{-1} yr^{-1}) and decreased from 7.7 ± 0.4 Mg C ha^{-1} yr^{-1} in the first decade to 3.0 ± 0.2 and 1.8 ± 0.3 Mg C ha^{-1} yr^{-1} in the second and third decades of the rotation. The modeled N_2O-N EF from peat decomposition was higher than the IPCC default (1.2 kg N ha^{-1} yr^{-1}) and increased from 3.5 ± 0.3 kg N ha^{-1} yr^{-1} in the first decade to 4.7- 4.6 ± 0.5 kg N ha^{-1} yr^{-1} in the following ones. Modeled fertilizer-induced N_2O emissions were minimal and much less than 1.6% of N inputs recommended by the IPCC in wet climates regardless of soil type. Temporal variations in EFs were strongly linked to soil C:N ratio and soil mineral N content for CO_2 and fertilizer-induced N_2O emissions, and to precipitation, water table level and soil NH_4^+ content for peat decomposition N_2O emissions. These results suggest that current IPCC EFs for oil palm on organic soil could over-estimate peat onsite CO_2 emissions and underestimate peat decomposition N_2O emissions and that temporal variation in emissions should be considered for further improvement of EFs.

THE CORRELATION BETWEEN PEAT WATER TABLE DEPTH AND SATELLITE-BASED SOIL MOISTURE DATA IN BURNAI-SIBUMBUNG PEAT HYDROLOGICAL UNIT

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Peat fires have been recognized as an enormous problem in recent decades and caused peatland degradation in Indonesia. Excessive drainage caused the depletion of water table depth and soil moisture on the surface and makes peat soil highly flammable. In 2015, the country suffered one of its worst burning seasons in years. Large parts of the country's peatland area were burned out of control impacting the health, education, and livelihoods of millions of Indonesians living in the areas with the worst burning. The peat fire event also caused carbon released into the atmosphere. The Indonesian Government is carried out rewetting activities in the form of canal blocking and canal back-filling implementation to prevent excessive water drainage from the peatlands and keep the peatland's water table at a specific elevation to control soil moisture and avoid peat fires. The peat water table is known to correlate with surface peat soil moisture through capillary movements. Therefore, it is important to understand peat soil moisture's characteristics and its relationship with peat water table depth. This study aims to assess the relationship between peat water table depth and soil moisture data. Another objective is to formulate an empirical equation to estimate peat water table depth based on peat soil moisture data. Peat water table depth data were obtained by conducting field observation and were measured by installing piezometers equipped with peat water level loggers. Meanwhile, soil moisture data were gained from the System for Earth Observation Data Access, Processing, and Analysis for Land Monitoring (SEPAL), a big-data platform for forest and land monitoring developed by the Food and Agriculture Organization of the United Nations (FAO). The relationship between soil moisture and water table depth was analyzed using correlation analysis. Results showed that soil moisture correlates sufficiently against peat water table depth data with the coefficient determination (R^2) value ranging between 0.64-0.81. With this finding, it is expected that monitoring activities of peat wetness in preventing fires can be carried out more efficiently using satellite-based soil moisture data since it can be used to predict the peat water table depth in the field.

The SWAMP Program: Past, Present, and Looking into the Future

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Carbon-rich tropical peatlands are important in climate change adaptation and mitigation strategies and provide numerous ecosystem services such as storm protection, nursery areas for fish, habitat for rare species, long-term storage of carbon, and food, fiber, and fuel for humans. Because of their importance we developed the Sustainable Wetlands Adaptation and Mitigation Program (SWAMP) to assist countries with their accounting and conservation of tropical wetlands. SWAMP is a collaborative effort between the Center for International Forestry Research and the USDA Forest Service through support from the US Agency for International Development. The goal of SWAMP is to provide policy makers and natural resource professionals with credible information and training to make sound decisions regarding the role of tropical wetlands in climate change adaptation and mitigation strategies. For the past 10+ years SWAMP has developed a global network of peatland studies in the tropics, led training and numerous other capacity building activities, and has led to both in-country and global polices on peatland conservation and their role in climate change. We anticipate that more research on mapping of peatlands and better greenhouse gas emission accounting across an array of tropical peatlands and disturbance gradients to further help in country and international reporting requirements.

Understanding the central Congo Peatlands to enhance their protection

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: In 2017 the extent of the central Congo peatlands was first mapped, bringing them to world attention. This mapping showed that the central Congo peatlands are the world's largest tropical peatland complex. This newly described system is formed of hardwood-dominated tropical peat swamp forest and palm-dominated tropical peat swamp forest. Spanning millions of hectares, it is wildlife rich, home to elephants, lowland gorillas and bonobos. In 2018 the Brazzaville Declaration was signed to protect the newly mapped peatlands, and protect the ~30 billion tonnes of carbon stored in the peat. Here we provide a synthetic update on our understanding of the genesis, development, contemporary functioning and potential futures of the peatlands from the large interdisciplinary project called CongoPeat, a collaboration between universities in the Democratic Republic of the Congo and the Republic of the Congo and the UK. We show that back in 2017 we underestimated the extent of the peatlands, and have substantially reduced the uncertainty on how much carbon is stored in the peat; understood that the peatlands are much older than we initially thought; their developmental history is now documented from one site for the first time; and we show that they are much closer to a tipping point than we anticipated, where they may begin to release the stored carbon. We also include some discussion of how people utilise the peatlands. This knowledge can help craft plans to better protect the peatlands while increasing the incomes and improving the lives and livelihoods of the people who live adjacent to and utilise the peatlands.

Using JULES to Model the Congo Peatlands

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: The Cuvette Centrale swamp forest around the Congo river has the most extensive peatland complex in the tropics, but due to its remoteness the peat was only recently discovered. The international project CongoPeat, which includes scientists from the Republic of the Congo and the Democratic Republic of the Congo and works with the local people of the Cuvette Centrale, is studying the peatlands to determine how they formed and the possible threats since it is vital that the peat is preserved. While the peatlands are at least 20,000 years old the peat is thin compared to other tropical peatlands of similar age. The JULES land surface model has been used to simulate the development of the peatlands, by means of a reconstruction of the past annual rainfall and with other climate variables from a long paleo run of the HadCM3 global climate model. The results support the hypothesis that a long period of reduced rainfall a few thousand years ago lead to a large loss of peat and recreate the age-depth profiles of the peat in measured soil cores. This confirms that a constantly high water table is needed to keep decomposition of the peat to a minimum and hence preserve the peatlands. JULES was then run with future climate projections from five global climate models to simulate how the peatlands could change up to 2100. In most projections the increased temperatures lead to increased evapotranspiration, lower water tables and increased decomposition of peat. So that in most cases peat is lost overall, particularly when rainfall is also reduced further lowering the water tables. In-spite of an increased atmospheric CO_2 concentration affecting the vegetation by increasing the productivity and litterfall while reducing the amount of transpiration. The risk to the peatland Carbon is greater at higher levels of global warming.

What do we need to know to create effective, science based national peatland policy?

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: This work creates a guide illustrating what information is needed to develop science-based national policy regarding peatlands. It is designed to be useful for government agencies, and their partners in NGOs, as well as academic scientists wishing to produce information that can contribute to peatland protection. Peatlands store enough carbon to double the current atmospheric content if released, meaning their protection, management, and restoration represent a key opportunity to mitigate, or avoid further contributions to, climate change. Maintenance and restoration of peatlands for climate mitigation frequently requires trade-offs with land uses important to human livelihoods such as grazing or drainage for agriculture, pasture, or plantation. Despite their economic incentives, such uses lead to carbon loss through degradation, increased decomposition, and increased risk of fire. Many nations have policies for wetland or forest management but limited policy regarding peatlands specifically. This may be due to a lack of available information on peatland extent and typology or lack of awareness of the importance of policy specific to peatlands. Here, we aim to identify foundational knowledge and best practices for development of tools such as emissions factors as well as policy impacting peatland management such as nationally determined contributions to climate change mitigation.

Where are the knowledge gaps in Brazilian scientific perceptions of peatlands tropical forests?

T2.34 Tropical Peatland Forest Conservation and Sustainability: Challenges and Opportunities

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Abstract: Peat is characterised by its high soil carbon content, and the categorization of soils is a subject of ongoing debate in Brazil, leading to uncertainty in the classification used by official soil maps. In Brazil, the number of research organisations dedicated to studying peatlands is limited, resulting in significant gaps in information that impede scientific progress in this field. Our objective is to identify existing gaps in the knowledge about peatlands and strategize pathways to fulfill those gaps through planned research. A survey will be conducted using the expert-based participatory technique, with the inclusion of peatlands, wetlands specialists, and soil researchers from Brazil as participants. Therefore, the involvement of peatlands, wetlands specialists, and soil researchers from Brazil as components in this participatory technique is crucial. By bringing together experts from various disciplines, we can bridge the existing knowledge gaps and enhance scientific progress in understanding the ecological services provided by peatlands in Brazil. This collaborative approach will not only help identify areas of little knowledge among academics but also prioritize research efforts to ensure the sustainable management and conservation. Furthermore, the involvement of Brazilian specialists and soil researchers is essential as they possess invaluable local knowledge and expertise that can contribute to a comprehensive understanding of peatland ecosystems. Their participation will also ensure that the research addresses specific challenges and opportunities unique to Brazil's peatlands. By fostering a collaborative approach, we can encourage knowledge exchange, foster innovation, and ultimately drive effective conservation strategies that benefit both the environment and local communities dependent on this ecosystem.

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

Assessing the performance of new bio-based surface gel treatment in outdoor applications

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: Many species of wood that are suitable for use in construction need to be pressure impregnated before they can be used. Pressure impregnation requires expensive equipment, specialised and trained operators, very restrictive environmental and human protection measures, and regulatory authorisations to operate for sawmills, all of which are becoming increasingly difficult for wood industry these days. R&D Laboratories from Groupe Berkem has developped a new generation of bio-based gel treatments that can protect impregnable and refractory wood with a good diffusion and penetration rate in the treated material. Effective treatment with this new technology requires good understanding of how the preservatives diffuse through wood. This paper reports on the penetration kinetics and retentions obtained over six weeks with three types of wood (pine sapwood, spruce and douglas fir) treated at ambient temperature on all sides at fixed application rate with fine spray of a bio-based insecticide and fungicide gel. For each type of wood, three samples measuring 140 to 180 cm x 15 cm x 5 cm were prepared and then conditonned at 20°C and 65% RH for 7 days before application of the test products with the Unisprayer equipment . For each sample, a piece was weighed and removed by lateral cutting 25 cm from one end after 1, 2, 3, 4 and 6 weeks. These pieces were used for diffusion analysis by visual inspection (on the freshly cut cross-section) and by analysis and for biological testings (termites, basidiomycetes). The chemical diffusion of the test products was determined using wood shavings taken to a thickness of 2 mm beyond the first and second centimetres, on both sides. Satisfactory penetration of gel treatments and good resistance to termites and wood rots appeared within a few weeks.
The data suggests that this new bio-gel-based surface treatment could protect all types of wood worldwide with a simple that does not demand specialized equipment, low-cost device and in a minimum of time using local resources and labour, thus replacing the copper solutions used by vacuum pressure.

Boron preservative treatment of minor species for extended carbon storage in the built environment

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: Early research in New Zealand with boron indicated that the dip/diffusion method for green timber would give adequate preservative retention in sapwood for most species and in some cases would also penetrate heartwood. This was widely accepted by the industry as being the case for species other than radiata pine including those regarded as resistant to preservative treatment such as Douglas-fir (*Pseudotsuga menziesii*). Some further work was done on treatment of radiata pine (*Pinus radiata*) and Douglas-fir framing using boron-glycol formulations and low-pressure systems but the treatment of species other than radiata pine with boron using current commercial processes has not been widely tested.

The inclusion of alternative species to radiata pine, predominantly exotic species, in the building code (NZS 3602) raises questions as to whether they require preservative treatment and, if so, whether they can be adequately treated using current industry processes.

This work summarises research conducted at Scion on the performance of boron preservatives applied to species other than radiata and similar plantation-grown pines. The boron-treated wood is resistant to fungal decay and can extend the service life and subsequently carbon storage for a longer period in the built environment.

Challenges and Possibilities for Protection of Non-Durable Wood. A retrospective and prospective analysis.

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: Non-sustainable wood needs protection! The challenge today is how to ensure its sustainability in the face of the impact of climate change and with safer, sustainable alternatives to chemical pesticides that will have no impact on human health or the environment. A retrospective and prospective analysis is presented here. All wood preservatives used in timber construction are made from synthetic fossil pesticides, whereas wood is a bio-based material. Growing interest in ecology, protecting the planet and protecting human health have for many years stimulated research aimed at replacing these fossil preservatives with safer sustainable products. A review of the literature and experimental analyses have been carried out from 1950 until today to illustrate the evolution in the formulation of wood preservatives. New treatments and technologies based on Bio-based solutions and Plant polyphenolic extracts from Berkem Biosolutions are also described.

Comparative in-ground durability, termite and decay resistance of some Malaysian and exotic wood species related to biological hazard class situations

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: Classifying overall biological resistance of a wood species for terrestrial end-use product applications depends on the intended biological hazard class of exposure involving specific types of wood biodeteriogents. A comprehensive Malaysian study compares the biological durability of 51 native renown/commercial or lesser-used native medium and light hardwoods of Sarawak and Peninsular Malaysia including 3 imported woods Burmese teak, Australian radiata pine and Oregon Douglas Fir, against subterranean termites (*Coptotermes curvignathus*), white rot (*Pycnoporus sanguineus*), soft rot (mixed microflora of unsterile soil with *Chaetomium globosum*) decay and in-ground natural durability. This work partly aims to also understand the overall durability of the lesser-used (secondary) hardwoods of mainly Sarawak. Percent mass loss data for each wood decay type, visual termite attack ratings and stake test visual ratings form the basis for assigning a 4-point relative biological resistance classification (Class 1 to 4) for each evaluation type on each wood species. Overall durability class for each wood being the worst resistance class among the 4 assessed attack types are shown among the H2 to H5 biological hazard classes of wood in service. Light hardwoods are generally of low overall durability class in all hazard classes while mixed durability classes exist among the medium hardwoods among hazard classes. Species with Class 3-4 overall durability predominate, requiring wood protection strategies for target biological hazard class situations. Hence assigning overall wood durability of each wood species to each hazard class situation as such would augment the end-use guidelines for these untreated (or else treated) native light and medium Malaysian woods.

Decay resistance, color properties, and polyphenol contents in heartwood of the third-generation Acacia mangium grown in Indonesia

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: The tree breeding of *Acacia mangium* in Indonesia has entered in the third-generation. In this study, the mass loss by a white-rot fungus *(Trametes versicolor*) and a brown-rot fungus *(Fomitopsis palustris*), color properties, and polyphenol contents were investigated for inner heartwood and outer heartwood of total 60 trees (20 half-sib families originated from four different provenances by three individuals, 10-year-old) of the third-generation *A. mangium* planted in Wonogiri, Central Java. The mean values of Y, x, y, the amounts of extractive contents, total phenol contents, and total flavanols contents in all 60 trees were 24.14, 0.38, 0.37, 5.7%, 28.29 µg/mg, and 6.76 µg/mg, respectively. Among measured properties, high family-mean heritability was found in outer heartwood color of Y (0.636) and y (0.509), while those of total phenol contents and total flavanol contents family-mean heritability were relatively low (0.087–0.112). The Y value was significantly negatively correlated with total flavanol contents at the family levels. These results indicate that the wood color with lower Y value in heartwood could produce progenies with higher total flavanol contents in heartwood.

Drying and heat treatment of large cross-section timbers for enhancing durability and performing long-term carbon storage role

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract:
After World War II and the Korean War, the Republic of Korea, which started afforestation on bare mountains, has succeeded in reforestation by diligently cultivating and preserving, and is currently showing the world's fastest growing rate of tree accumulation.

Due to the short history of afforestation, the Korean wood industry, which uses domestic wood as raw material, had until recently been forced to use small diameter trees harvested from young forests. Most of them have been crushed and supplied to the thermal power energy industry, paper industry, or board industry in the form of chips, and used as wood products serving as short-term carbon storage.

However, since the proportion of old forests in Korea's forests is higher than that of young forests, it is time to harvest timber from these old forests and establish and implement measures to use them.

The large logs harvested by felling the large standing trees that make up this old forest provide an opportunity to create high value-added, large-scale building members with large cross-sections in an eco-friendly way without gluing or connecting processes, rather than chips or small square materials.

In order for such large-sized timber, which is expensively supplied as a building material for important large-scale buildings such as palaces, religious facilities, exhibition halls, and public centers, to serve as carbon storage for a very long time, artificially well-controlled drying processes and the development of durability enhancement processes are required.

In this study, a defect-free kiln drying process and a chemical-free heat treatment process were developed and applied so that large cross-section timbers can faithfully play their role as long-term carbon storage.

The processes were optimized by analyzing the moisture content distribution and temperature distribution inside the wood during the drying and heat treatment processes. Sectional temperature and humidity inside the wood were remotely monitored in real time by electronic sensors, and the

humidity signal was converted to moisture content by the equilibrium sorption equation.

By considering the directional moisture movement and heat transfer within the wood, internal moisture and temperature gradients are well controlled, reducing process time and energy consumption while maintaining quality.

Examining Heartwood Formation in European Oak Trees

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: Oak trees are widely planted across Europe due to their resilience against climate change and the production of high-quality, long-lasting timber.

The heartwood, the most valuable part of the tree, is the inner and darker portion of a tree trunk that is distinguished by its durability and strength. It is the non-living core that forms as a result of the gradual accumulation of secondary metabolites called extractives.

These compounds can include resins, tannins, lignins, and provide natural protection against biotic and abiotic attacks. While extractives play a crucial role in protecting the tree's structure, the process of heartwood formation and the genes influencing its quality are still under investigation.

We collected 5 mm diameter oak (*Quercus robur*) wood cores from 300 trees representing 100 maternal sources. To investigate heartwood formation, we employed widefield fluorescence microscopy and Confocal Laser Scanning Microscopy (CLSM) to track the distribution of extractives within the heartwood from the micron to the sub-micron scale. Hydrophilic and hydrophobic extractives were extracted using Soxhlet extraction techniques. Then, steady-state fluorescence spectroscopy was utilized to profile the extractives. Additionally, tree genotyping was performed to explore genetic factors associated with heartwood formation. Variation in fluorescence properties among half-siblings and unrelated oak trees was observed. Additionally, fluorescence profiles of the inner heartwood in the pith and newly formed heartwood were analyzed.

The observed fluorescence variations provide insights into the chemical composition of the heartwood, particularly the behavior and role of tannins. These findings contribute to understanding heartwood formation and heartwood aging and the role of extractives in this process, and how much of the variation between trees can be ascribed to genetic variation.

Import commodities: tracing and monitoring the sustainability effects of the EU wood supply

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: In the view of reducing dependency on non-renewable materials and fossil fuels, bioeconomy has emerged as an option towards a more sustainable economy in different national and international strategies. Sustainability impacts of a bioeconomic system occur along the complete value chain, most severe impacts, however, are associated with biomass production. Therefore, an appropriate assessment of a sustainable bioeconomy has to consider all impacts along the value chain independent of where they occur. The European pulp demand has been partly met by imports of highly export-oriented pulp factories in South America. This development has been accompanied by an increasing attention on the sustainability of supply chains in the policy arena, specifically considering import commodities. A novel hybrid physical accounting model combined with a material flow approach were used to track wood origin and sustainability impacts of the most important wood suppliers for the European production and consumption in 2018. Around one third of the wood fibre input present in finish paper products and in the form of pulp consumed in Europe was imported. The main origins were Brazil, the United States and Uruguay. As a case study we used the example of Uruguay, which is a key player regarding the production of roundwood and pulp for Europe and is expected to become the second world largest producer of short-fiber pulp in the next years. The assessment of sustainability impacts in Uruguay covers environmental sustainability impacts including land use change (grassland afforestation) and GHG emissions, socio-economic impacts including employment and value-added generation. The results reveal synergies and trade-offs between socio-economic and environmental impacts as well as a disproportional share of impacts in the EU. This approach captures the impacts along the different steps of the supply chain and identify which sustainability impacts are connected to the production of wood and in which steps of the supply chain there are opportunities to improve sustainability. We highlight the need to consider not only territorial sustainability impacts in isolation but from a global perspective. We strongly support the importance to assess impacts in the three dimensions of sustainability in order to have a holistic overview.

Induction of heartwood formation in young sandalwood (Santalum album)

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: Sandal (*Santalum album* L.), commonly known as East Indian Sandalwood, is the most famous valuable tree species belonging to the Santalaceae family and is highly valued for its fragrant heartwood, which has various applications in the perfumery, religion, cosmetic, wood carving, and pharmacological industries. Sandal was first introduced into China in 1962 and has exhibited encouraging growth performance in most planting areas in the recent decades in southern China. However, very few sandal plantations formed aromatic heartwood naturally when they were young, and the quality of essential oil distilled from those young sandals was quite poor. Therefore, induction of fragrant heartwood formation in young sandal plantations has great importance in large-scale cultivation practices because the values of sandal at harvest will depend largely on the volume and the quality of heartwood. Several studies have shown that some chemical elicitors, such as $CuSO_4$, ethrel, paraquat, benzyladenine and H_2O_2 can induce heartwood formation in young sandals. However, all these chemical elicitors were used as liquid solutions, and the induced heartwood was generally formed around the injection holes; moreover, the amount was quite low. In this study, induction of heartwood formation in 6-year-old sandal by treatment with carbon dioxide, ethylene, nitrogen, and wounding was investigated. All treatments induced fragrant heartwood formation upward and downward from the drill hole. The amount of heartwood formed above and below the drill hole depended on the treatment in the order nitrogen>carbon dioxide>ethylene>wounding, whereas the radial extension proportion was, in order, nitrogen>carbon dioxide>ethylene=wounding. Based on the chemical analysis (GC–MS) and evaluation of the essential oil quality and heartwood properties, heartwood induced by carbon dioxide showed the maximum similarities to naturally formed heartwood, which included the same color, similar chemical composition, reasonable oil content, and quality essential oil, whereas ethylene, nitrogen, and wounding treatment showed fewer similarities to natural heartwood. The results suggest that carbon dioxide is a promising candidate gas elicitor for inducing heartwood formation in young sandal.

Termite resistance of weathered Malaysian hardwood kempas envelope-treated with new generation biobased/vegetal extracts in water-borne solutions

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: In fulfilling the need to develop fit-for-purpose, cost-effective, and environmentally-friendly wood protecting chemicals for permanent wood protection, equatorial tropical termite field tests were conducted on Malaysian hardwood kempas (*Koompassia malaccensis*) test blocks envelope-treated by brushed-on with either a proprietary formulation containing cypermethrin boostered with vegetal extracts (SYNERKEM® technology), or dip-treated for 3 minutes with either a permethrin-based micro-emulsion proprietary formulation or cypermethrin-based micro-emulsion formulation. Conditioned enveloped-treated woods were then artificially weathered to simulate aboveground indoor exposure conditions (H2 hazard class: lab evaporative ageing of treated wood) or aboveground outdoor conditions (H3: lab leaching plus evaporative ageing of treated wood) before subjected to a unique (Wong 2005) Malaysian/Australian H2-hazard class (aboveground and not exposed to wetting) field termite test against *Coptotermes curvignathus* at a humid near peatswamp forest site in Kota Samarahan, Malaysia. After 6 months test, untreated kempas was clearly termite-susceptible (both high percent and absolute (=milligram) wood mass losses, poor termite visual ratings) unlike those treated with the SYNERKEM® technology biocide and 2 pyrethroid-biobased micro-emulsion solutions, reference permethrin-based LOSP (3 minutes dipping) and reference CCA-treated radiata pine, all these displaying total hardwood protection (negligible mass losses, highest termite rating). These three novel wood preservatives are clearly suitable for "permanent" protection of up to H3-weathered envelope-treated hardwood against *Coptotermes* termites under both aboveground indoor (H2-hazard class) and aboveground outdoor (H3-hazard class) situations for contructed wood in service where only minimal quantities and adequate dosages of biobased preservatives are desired in an increasingly environmentally-conscious society in favour of green building constructions.

The durability of preservative-treated Glulam as a timber bridge component

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: For the last 70 years, New Zealand Forest Research Institute (now Scion) has had an in-service testing programme for wooden products, including timber bridges. Based on the conditions of those bridges, history, and evidence, the following conclusions can be drawn;

- Preservative-treated radiata pine laminated bridge beams have been in service for 60 years in and have shown few problems with durability associated with decay, particularly if glue laminated beams are not in direct contact with soil.
- Preservative treatment of laminated components after assembly with heavy oil-based or creosote preservatives is not available in New Zealand. However, treatment with water-based CCA formulations before lamination has been just as successful as treatment with oil-based formulations after lamination.
- While we have little experience with treatment of Douglas-fir laminated products in New Zealand, the refractory nature of Douglas-fir and its poor natural durability indicates that it is less suitable for laminated bridge beams than CCA-treated radiata pine.
- For exterior components, the use and type of glue are critical. Only resorcinol-formaldehyde (RF) or phenol-formaldehyde (PF) glues have shown long-term durability in Scion test bridges. More recent PU (Polyurethane) and PUR (polyurethane reactive) glues have not been included in long-term exposure trials at Scion although anecdotal overseas data indicates that they may be a suitable replacement for RF and PF glues.
- Evidence from service testing indicates that the use of film-forming surface coatings to protect glue laminated components have some benefits in extending the service life providing coatings are well maintained.
- Design and maintenance are the key elements of timber bridge durability. If glue laminated beams are not in direct contact with soil and decaying vegetation, the service life of the elements can be extended. Laminated beams that are on the exterior of the structure and fully exposed to weather, particularly where the upper edge is exposed, are likely to deteriorate more rapidly than those which are partly protected by decking.

Unlocking innovation: novel durability assessment techniques paving the way for preservative-free wood protection methods.

T2.35 Wood durability and wood protection strategies for long-term carbon storage of wood products

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Abstract: In order for future cities to become more sustainable and serve as carbon sinks, the wood volume used in buildings needs to substantially increase. However, wood(-engineered) products are (to some extent) biodegradable when used in applications with fungal decay risk. There is need for sustainable wood protection methods that can be applied on a large scale. Wood protection against fungal decay used to focus on durable wood species, often from tropical regions, or non-durable wood species treated with wood preservatives. However, preservatives should ideally be replaced by techniques with a reduced environmental impact. Extending service life of wooden elements through other means than preservative treatment have gained attention, most of which evolve around moisture control, such as wood modification and protection by design.

Current methods for assessing durability leave little room for assessing the impact of improved moisture dynamics or the structural design of a wood product, due the small size and large end grain to surface ratio of the tested wood samples. Here, we present a novel X-ray CT scanning set-up and analysis pipeline for assessing the influence of material structure on degradation progress under laboratory conditions. The influence of anatomical features, such as the vessel orientation and the number of growth rings, as well as the impact of modified barrier layers on wood degradation patterns is demonstrated. In addition, a floating test was performed to derive the influence of additives, manufacturing process and material structure on the liquid water absorption and desorption behavior of wood-based panels and wood-fibre insulation materials. Hydrophobic properties achieved by thermal treatment or hydrophobic additives significantly decreased water absorption rates. However, the manufacturing process (wet or dry) had a decisive influence on the absorption rates and could overrule the addition of hydrophobic substances. Water was less easily released from oriented strand board and plywood due to the material structure, which enhances the risk of water entrapment in practice.
Through combination of assessment methods we aim to unlock innovation potential, especially with regards to engineered wood products, as there are many opportunities to modify material structure, incorporate barrier layers and integrate moisture control functionalities.

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

A design-based view of species richness estimation with applications to forest surveys

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: For the first time, the estimation of species richness is approached from a design-based perspective. In this framework, the properties of estimators are derived from the schemes actually adopted for sampling ecological communities, without any unrealistic assumption about sampling and communities widely exploited in model-based approaches. Probabilistic sampling of species is considered, and the widely applied estimators automatized in the SPADE software are considered in a design-based setting. A simulation study performed on two real communities of trees highlights the massive presence of negative bias due to loss of rare species that invariably affects the SPADE estimators. Then, a data integration is attempted in which the lists of rare species usually compiled by purposive surveys are exploited and richness estimation is performed on the residual community of those species not included in the purposive lists. The Chao & Lee (1992, doi: 10.1080/01621459.1992.10475194) estimator is adopted for estimating the residual richness and a bootstrap mean squared error estimator is applied.
The strategy has been empirically checked by the same simulation study adopted for checking SPADE estimators, achieving much better and encouraging results. The proposal is applied to the estimation of the richness of plant species in chestnut forests of Sabatini Mountains (Central Italy).

A European platform of forest multi-taxon biodiversity and stand structure data

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Forestry implementation significantly impacts forest biodiversity. Despite the promotion of Sustainable Forest Management (SFM) in Europe, sustainability assessments hardly account for direct biodiversity indicators accounting for multiple taxonomic groups. Indeed, multi-taxon biodiversity sampling and analysis requires significant funding, time, and a broad range of expertise and competences.

The challenges of multi-taxonomic field sampling, including exhaustive species censuses across single- or multiple sites are being increasingly addressed at the local or regional scales to assess the effects of forest structure and management on the diversity of multiple taxonomic groups.

Here we present an effort to: i) gather and map the existing information on forest multi-taxon biodiversity associated with stand structure and management in Europe; ii) identify knowledge gaps for forest biodiversity research; and iii) discuss the research potential associated with multi-taxon biodiversity data.

We established a research network focused on multi-taxon biodiversity, stand structure and management data of European forests; and fitted species records, standing trees, lying deadwood, and sampling unit metadata from 34 local datasets.

Suitable information was available for 3,591 sampling units, each surveyed for on average 4.6 taxonomic groups. Standing tree diameters, tree height deadwood and tree-related microhabitats were sampled in respectively 2,889; 2,356; 2,309 and 1,388 sampling units. Sampling unit metadata includes spatial coordinates, and compositional and management descriptors.

Available data cover all the 14 European forest compositional categories but are unevenly distributed among them, with European beech forests being over-represented as compared to thermophilous and boreal forests.

Overall, the available information has the potential to inform the development of conservation and SFM strategies for European forests by supporting: (i) methodological harmonization and coordinated monitoring; (ii) the definition and testing of SFM indicators and thresholds; (iii) data-

driven assessment of the effects of environmental and management drivers on multi-taxon forest biological and functional diversity, (iv) multi-scale forest monitoring integrating *in-situ* and remotely sensed information.

A simple measure of habitat heterogeneity is a good proxy of species of conservation concern

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Biodiversity assessment is a fundamental part of sustainable forestry and biodiversity conservation. Nevertheless, measuring biodiversity is far from simple and remains a challenge for practitioners who must make management decisions and report the national state of biodiversity at the EU-level. We tested if habitat heterogeneity or a set of habitat amount measures could predict biodiversity in Swedish boreal forests. We used 77 mature coniferous forest stands (2ha each) varying from structurally simple production forests to woodland key habitats, to evaluate the relationship between habitat heterogeneity, habitat amount and richness and abundance of species of conservation concern (SoCC) belonging to fungi, bryophytes, lichens and vascular plants. As the most important result, we found stand-level habitat heterogeneity to be the best proxy to explain the richness of SoCC, but when only red-listed species were included, volume of dead trees (deadwood) and age of the oldest tree proved to be more precise proxies. Habitat heterogeneity score was most often the best predictor of the number of SoCC among the different organisms groups. Also deadwood proved to be an important characteristic predicting the number of species, emphasizing its essential role in the mitigation of biodiversity loss in boreal forest systems. Finally, we calculated threshold values for deadwood volume and habitat heterogeneity score depicting the level above which the number of red-listed species is significantly higher, and found this value to be higher in the southern region (22.4 m3 ha−1 deadwood and a habitat heterogeneity score value of 17) than in the north (20.0 m3 ha−1 and 16). These values can be used as guidance when identifying coniferous forests with high enough qualities to support red-listed species. The more intensively managed southern region revealed an alarming species loss; despite the similar habitat availability, the average number of SoCC was only half of the richness and one fourth of the abundance in the north.

We conclude that habitat heterogeneity can be used as a reliable proxy for the number of species of conservation concern, but it must not be used to prioritize conservation between geographical regions.

Added Value and Limits of Citizen-Science Approaches supported by Artificial Intelligence to Monitor Ecological Forest Conditions

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: AI (Artificial Intelligence) approaches are already being used for species recognition in images to identify individual plant species, especially trees. To monitor the ecological status of forests, it is necessary to extend and improve AI-based species and structure recognition on forest images of image data from different sources. Image data is partly collected via citizen science approaches to improve coverage and resource utilization. Specifically, the usability of citizen science generated images for AI image recognition provides a likely fruitful pathway. Here, it is necessary to examine whether citizen science-supported recording of parameters of the ecological condition of forest habitats can usefully complement traditional monitoring.

This contribution will explore the quality of citizen science provided images to monitor the ecological status of different forests in Saxony-Anhalt (Germany). These will cover amongst others floodplain forests in conservation areas as well as intensively managed low mountain range forests with severe calamities. In collaboration with outdoor navigation and exploration app providers, we will explore the suitability of citizen-science based imagery sources to monitor the ecological status of forests. The collaboration with the Outdoor app providers will likely increase the spatial and temporal coverage of images from citizens in the target regions. We will explore different approaches to classify and predict e.g. forest development phases, conservation status and forest health supported by AI image recognition. The application will be tested for nature conservation relevant spaces (e.g. riparian forests) and use intensities for recreation (e.g. urban forest, biosphere reserve).

Approximating the Complexity of Biodiversity in Tropical Forest Ecosystems

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Tropical forest ecosystems are complex and diverse, making it difficult and costly to exhaustively identify all the species present at different spatial scales. These forests may be home to rare, endemic or poorly known species, making it difficult to estimate their diversity. In addition, data collection methods are costly, time-consuming and difficult to standardise, making it difficult to obtain complete and representative data on biodiversity.

To overcome these difficulties, it is important to develop forest biodiversity indicators as proxies, such as species assemblages. In this study, we propose to identify and characterise natural tropical forest ecosystems at different scales (from in situ to national level in Costa Rica) using a network analysis of species spatial distribution patterns. This method allows to approximate the biodiversity of these ecosystems from the species networks obtained, and to understand the structure and dynamics of ecological assemblages by highlighting the relationships between different species. We used global databases, as well as national and local forest and botanical inventories containing about 80,000 occurrences. We are working on Costa Rica, divided into twenty ecoregions that follow a climatic, edaphic and topographic gradient. It is one of the leaders in biodiversity conservation, with 54% of the country's surface area protected, but it is also a fragmented country under pressure from agriculture.

The methodology of this study consists of three steps: (i) Species network analysis, based on biogeographical bipartite network, to approximate the biodiversity and characterise the structure of forest ecosystems representative at different scales, up to the Costa Rican ecoregions; (ii) Botanical verification of the results to validate the modelled species networks; (iii) Study of the interactions between species in each network and their functional traits to understand why they characterise these forest ecosystems.

The species assemblages obtained in this study can be considered as indicator species for the forest ecosystems they define. They can then be included in multi-species distribution models to approximate the distribution of biodiversity in these forest ecosystems, in order to better assess and monitor the biodiversity of tropical forests.

Arthropod species biodiversity in forest inventories: challenges and implications for regional conservation

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Despite global efforts to identify and classify species to improve biodiversity baselines, there still remains large knowledge shortfalls that affect our understanding of the functioning of ecosystems and the design of effective conservation practices. Using the results of the first ongoing large-scale biodiversity inventory for Chile which has already recorded more than 2,000 species and discovered 103 new species of arthropods, in this presentation we explore the role of forest inventories, and discuss taxonomy (Linnean) and distribution (Wallacean) shortfalls that preclude large-scale knowledge of biodiversity of vegetated lands for one of the lesser studied groups in the world -the arthropods. Moreover, we explored spatial indicators of richness, abundance and new species with structural and compositional flora. Linnean shortfalls are mainly associated to the lack of funding of monitoring and inventory initiatives and the bias towards most charismatic or umbrella species, which in turn trigger effects on the experts' availability, recruitment of taxonomists in research centers, journal impact factors, and the as well as the availability of scientific collections of type specimens. Instead, Wallacean shortfalls are related to accessibility to remote areas, and the spatial and temporal resolution of sampling efforts. Based on our results and literature review, we discussed the findings and also proposed a novel conceptual framework aimed to reduce data gaps and support biodiversity conservation policies, particularly in developing countries. The framework has three main components: (1) the ecosystems, their species, and the threats; (2) the key elements for a biodiversity assessment strategy, and (3) an action plan for protecting biodiversity.

Assessing the precise dietary spectrum of the white-bellied pangolin in Benin using DNA metabarcoding

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Accurate data on dietary profiles is a perquisite to understanding how wild animals, especially cryptic and elusive species such as pangolins, make use of their habitats, in order to design effective conservation plans. Using 23 rejected fecal samples and 29 gut content samples, this preliminary molecular analyses of the feeding ecology of white-bellied pangolin assesses the efficacy of a DNA metabarcoding approach to performing dietary analyses. This extends to the dietary profile and the variation in dietary preference of the focal species following a latitudinal gradient and across varied habitats. Our study demonstrated the potential of DNA metabarcoding in assessing the diet of the white-bellied pangolin when combined with the capture, amplification, sequencing and detection of prey species DNA barcodes within the feacal/stomach content samples. We observed a relatively wide prey spectrum for the white-bellied pangolin compared to that previously recorded through visual observation using radio-tracking. The detected prey species included *Camponotus acvapimensis, Camponotus conradti, Camponotus (Myrmotrema) carbo, Camponotus (Tanaemyrmex) maculatus, Cataulacus guineensis, Lepisiota capensis, Oecophylla longinoda, Pheidole megacephala, Platythyrea conradti, Polyrhachis militaris, Dorylus nigricans,* with eight other photo-based ant species *(2 Ppheidole sp. and 6 Crematogaster sp.)* and eight termite species. *Pheidole sp., Camponotus sp.* and *Cremastogaster sp.* were the genera with the most abundant reads. DNA metabarcoding analyses confirmed the prey selective behaviour previously observed for pangolin species using traditional methods. The alpha diversity of detected prey items varied significantly ($p<0.05$) following sample types, habitats and regions, with our limited data suggesting that individual sex, and a variation to sample pre-processing did not. Bray-Curtis dissimilarity index showed highly significant dietary profile dissimilarities ($p<0.001$) between southern and central regions. Our study demonstrated that DNA metarbarcoding is a promising tool for disentangling the diet intake of pangolins, providing substantial knowledge on their feeding ecology which can inform management decisions for the conservation of the species in its wild habitat. It supports the need for further investigations with a balanced number of sample types to clearly elucidate the dietary profile variation following the latitudinal gradient and ecosystems.

Assessing the utility of eDNA to characterize diversity and dynamics of tropical forests

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Characterizing community composition is the bedrock of community ecology and monitoring biodiversity dynamics. There has been increasing excitement for the prospect of using environmental DNA (eDNA) over the past decade. The proposed advantages of this nascent approach are that it is rapid, highly scalable, and does not require the taxonomic expertise that traditional community surveys demand. Consequently, there has been an exponential rise in publications using eDNA approaches to infer biodiversity patterns and processes. However, eDNA can be physically transported after original deposition and may derive not only from host organisms (the so-called 'ecology of eDNA'), thus potentially be uninformative. The overarching objective of this study is to assess the utility of soil eDNA to infer composition of tropical forest plant communities by comparing eDNA data with traditional censuses of extant communities in Puerto Rico.

We have produced a reference library of P6-loop sequences for all tree species present in the 16 ha Luquillo Forest Dynamics Plot (LFDP). We compared several methodological approaches for sampling and generating eDNA data, such as sample storage and isolation of DNA. Then, we assessed the correspondence between biodiversity estimates based on eDNA data and those based on field observations by leveraging the long-term and spatially explicit data on forest composition and dynamics from the LFDP.

The resulting dataset will be available open-access online and uploaded to appropriate online genetic database. The plant meta barcode derived from soil eDNA in the LFDP will be published online and freely available as well.

Biodiversity reporting trends in the Finnish forest industry

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Globally, biodiversity in forests is declining. The main drivers are forest loss and the conversion of natural forests into managed forests. Forest industry companies use sustainability reports to inform the stakeholders on their sustainability impacts and actions. Biodiversity actions are part of companies' sustainability work. The aim of our research was to study how the Finnish forest industry companies report on biodiversity in their sustainability reports. We focused on the changes and trends of the reporting in 1998-2021. We analysed sustainability reports of the three largest Finnish forest industry companies (Stora Enso, UPM and Metsä Board) with qualitative content analysis. First, we read the reports and identified sections that focus on biodiversity. Second, we coded these sections with themes to describe the content of biodiversity reporting in each section. We identified three trends in our data. First, the amount of biodiversity reporting increased over time. The early reports have only a few mentions and a few sentences on biodiversity, whereas the late reports have entire sections devoted to it. Second, the content of the reporting varies over time with four main themes (risks, values, aims and actions). In the first reports, loss of biodiversity was seen as a major environmental risk, whereas in the last reports, it was seen as a financial risk. The first reports emphasized the "value talk": Protecting biodiversity was seen as important for the companies and the whole industry. From quite early on, companies started to set biodiversity aims, but the early reports failed to describe both indicators and actions to meet the aims. Biodiversity actions were reported steadily during the analysis period but with varying emphasis. The first reports highlighted the role of legislation and certification. The last reports focused on companies' own actions in their own forests and other actions towards biodiversity aims. As a conclusion, the Finnish forest industry companies have a long tradition in biodiversity reporting. The early reports have only a few mentions on biodiversity while the last reports are rather comprehensive descriptions with biodiversity aims, indicators and actions.

Deadwood structure as a potential indicator of boreal forest biodiversity.

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: We are experiencing a biodiversity crisis. To address biodiversity loss, we need to safeguard high quality sites. Detailed inventories of multiple taxa are preferred for differentiating site quality for biodiversity, but they are difficult, time consuming, and expensive. Finding cheaper and easier ways of recognizing high biodiversity, like assessing easily inventoried physical attributes of sites, is crucial for effective prioritisation of areas to conserve. The links between different taxa diversity and their physical environment is very complex, though, so we must ensure that surveyed structural qualities do indicate high biodiversity value.

We aim to address the question of which forest structural features are the most appropriate for indicating high biodiversity sites in boreal forest. We take a multi-taxon, whole-assemblage, approach, where we ask how epiphytic moss, lichen, polypore, and carabid beetle diversity in Finland and Sweden relate to key structural components including deadwood volume, deadwood diversity, and living tree density and species composition. The relationship between biodiversity and forest structural features is context specific, so we assess relationships across three important forest management types: set-asides (not intensively managed for forest production), retention patches (areas left unharvested within clearcuts stands) and young forests (harvested 25-30 years ago).

We have 240 plots split evenly between Sweden and Finland and the three forest management types. Species experts surveyed all species of target taxa within 10-20m radius plots during 2021 and 2022. We also collected data on potential indicators of biodiversity at these sites, including deadwood decay stage, type and volume, and living tree size, and density. We used Bayesian hierarchical models to regress different aspects of biodiversity against potential site structural indicators.

The suitability of different potential indicators may vary between taxa and forest management type. Deadwood quality should relate more closely to polypores than other taxa, likely because these species live directly on deadwood whereas deadwood may be a less direct indicator of general high quality sites for other taxonomic groups. Our results will suggest appropriate biodiversity indicators in boreal forests, and elucidate some of the complex relationships between species habitat requirements, biodiversity, and management decisions in commercial forestry landscapes.

Drivers of acoustic diversity in managed forests

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Forests harbour large parts of terrestrial biodiversity; at the same time, large parts of the global forests are actively used. Management decisions require reliable information on their consequences for biodiversity. The possibility to observe large temporal and spatial scales make eco-acoustic techniques attractive to forest biodiversity monitoring. Acoustic indices, just like well-known diversity indices (e.g. Shannon diversity), are related to the species richness of vocal taxa, and their vocal activity, but are also driven by abiotic and anthropogenic sound sources. To make sense of large-scale monitoring programs, we need to understand the effects of forest management, structure and regional land use on these.

We collected acoustic data throughout several months and regions in managed forests in Germany. Through structural equation modelling, we tested if bird richness versus bird abundance explained acoustic diversity better and how forest management and forest structure as well as landscape parameters such as distance to forest edge and distance to nearest road mediated this relation.

Results: Forest management negatively affected acoustic diversity, which was directly driven by bird abundance, rather than bird species richness. Although, bird abundance and bird richness were strongly correlated on our study sites. Forest management directly affected bird richness as well as abundance of birds. Forest structural complexity had no direct effect on bird species richness and abundance but on bird composition.

Despite certain limitations, the presented results suggest that acoustic diversity indices add a powerful metric to other biodiversity measures when detecting biodiversity changes in managed forests.

Forest biodiversity monitoring: the example of bird survey in Finland and their responses to forest habitat at multiple scales

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Long-term biodiversity and forest habitat surveys are scarce and, therefore, precious to study the land management-biodiversity relationship. The response of biodiversity to habitat heterogeneity measured at a fine resolution and on a landscape scale, is not yet fully understood due to the lack of such habitat mapping on a global scale. In Finland, standardized national bird transects and forest structure data have been available since 2009. We explore how these data can be used to better understand the forest habitat-biodiversity relationship at various scales and indirectly inform about the effects of management practices. We mobilize 566 bird transects, multisource national forest inventory, and disturbance map to investigate the bird assemblage responses to landscape habitat heterogeneity (i.e., composition and configuration). We characterize landscapes based on land cover and forest habitat diversity (e.g., mean patch size, area of old and broadleaf forests, age class diversity, etc.). We also implement habitat functional heterogeneity indices such as richness, evenness, and the Rao's Q index, based on vegetation structural features (i.e., tree canopy closure, mean tree diameter, age, height, vegetation type). We study bird assemblages through species compositions but also included functional traits and specialization indices. We hypothesize a positive response of taxonomic and functional biodiversity to both landscape compositional and configurational habitat heterogeneities. We expect to see a greater effect of compositional heterogeneity, particularly when studied through the functional prism of vegetation structure. We also expect that the amounts of old forests (i.e., ≥ 100 years) and broadleaf forests (i.e., ≥ 80 % of broadleaf tree volume) have a positive effect on forest bird species, since they are scarce in Finnish landscapes but associated with multiple key (micro-)habitats (e.g., deadwood, large old trees, tree-related microhabitats). In contrast, we expect mixed effects of disturbances: quadratic effect of the natural disturbance severity to the overall bird community, while amount of clear-cuts in landscape should have negative effects on forest bird species but could also represents opportunities for open-land species.

Forest reserves of Hungary: monitoring of the natural processes

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Designation of forest reserves have been started in the late 80's in Hungary. The majority of the first-growth forests disappeared by the end of the world wars, therefore most of the reserves were managed stands of forests. The Forest Reserve Monitoring Program (FRMP) involved 63 forests with a total cover of 3635.7 hectares that represented a wide scale of natural woodlands of Hungary. FRMP set sights on the investigation of undisturbed natural processes, focused mainly on the understory, stand structure and soil composition. Sampling points were assigned in the intersections of 50x50 m grid in each forest. Survey of herb layer was performed in 6 m radius circles, using 30 pieces of subunits (randomly marked) with 0.4 m radius. We registered the presence of herb species and woody plants under 0.5 m height in each subunit. Sampling plots of shrub layer (1.13 m radius) assigned along the 6 m radius circle, using cardinal- and intercardinal directions. Regeneration layer defined between 0.5 m to 1.3 m height. Shrub layer was specified over 1.3 m height, but under 5 cm diameter at breast height (DBH). Survey of stand structure was carried out in 8.92 m radius circles, supplemented with relascope sampling method (using k=2 factor). Trees were defined as woody plants over 5 cm DBH. The examination of soil composition and structure were performed in laboratory, using bore hole samples from different topographical conditions within the examined forest. The standard FRMP often complemented with further investigations, e. g saprophagous beetles and Lepidoptera assemblages.

GoProForMed – Monitoring the conservation status of Mediterranean forest habitats through sound biodiversity indicators

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Due to unique biogeographical features, the Mediterranean-European region includes an extraordinarily high number of tree taxa, almost 200 tree taxa more than in the central European region[1]. Forests of the Mediterranean underwent thousands of years of human influence through forest logging, fires, grazing, agriculture, soil disturbances, water uptake, changes in the distribution of native species, and introductions of alien taxa[2]. As a result, Mediterranean forest habitats are unique and worthy of conservation efforts for both their biodiversity and cultural values.

On the one hand, their conservation poses strong challenges as the incidence of extreme drought and fires increases with the ongoing changes in climate [3]. On the other hand, novel indicators of forest conservation state and sustainable management were designed and tested mostly in central Europe[4]. These premises undermine the conservation and sustainable use of Mediterranean forest habitats.

The LIFE project GoProForMed, focuses on four key habitats within the region, covering evergreen broadleaf (dominated by either Quercus ilex or Q. suber), pine-dominated and chestnut forests across France, Greece, Italy and Spain.

We selected twelve sites in which reference and intervention area could be identified for the four target habitats and sampled these sites for multi-taxon biodiversity (vascular plants, lichens, insects), stand structure, tree-related microhabitats and the Index of Biodiversity Potential (IBP).

To define sound indicators for the assessment of the Mediterranean forest conservation status, we studied the relationships between species diversity for multiple taxonomic groups and structure-based indicators that until now have been used mainly in the forests of central European forests.

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2. Blondel, J. The 'Design' of Mediterranean Landscapes: A Millennial Story of Humans and Ecological Systems during the Historic Period. *Hum Ecol* **34**, 713–729 (2006).
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How to optimize passive acoustic monitoring of forest birds to support rapid biodiversity assessments?

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Biodiversity in forests include an overwhelming number of species and their composition is driven by a multitude of factors. To support effective management decisions, conservation efforts and restoration strategies, many research projects are dedicated to developing rapid biodiversity assessment methods that yield reliable data. These projects aim to identify key indicator species, including various bird species as they provide ecosystem services or exhibit a pronounced habitat association with specific forest characteristics.
Acoustic monitoring techniques are generally more important in forest bird surveys than visual identification, but the courtship of some migratory species is comparably short and their detection is limited to only a few weeks before incubation. Due to time and budget constraints for field work, such behavior can result in data deficiencies. These methodological challenges are especially pronounced in remote areas with low infrastructure such as close-to-nature forests in mountainous regions. Recent advancements in conservation technology facilitate research at those sites as they enable simultaneous data collection and open up the possibility to increase sample size.
Our study encompasses a network of 40 forest sites located as stepping stones and sites in two national parks aimed to be connected. Throughout the entire breeding season, we deployed autonomous recording units at these sites. Target species were cavity-breeders with particular emphasis on three long-distant migratory species belonging to the genus *Ficedula*, all of which breed in forests and co-occur within our study area. Naturally, these species compete with other non-migratory species from the family Paridae for cavities and their occurrence indicate a sufficient number of such breeding sites in forests. In fact, the inclusion of *Ficedula parva* in the Austrian woodland bird index highlights its significance as a reliable indicator for species richness. Occurrence data is however insufficient in some regions, underscoring the need for further research to enhance monitoring effectiveness. We used hierarchical modeling to analyze parameters that potentially influence the detection probability of selected species, including environmental and methodological factors. Our study aimed to propose an optimized workflow for passive acoustic monitoring of forest birds and to provide insights towards the integration of this method within rapid biodiversity assessments.

Improving Forest Habitat Monitoring and Biodiversity Assessment: National Inventory and Innovative Sampling Design

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: There is an increasing recognition of the need to enhance information on biodiversity, habitat conservation status and trends. This data is crucial for reporting to national and international forums and supporting policy development. To address this, the new revised National Inventories of Landscapes in Sweden (NILS) program was initiated in 2020. NILS consists of several inventories, including the NILS Deciduous forests inventory, NILS Grassland inventory, NILS Alpine mountainous inventory, and THUF Sea shore inventory, all operating within a general framework. The objective is to collect and analyse data on habitats that are underrepresented in other monitoring programs, typically because they are rare or neglected.

The new sample design of NILS allows for additional inventories to be included based on new needs at both national and regional levels, using the same design. This enables monitoring of both uncommon and common habitats by choosing different sample densities depending on the prevalence of the focal habitat type. The consistent sample design allows for the use of the same estimation procedures and algorithms at national, regional, and different sample density levels. The new design incorporates several innovations aimed at establishing a long-term, flexible, and sustainable inventory methodology. While some of these innovations have been used individually in previous inventories, to our knowledge, they have never been integrated within a single design before. Overall, the new design employs a two-step sampling approach that combines remote sensing and field inventories. During the first step, a coordinated sample of tracts is randomly selected using a spatially balanced sampling technique. In the second step, specific plots for field inventory are chosen.

Specifically, the NILS Deciduous forests inventory complements data from the Swedish National Forest Inventory by focusing on relatively rare forest habitats that cover small areas and their quality and biodiversity. These include Broad leaf forests, Alluvial forests, Deciduous swamp woods, and old deciduous forests in the western taiga, which are included in Appendix 1 of the EU Species and Habitat Directive. The field inventory includes diverse number of variables that may act as biodiversity indicators, providing valuable information on forest habitat status and potential changes over time.

Mapping forest habitat types from satellite hyperspectral imagery: challenges and opportunities

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Tree canopy species play an important role in creating and maintaining biodiversity in the forest habitat. Mapping the extent of different forest habitats, based on forest canopy composition, can help to optimize the sampling design for monitoring other biodiversity indicators at scales relevant to research and decision-making in biodiversity conservation.

However, this task can be challenging even with the support of remote sensing technology, because the possibility to discriminate differences in forest canopy composition from optical imagery is primarily determined by the similarity or uniqueness of the biochemical and structural properties of the foliage among tree species.

Hyperspectral satellite missions offer a tremendous opportunity to explore new approaches for the delineation of forest and other natural habitat types, thanks to the ability of hyperspectral data to measure the spectral reflectance of plant canopies in a huge number of bands of the electromagnetic spectrum.

In this contribution we discuss whether satellite imaging spectroscopy can offer a solution for the automated delineation of forest habitat types. Lessons learned from a study conducted in a pilot site of nearly 6000 ha in central Italy will be presented, where methods to process and analyse PRISMA hyperspectral satellite imagery (30 m spatial resolution, 234 spectral bands throughout VIS-NIR-SWIR regions) have been tested to map the extent of forest habitats and heathland habitat types (matorral, maquis, garrigues). In particular, one (or two) tree canopy species are expected to dominate the signal at pixel level of the following groups: broadleaved deciduous (*Quercus cerris, Quercus frainetto, Fraxinus sp., Populus sp.*), broadleaved evergreen (*Quercus ilex, Quercus suber*), needleleaf evergreen (*Pinus pinea*).

Monitoring forest biodiversity at a national scale: how to build upon existing monitoring networks

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Due to the scarcity of rigorous species monitoring across several taxonomic groups, sustainable forest management indicators related to the biodiversity criterion in Europe are mainly indirect indicators based on tree-related data. Direct monitoring of species, however, often permit more thorough monitoring of the status of biodiversity and its dynamics, with a more rapid assessment of the impact of forest management and forest policies. Using French metropolitan forests as a case study, the PASSIFOR2 project combined the use of direct forest biodiversity indicators as well as associated dendrometric and management-related variables in designing monitoring templates. The project was developed based on (i) the specification of refined monitoring objectives, (ii) a broad consultation of existing networks for collecting biodiversity data in forests and (iii) some methodological research to improve the quality of sampling and data analysis. We present our lessons learned as well as the four main advances that have been made: (i) a method and a protocol for building multi-network biodiversity monitoring templates; (ii) an objective choice of taxa to be favored in monitoring in French forests, based on a multi-criteria analysis, and associated protocols to monitor them (direct biodiversity indicators); (iii) proposals for dendrometric and management variables to be documented and be related to the direct biodiversity indicators; and (iv) statistical results to guide the choices in terms of sampling schemes and data analysis.

National Biodiversity Monitoring in Forests (NaBioWald) - a federal-state initiative

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: The conservation of biodiversity is of great societal interest. The status and future development of biodiversity in German forests cannot be sufficiently determined by the national monitoring programs already existing. NaBioWald aims to close this gap by providing comprehensive and representative information on the development of biodiversity and on the effects of influencing variables. NaBioWald is intended to provide an important basis for biodiversity-oriented forest management, to support the forest and nature conservation policies of the federal and state governments, and to contribute to the fulfilment of national and international reporting obligations.

A working group consisting of representatives of federal and state institutions in forestry and nature conservation including further experts from scientific institutions is currently working on a monitoring concept. One focus is on the possible influences of forest management, climate change, air pollution and air borne pesticides on biodiversity.

To implement the necessary monitoring work, existing German-wide (forest) surveys are to be supplemented with additional surveys and interfaces to ongoing and developing biodiversity monitoring programs are to be created. This approach will be integrated into the activities of the National Biodiversity Monitoring Center. Due to the manifold anthropogenic influences, as well as the complexity of the topic and the effort of monitoring, a shared workload among the many different actors from science, administration, forestry and nature conservation on federal and state level is required. A draft concept is to be discussed in an extended circle of experts and presented as a final draft to politicians for a decision on implementation.

The poster presents the current state of work and the further process of NaBioWald.

The Index of Biodiversity Potential (IBP): A success story of 15 years of Research and Development

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: The Index of Biodiversity Potential (IBP) is a biodiversity evaluation tool created in 2008 to help forest managers to easily take taxonomic biodiversity into account in their daily working routine. This rapid habitat assessment method combines ten historical, structural and compositional key factors for forest-dwelling species. These factors are easily and directly measurable in the field by forest managers with no specialized taxonomic skills. By comparing threshold values with field observations recorded along a standardized route inside the stand, a scoring system awards a score of 0, 1, 2 or 5 per factor. Seven factors directly concern the stand and its current management; three supplementary factors concern site history and context. Both factors and scores were calibrated by large-scale taxonomic data. The observer effect was estimated and helped us to refine factor definitions and shape optimal training sessions. A huge development effort has been rolled out, which includes developing methods for a wide range of forest contexts, numerous training sessions and communication actions through a large array of media. A sociological study showed that the IBP is not only used by forest managers but also by a wide range of actors not initially targeted, due to both its intrinsic features and the strategies used to relay it to these actors. As a boundary object, the IBP facilitates discussion and negotiation among actors with different beliefs and interests within territories. Started in 2009, the research and development programme is continuing. Widely used in France, the IBP is currently spreading in Europe under the guidance of an international expert committee.

Towards new biodiversity indicators for sustainable forestry based on a multitaxonomic analysis at the European scale

T3.1 Advances towards more accurate forest biodiversity indicators and monitoring

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Abstract: Monitoring the state and dynamics of forest biodiversity to assess sustainability of forest management remains a challenge since most biodiversity indicators are based on structural proxies issued from national forest inventories. In addition, the metrics used to qualify and quantify these

indicators generally are abundance indices, while ecological theory predicts that the diversity of habitat may have a greater role than abundance.

Within the framework of the COST Action Bottoms-up (CA18207), we gathered data on multi-taxonomic biodiversity and forest structure across more than 3,000 plots in Europe. Building on biodiversity indicators from Forest Europe, we calculated novel metrics of forest structure describing diversity in addition to abundance. We then tested and consolidated new biodiversity indicators based on sustainable forest management reportings, and tested them on six model taxa: tracheophytes, bryophytes, birds, saproxylic beetles, lichenized fungi, and non-lichenized fungi.

While current indicators have been chosen for their availability and the fact that they are understandable to most stakeholders within the forest sector, our analyses show that, depending on the taxa studied, some indicators based on diversity indices perform better than those currently used to assess biodiversity. Our work can contribute to a better assessment and reporting on forest biodiversity at a large scale.

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

Accelerating innovation in forest operations for Ecosystem Restoration: How improve genetic material to achieve restoration at scale

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: Global targets including the recently launched Post-2020 Biodiversity framework from the Convention on Biological Diversity call for restoration in millions of hectares. In addition to this challenge, Climate Change is affecting precipitation and temperature patters impacting natural forest and slowing down efforts to restore degraded lands. To achieve the scale needed a set of sustainable forest operation are required to improve the genetic material demanded and ensuring the quality of the restoration process. Most of genetic material available for planting in Latin America is distributed in a few commercial species, however the multiple objectives of landscape restoration demand the use of a diverse set of species. The production of the genetic material as well as the distribution to the planting sites constitutes challenges and potential bottlenecks to reach the desired outcomes in times of urgency. In this presentation we will present a diagnostic focused in seven countries in Latin America, Mexico, Guatemala, Costa Rica, Colombia, Peru, Chile, and Argentina that analyses the gaps along the supply chain and provides recommendations for improvement. We will also share a framework to assess the structure of seed and plant supply systems based on adaptive management. The results from the diagnostic showed that gaps around finding local material are present in many countries. Also, the definition of what constitutes a "native" specie bring problems when selecting genetic material for restoration. Additionally, the lack of long-term objectives provides challenges when defining the "quality" of the genetic material. As many areas under restoration are severely degraded part of the quality of the genetic material needed relates to the adaptability to hard conditions in the field. We finally provide policy recommendations for governments to take into account when designing National Restoration Strategies and key operational aspects to consider.

Adaptive Silviculture for Climate Change: where are we?

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: The Adaptive Silviculture for Climate Change (ASCC) project is a collaborative effort that has established a series of experimental silvicultural trials across a network of different forest ecosystem types throughout the United States and Canada. Scientists, land managers, and a variety of partners have co-developed fourteen experimental sites as part of this international study to research long-term ecosystem response to a range of climate change adaptation approaches, enabling forest ecosystems to continue to provide valuable ecosystem services into the future. The big question ASCC is poised to answer is: What actions can be taken to enhance the ability of a system to cope with change while continuing to meet management goals and objectives? Silvicultural treatments at each ASCC study site were developed following the adaptation framework in *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers* (Swanston et al. 2016). Treatments approximate a gradient of climate-adaptive management approaches: (1) resistance – maintaining relatively unchanged conditions over time; (2) resilience – allowing some change in current conditions, but encouraging an eventual return to reference conditions; (3) transition – actively facilitating change to encourage adaptive responses; and (4) no action control – allowing forests to respond to climate change without direct management intervention. This presentation will cover an overview of the ASCC Network experimental design, some key climate change challenges and opportunities across the sites, how these are being addressed through innovative silvicultural practices and management, examples of forest assisted migration being applied across ASCC sites, and preliminary results and lessons learned from this collaborative manager-scientist Network.

Challenge of ozone FACE experiments in Mediterranean Europe

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: Tropospheric ozone (O_3) is an oxidative air pollutant with causing a significant negative effect on forest tree species. Free-air controlled exposure (FACE) facilities are considered as an ideal tool which can provide realistic estimates of tree response to O_3 under real world conditions. Since 2015, a last generation of O_3 FACE facility has been available at the CNR experimental garden in central Italy (FO_3X), which is a unique facility in Europe within an AnaEE (Analysis and Experimentation on Ecosystems) European research platform. This facility permits the exposure of plants to three levels of O_3 concentrations (ambient, 1.5- and 2.0-times ambient concentration, denoted as AA, 1.5×AA and 2.0×AA, respectively), with main environmental variables continuously monitored. The phytotoxic nature of O_3 can impair forest productivity. In addition, O_3 affects stomatal functions, by both favoring stomatal closure and impairing stomatal control. Ozone-induced stomatal sluggishness, i.e., a delay in stomatal responses to fluctuating stimuli, has the potential to change the carbon and water balance of forests. In particular, the O_3-induced stomatal sluggishness becomes more important in water-limited environments such as Mediterranean Europe where stomatal regulation of water losses under low soil water availability are critical. In this presentation, we will introduce our FACE facility with a future perspective, and recent experimental results about stomatal sluggishness will be summarized.

Fluctuating asymmetry of pedunculate oak leaves as an indicator of abiotic stress

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: Fluctuating asymmetry (FA) is characterised by deviations from "ideal" symmetry in bilateral structures and, therefore, it is used as a reliable indicator of the impact of different types of stress on plants. FA indices have been widely used in monitoring the habitat of individuals, assessing habitat quality as a measure of environmentally induced developmental instability. In this study, the FA, and its relationship with the climatic variables (i.e. air temperature, precipitations and relative air humidity), are analysed in pedunculate oak (*Quercus robur* L.) leaves originating from nine *in situ* populations located at the species rear edge, in Serbia. The results showed that FA was primarily influenced by mean annual air temperature, while relative air humidity and annual precipitation sums had smaller effect on this phenomena. These methods can be used to better understand how environmental changes (on a spatial scale, at a distance of approximately 350 km) affect leaf growth and development within populations. Ultimately, these insights may benefit conservation efforts for this economically and ecologically important deciduous forest tree species in Europe and its unique adaptations. By continuing to explore the variability in developmental instability of pedunculate oak leaves among populations, we can deepen our understanding of this remarkable tree species and its place in our natural world.

Keywords: pedunculate oak, populations, fluctuating asymmetry, development instability.

Genome-Wide Diversity across Natural Populations and Varieties of Ponderosa Pine (Pinus Ponderosa)

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: Ponderosa pine is one of the most widely distributed conifers in North America, and also has one of the most unclear histories, in terms of migration and intra-specific varieties, in any North American conifer. Previous microsatellite studies have produced results that could support two, four, eight or nine varieties within the species and morphological studies have postulated up to five varieties within the species. Better understanding varieties within ponderosa pine can help better inform future conservation efforts as conservation efforts can become variety specific. A genome-level approach to examine ponderosa pine varieties across the range has never been done. The goal of our project is to examine relatedness and genomic variation of ponderosa pine populations throughout the range using pool-seq exome capture to see if an exome-level approach may provide clearer inferences on the number of varieties within the species compared to previous studies. DNA was extracted from 12-20 individuals across 26 locations across the range of ponderosa pine. Within each location 4 individual samples were pooled to create 3-5 composite exomes for each location. 55,000 capture probes, from 40,000 coding regions and 15,000 intergenic regions, were designed using publicly available transcriptome data and the *Pinus taeda* genome to supplement intergenic regions. A genome and environmental association will also be conducted to examine what environmental factors may drive differences among varieties. The results of our study will help aid restoration efforts on public lands, as land managers can select varieties that are best adapted for their specific area and to future climate change, which can help ensure the persistence and health of the species across its wide range.

Impact of wildlife browsing on genetic diversity in the young forest tree population

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: Wildlife browsing is known to have significant impacts on forest ecosystems. Ungulate game selectively target certain tree species or individuals, giving an advantage to other species that are less preferred by browsing animals. Therefore it strongly influences the structure, composition, growth and succession of forest. That may in the long run lead to species diversity reduction and threaten the resilience of the forest to future disturbances. In the last century, the density and spatial distribution of large herbivores, especially roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*) has increased significantly in most of European countries. The monitoring of a wildlife browsing is crucial for assessing its effects. The Life Systemic project experiment findings and the results from the monitoring of wildlife browsing in Slovenia over the previous 14 years will be presented. Results also include an assessment of how wildlife browsing affects the genetic diversity of silver fir natural regeneration. The experiment is being conducted on 8 experimental plots (4 fenced and 4 unfenced) in a forest stand, dominated by silver fir in Slovenia. All saplings were counted, measured and assessed for browsing damage. 50 saplings from each plot were sampled for genetic analysis, totalling 400 samples. Another part of the experiment was carried out nearby, in a region that had been fenced more than two decades prior. Additional 400 saplings were sampled, including 200 samples from a fenced area and 200 samples from outside the fenced area with comparable conditions. For the purpose of managing forests and implementing conservation efforts, it is crucial to comprehend how wildlife browsing affects forest genetic diversity. It can guide strategies to lessen the effects of browsing, such as installing fencing or taking other steps to keep ungulates out of sensitive areas.

Is beech forest management driving soil microbiota?

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: Vital soil resulting from interaction of physical, chemical and biological soil properties is critical for sustaining forest growth and ecosystem services. High soil biodiversity supports functional flexibility for adaptation to unknown changes that may occur in the future. Forest management practices result in numerous direct and indirect changes that can affect soil quality, including the soil microbial biodiversity. Nevertheless, the effects of forest management on soil microbiota remain largely unexplored.

In our study, soil and root samples were collected from nine beech (*Fagus sylvatica* L.) forests with different forest management regimes (unmanaged forest nature reserve, low close-to-nature forestry, medium combined system) in Italy, Croatia, and Slovenia. Soil samples were analysed for pedological characteristics, while bacterial, fungal, and archaeal communities were analysed using Illumina MiSeq. Root samples were used to characterize the active community of ectomycorrhizal (ECM) fungi by a combination of morpho-anatomical and molecular approach (Sanger sequencing). In addition, environmental parameters that may affect the microbial community were collected.

Species richness of bacteria, fungi, and a subgroup of ECM fungi were significantly affected by the forest management regime. However, no significant relationship was found with the species richness of the active community of ECM fungi on beech roots, which varied among the sites. Weather parameters, specifically temperature and precipitation in certain months of the year, were positively correlated with species richness of active ECM fungi. Soil pH was found to be a significant driver of bacterial and fungal community in the beech forests studied.

These results suggest that the forest management practices should be considered in the context of preservation of the soil microbial pool.

The study was carried out within the LIFE SySTEMiC project - LIFE18ENV/IT/000124.

Landscape genomics to support Sustainable Forest Management

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: Forest ecosystems represent complex adaptive systems that cover a wide range of climatic zones and form different forest types. Forest areas are important for ecosystem services, ranging from economic and social serving to the biodiversity they host and represent. Climate change, unsustainable forest management, invasive species, urbanization, and fragmentation reduce forest biodiversity, may adversely affect genetic diversity, and put at threat the future adaptive potential and sustainability of forests ecosystems. The genetic diversity in locally adapted forest is essential for adapting to changing environmental conditions. Nowadays, many forest species were found to be threatened or subject to genetic erosion, making forests less resilient and compromising future adaptability to changing environmental conditions. Therefore, it is extremely important to provide a sustainable forest management (SFM) for a correct sustainable use of forest products but preserving biodiversity. In particular, forest genetic resources (FGR) are the basis of the long-term evolutionary processes maintaining the adaptive potential of forests. LIFE SySTEMiC (LIFE18 ENV/IT/000124) examines best close-to-nature forest managements regarding FGR in different European Forest Types, for diverse forest management systems comparing to non-managed forests to preserve adaptability of forest ecosystems. The principal aim is to use a combination of advanced landscape genomics, applied genetics, modelling and silvicultural methods resulting an innovative Genetic Biodiversity and Silvicultural model (GenBioSilvi) to be used as tool for a SFM. The Project involved a multidisciplinary study approach: (i) the study concerning the adaptive component of the genetic variability of the stands; (ii) the study of biodiversity at species and ecosystem level obtained through the study of the fungal and microbial communities of the forest soil; (iii) the study of past and current silvicultural management. The information processed on biodiversity and genetic

characterization enabled the definition of biogenetic indicators useful in providing the best adaptive management of the forest, with respect to climate change, also considering the species and different silvicultural treatment conditions (for details see our presentation in Session T3.7). Here, we have reported the results obtained at the end of the LIFE SySTEMiC project.

Phylogeny and evolution of molecular response to abiotic stresses: a comparison between angiosperms and gymnosperms

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: The study of forest species adaptation to abiotic and biotic stresses has always been of great interest. Adaptation to environmental stresses has been studied using a variety of approaches. Comprehending the evolutionary history of this molecular response can help to understand how different abiotic and biotic stressors have driven the adaptation of major forest species, leading to their current distribution across geographic ranges. However, the size and complexity of higher plant genomes has always been a major obstacle to genetic and genomic analyses of these species. Studies on the evolution and phylogeny of forest species are characterized by the analysis of only a few species (often model species) and/or a limited number of gene sequences. In this work, we used a newly identified database of 616 gene sequences representative of responses to abiotic stresses to perform evolutionary analyses and compare two major taxonomic groups: Conifers and Deciduous trees. The analyses performed led to interesting results regarding the phylogeny and evolutionary history of the molecular response of these species. The results show that the response to abiotic stresses is remarkably conserved in the two taxonomic groups studied. Despite the different evolutionary histories over the past 300 million years, genetic diversity is not abysmal. As expected, the evolutionary history appears to reflect an already widely held assumption: a slowdown in the overall mutation rate of conifer orthologs relative to those of angiosperms. This finding is consistent with an increase in the fixation of nonsynonymous mutations that could be beneficial for adaptation

Stronger together: genetics and ecophysiology of drought stress in Fagus sylvatica

T3.2 Can adaptive genomic drive sustainable forest management under climate change?

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Abstract: European beech (*Fagus sylvatica* L.) has a large distribution area across the European continent. At its southern edge, this species is confronted with different climatic conditions than in Central or Northern Europe: average annual temperature is higher; precipitation is lower. To investigate possible different drought stress tolerances of beech provenances, a provenance trial ("climate forest") was established in the Grunewald Forest in Berlin/Germany, where individual trial members (a group of trees) can be irrigated, while other trial members are affected by the (naturally occurring) drought conditions in summer. A drought stress experiment was initiated in the summer of 2022 with one provenance each from Germany, France, Italy, and Spain. In a unique interdisciplinary approach, ecophysiological, biochemical and genetic analyses were performed following different stress intensities. The data will be used to unravel possible different drought stress tolerances of individual European beech provenances.

Genetic regulation of drought stress will be investigated by transcriptome analysis. For this purpose, mRNA was isolated from leaf samples of selected trial members and a sequencing approach was conducted. Based on the deciphered mRNA sequences, the activity of the different genes will be determined. Biochemical measurements will be performed for the levels of the drought stress markers proline, malondialdehyde and peroxide, among others. Together with physiological data such as photosynthetic activity, stomatal conductance, and water potential, the analytical triad should provide a comprehensive picture of the drought stress response of the trees in this trial.

We expect answers to the questions: what is the overall response of European beech under drought stress? Do the selected provenances differ in their drought stress response? Which genes are switched on or off, and how fast or how strongly is gene activity regulated? Is the provenance-dependent differential stress tolerance related to differential gene regulation? The findings from this collaborative research may be helpful to develop genetic, biochemical and/or ecophysiological markers which can be used to select suitable drought-tolerant provenances.

T3.3 Disappearing oak woods: conservation and management of global oak forests

An integrative perspective of species limits, gene-flow and local adaptation in Southeast European white oaks

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Oaks (genus *Quercus* L.) are considered potential winners under future drier and warmer climates. The white oaks species-complex includes some of the most widespread oak species in Europe – namely *Q. robur*, *Q. petraea*, and *Q. pubescens* – and is strikingly diverse in Southeast Europe, where a number of minor lineages have been reported. To date, it is unclear what evolutionary processes underlie this taxonomic richness. We hypothesize that local adaptation and (adaptive) introgression likely driven by post-glacial secondary contact play a major role. Our project features whole-genome resequencing (WGR) and leaf morphological data of 46 populations (ca. 15 individuals per population) scattered across Eastern Austria, Hungary, Croatia, Romania, and Bulgaria, including some white-oaks diversity hotspots. We test if leaf morphology can be used to discriminate among main and minor lineages and identify putative hybrids, extending knowledge from previous studies to a larger geographic scale. Further, we explore which demographic scenarios of secondary contact and gene-flow better explain the present white oak genetic composition. Lastly, we exploit populations growing under dry and warm conditions at the limit of the ecological range to better understand the adaptive potential of white oaks to the future climate. We show that leaf morphology can be used to characterize hybrids, which are intermediate between the parental species. While at least 5 leaf traits are significantly different between the main species, the same traits fail to discriminate between major species and minor taxa, mainly due to the large within-species variation. Ongoing analyses of WGR show very little to no reference-species bias when mapping genomic reads of different sample species to the *Q. robur* chromosome-level reference genome v. 3, likely as a consequence of frequent hybridization. These initial results support our approach towards a better understanding of the evolutionary processes underlying species and adaptive richness in white oaks.

Assessment of forest structures, soil carbon stocks, TREMs and deadwood in four secondary old-growth English Oak Forests in the Basque Country, Spain

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Old-growth forests contribute to biological diversity at many levels of the biological hierarchy. Old-growth primary forests disappeared from the Basque Country in the Middle Ages due to the iron industry. As a result of the presence of the iron industry, forests were cut down and its timber was used for chacroal production. Today the region's forests are shaped by humans through extensive planting. In the last 120 years, coniferous forests have mainly been planted with the aim of production of raw materials, being *Pinus radiata* the main species. Planted forests occupy 68% of the forest surface in the Atlantic watershed of the Basque Country while forests dominated by English oak (*Q. robur*), that is the main potential forest system in the region, only covers 5,1% of this area.

Some small secondary old-growth forests are still present in the region and this study aims to assess forest structures, forest soil carbon stocks, quantity of deadwood, and tree related micro-habitats (TREMs) in four secondary old-growth oak forests in the Basque Country, Spain.
We aim to enhance our knowledge of the ecological characteristics, conservation significance, and potential relationships among these factors.

Preliminary results indicate variations in forest structural diversity among the four study sites, reflecting differences in stand age, disturbance history, and management practices. These variations are expected to have implications for tree-related micro habitats. The analysis of age and TREMs data reveals distinct assemblages associated with different forest structures, including species that are dependent on specific microhabitats provided by mature oak forests. Regarding to soil organic carbon stocks show that past forest management led to overuse of the forest and soil carbon stocks are still far from their potential carbon sequestration.

The findings contribute to the understanding of forest dynamics in these vulnerable ecosystems. The results can inform forest management practices and conservation strategies aimed at maintaining and enhancing the ecological integrity of English oak forests, ensuring the long-term persistence these ecosystems and their associated biodiversity.

Divergent climate responses in radial growth among three spatially displaced oak species along an altitudinal gradient

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Elucidating the underlying mechanisms driving the geographic and niche differentiation of forest tree species is amongst the key issues in studies of phytogeography as well as for determination of the climate-forest structure relationships. However, an explicit knowledge on the controls of the spatial displacement of congenic tree species by climatic factors is still lacking. Here we investigated changes in the radial growth of three deciduous oak species (*Quercus variabilis, Quercus aliena* var. *acuteserrata*, and *Quercus wutaishanica*) occurring sequentially along an altitudinal gradient on Mt. Taibai of the Qinling Mountains. We found that changes in moisture conditions with altitude, inferred by the standardized precipitation-evapotranspiration index (SPEI), dominated the influences on the radial growth of the three oak species. While an increase in temperature appeared to favor the radial growth in both *Q. aliena* var. *acuteserrata* and *Q. variabilis* across their altitudinal range, the association between rising temperature and drought (decreasing SPEI value) suppressed the radial growth of the high-altitude oak species *Q. wutaishanica*. Moreover, the growth in *Q. aliena* var. *acuteserrata* and *Q. variabilis* recovered better from extreme drought than that in *Q. wutaishanica*. Our findings suggest that with projected future warming and more frequent and severe drought events, a range contraction would likely occur in *Q.wutaishanica* at its upper limit, whereas the distributional range of *Q. aliena* var. *acuteserrata* and *Q. variabilis* would possibly shift upwards or remain unchanged due to their higher plasticity to environmental changes.

Dual RNAseq Analyses of the Oak Wilt Disease Complex: Unraveling the Silent Battles of Oak Hosts Against the Fungal Pathogen Bretziella fagacearum

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Oak (*Quercus* spp.) trees have significant economic and ecological value as urban landscape and forest resources. In addition to commercial demand, contributing factors that challenge tree health include vascular diseases such as oak wilt which is caused by the fungal pathogen *Bretziella fagacearum.* North American oaks differ in their susceptibility to oak wilt disease. Infected red oak species may die 4-6 weeks following infection due to vascular blockages by overproduction of tyloses. Whereas white oak species have shown moderate to high resistance by slowing and containing the infection. European white oak species are less resistant to oak wilt disease than their North American counterparts. Our understanding of the underlying host-resistance mechanisms involved in the differential defense responses to oak wilt disease among different oak species is severely limited. Our objective was to use a dual-RNAseq experiment to identify and characterize gene clusters that contribute to white oak resistance to oak wilt and genes involved in the pathogenicity and virulence of *B. fagacearum*. To accomplish these goals, first, we conducted a greenhouse experiment to test *B. fagacearum* virulence level with eight isolates collected from four regions and selected a highly virulent and a low virulent isolate. Then, we inoculated 52 container-grown red oak (*Q. rubra*) and 52 white oak (*Q. alba*) trees with one of three treatments: high virulent isolate, low virulent isolate, or water-glycerol treatment. To categorize changes in host responses to *B. fagacearum* inoculation, xylem tissues were sampled above the inoculation on days 0, 1, 3, 7, and 21 post-inoculation. Data are forthcoming. We expect that white and red oak transcriptomes will respond differently to infection. Particularly, we expect that in red oaks, gene clusters that are related to host defense responses will be up-regulated at later disease stages compared to white oak. In red oaks, we anticipate delayed and potentially uncontrolled expression of genes related to tylosis formation leading to tyloses overproduction resulting in system-wide vasculature blockage. The outcome of this study will inform future disease management strategies and develop biomarker(s) valuable for selecting oak wilt-resistant genotypes for selective breeding programs.

Genomic basis of Quercus robur resistance to acute oak decline in Britain

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Acute oak decline (AOD) is a complex syndrome characterised primarily by fluid exudation from necrotic inner bark lesions and is affecting thousands of oaks in the UK, many of which die each year. Prevalence of AOD at UK sites has been associated with multiple biotic and abiotic risk factors, but the genomic basis for AOD susceptibility has yet to be investigated. We phenotype and sequence the whole genome of 1478 oak trees and use a combination of genome-wide association study (GWAS) and genomic prediction models to understand for the first time whether there is a heritable basis to AOD susceptibility. Firstly, we identify single-nucleotide polymorphisms (SNPs) associated with AOD, some of which were in, or close to, genes with functions that could credibly be involved in insect, bacterial or stress response. Secondly, while we find that SNP heritability to AOD is relatively low (0.391), there was a high correlation between genomic estimated breeding values (GEBVs) and AOD phenotype. A Bolt-LMM prediction model trained with the 5000 most significant SNPs predicted the health status of individual trees with 87% accuracy. These results suggest resistance to AOD is a polygenic trait, and that genomic prediction tools can be used to select individuals with high breeding values. This should enable future selection of planting stocks, and if necessary, could inform a breeding programme aimed at rescuing threatened oak populations in the UK.

How the interaction of competition, annual climate variation and site conditions modulate tree growth – experiences from Nelder trials

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Pedunculate oak (*Quercus robur* L.) is considered as a tree species with high potential regarding climate stability of forests in Central Europe. However, some studies report a decline in oak in certain regions, particularly at the edge of its geographical distribution range. In addition, despite different approaches, natural and artificial regeneration of oak is still difficult to manage. Thus, the regeneration of oak is a field of intensive research worldwide.

To improve the understanding of intra-specific interactions in oak stands, Nelder trials were set up along a climatic gradient on five sites across Europe, from Belgium and Germany to Italy and Hungary 10 to 15 years ago. Nelder wheels allow to analyse development and growth at a single tree and stand level as a function of local stand density and site conditions. This emulation of complex ecosystems contributes to the understanding of basic tree interactions, while the results can also be relevant for forest management and stand regeneration.

In our study, we use the annual increment of biomass as an indicator for the reaction of trees on the different growing conditions and analyse it with linear mixed models. We further investigate if larger trees react differently from the smaller ones.

Our preliminarily results show (i) a significant influence of size, competition, site index and climate on tree growth dynamics. The negative effect of competition is (ii) increased on sites providing more beneficial growing conditions while (iii) more arid periods are likely to intensify the observed growth reduction by competition. This supports the importance of early thinning in stands with high growth potential to reduce competition induced growth losses.

Impact of black cherry on pedunculate oak vitality in mixed forests: balancing benefits and concerns

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: The vitality of European forests continues to decline due to increasing pressures such as new pests and diseases, climate-change related disturbances and high loads of atmospheric deposition of nitrogen. Deteriorating soil health and low overall biodiversity are major factors underpinning the low vitality of West-European oak forests. Boosting tree species diversity and, particularly selecting tree species with soil ameliorative traits, could be an avenue to counteract soil acidification and improve overall vitality. Here we evaluate the impact of black cherry (*Prunus serotina* Ehrh.) on the vitality of neighboring pedunculate oak (*Quercus robur* L.) in ten mixed forests on sand in Germany, Belgium and the Netherlands. Black cherry is a known rich litter species yet also considered an alien invasive species negatively impacting forest ecosystem functioning. As proxies for oak vitality, we measured foliar nutrient concentrations, total chlorophyl concentrations and leaf damage by herbivory. In this study, we tested the hypothesized positive effect of black cherry on litter decomposition and consequently soil nutrient availability, i.e. the 'improved soil health' pathway via structural equation modelling (SEM). Our analyses showed that black cherry admixture in the forest overstory causes reductions in foliar Mg concentrations of neighbouring oaks but increases in foliar N and P concentrations. Moreover, black cherry also leads to lower accumulation of organic material in the humus layer resulting in higher soil base saturation. This improved soil health has a positive effect on oak foliar Ca yet a negative effect on oak total chlorophyll via increased nitrification. Moreover, herbivory of oak leaves decreases when black cherry is admixed, both directly via dilution and indirectly via improved soil health. Our study showed that the combined positive and negative impacts of black cherry on oak vitality are limited, which tempers the potential benefits of using the rich litter species to counteract oak decline via improved soil health – yet, the concern of black cherry as an invasive alien species negatively affecting the vitality of mature pedunculate oak trees may also be overestimated.

Impact of thinning intensity on growth and regeneration of natural oak forests based on meta-analysis: implications for Chinese oak forest managenment

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: According to the "9th National Forest Resources Inventory Report" (2014-2018), oaks are the largest tree species group in China, which accounting for 11.95% and 9.98% in the total forest area and standing volume, respectively. However, despite the abundance of oak resources, the lack of scientific and effective management measures has led to the low quality of oak forests, which severely restricts its ecological, economic and social functions. As one of the most important forest management measures, thinning is of great significance to improve stand quality and achieve sustainable forest development. In this study, by carefully screening published relevant literature data (37 valid literatures; 149 pairs of data), a meta-analysis method was used to explore the effect of thinning intensity (mild, moderate, strong and heavy) on the average annual growth of diameter at breast height (DBH, mm / yr), average annual increment of stand volume (m^3 / ha·yr) and seedling density (individuals / 100 m^2). The results showed that moderate (20-39%) and strong thinning (40-59%) significantly faciliated the increment of stand DBH and volume, especially for middle-aged forests (21-40yr). All thinning intensities, except the mild intensity, significantly promoted the seedling density. Meanwhile, the three studied variables in the stands under sunny slope aspect or bottom slope position responsed more positively to thinning. The promoting effects of thinning generally lasted less than ten years, suggesting thinning interval with about ten years could contribute to persistently improve stand productivity and recruitment of oak forests in China. This study provides a certain scientific reference for the formulation and implementation of sustainable management strategies for oak forests in China. In the future, it is necessary to combine the long time series observation to obtain the optimal thinning mode, thinning intensity and thinning interval of oak stand with different density (age) under different site conditions, so as to lay a more solid foundation for further improving the production and service function of oak forests in China.

Investigating silvicultural methods using soil-scarification to overcome failed regeneration of Quercus crispula.

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Quercus crispula provides excellent wood, which is currently in high demand in the market.
However, in Hokkaido, northern Japan, where Quercus crispula is widely distributed, the resource of high-quality, large-diameter trees are declining by selective harvesting. In forests in the region, dwarf bamboos dominate the understory of forests, causing failed regeneration for this species. Therefore, regeneration techniques, in relation to the competition with dwarf bamboos and other tree species, need to be developed to consider the silvicultural method for its sustainable utilization.
The study was conducted in the Uryu Experimental Forest of Hokkaido University. In 2006, scarification treatment using heavy-machinery was carried out in non-wooded site to reduce competition from dwarf bamboos, followed by sowing of Quercus crispula acorns (c.a. 7 acorn /m^2). Then we measured establishment and growth at years 5, 6, 11 and 17.
Our results demonstrate that the scarification treatment effectively removed competition from dwarf bamboos, resulted in early establishment of Quercus crispula seedlings (5.51±sd 4.43 stems/m^2 at 5th year). However, in the 11th year, Quercus crispula (mean height 2.11±sd 0.56 m) was being suppressed by naturally regenerated Betula ermanii Cham. (2.86±sd 0.94 m), which gradually dominated the site. This suggests that thinning within this period (5-11th year) is essential for the growth of Quercus crispula, although the presence of dense Betula ermanii might have a positive effect to suppress excessive branching from the bole of Quercus crispula. Therefore, we carried out tree-stem analysis to identify the appropriate timing for thinning, and discussed silvicultural scenarios for the growth of Quercus crispula.

Long-term survival and growth response of large oaks following conservation cutting in mixed, structurally complex forests in southern Sweden

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Anthropogenic activities and a changing climate have put forest ecosystems worldwide under increasing pressure. Forest owner's preference of fast growing tree species in production forest and plantations further influence ecosystems with high biodiversity that support not only important ecosystem services but also have a high resilience to disturbances and environmental stress. Oak (*Quercus spp.*) can be regarded as a foundational species in many of these ecosystems that provide critical habitats for red-listed invertebrates, lichens, fungi, birds and microbes. Further, oak trees are highly interesting for production purposes such as high-quality timber, forage and firewood. The Swedish Oak Project was established in 2000 at 25 experimental study sites in temperate mixed forests across southern Sweden. All sites are part of forest reserves and woodland key habitats with a substantial component of large oak with ages ranging from 80-250 years. The study sites were divided and randomly assigned into one (almost untouched) reference plot and one experimental plot (selective cutting) with a size of one hectare, each. The selective cutting for removing ca. 25 % of the initial basal area was carried out in winter 2002/2003. In all reference and experimental plots, old oaks were further selected and treated with release cutting or not. Results of this long-term research will show how large oaks respond to selective cutting and release cutting in terms of growth, development and survival. Early results suggest that released oaks show a higher vitality and increased diameter growth which promotes their associated biodiversity. In addition, it will enable us to address conservation management options for sustaining survival and development of large oaks necessary for essential ecosystem functions and biodiversity conservation.

Post-glacial migration haplotypes of Quercus robur possess specific morphology features

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: In the PhD project, we studied crown, stem and bark morphotypes of cpDNA haplotypes of old growth Quercus robur trees nature-monuments located allover Lithuania. Based on three commonly used cpSSR loci, the haplotypes were assigned into Balkan, eastern Italian, western Italian and German postglacial migration lines. In total, 305 single standing ca. 300 to 700 years old Quercus robur trees were morphotyped and genotyped, assuming that the advanced age and unrestricted growth of standing alone trees would well reveal the morphologic features of Quercus robur. The results showed that the geographical distribution of the haplotypes was not random: the eastern Italian haplotypes were more common in the east, while the western Italian in the west of the country. Such distribution well corresponds to the postglacial migration patterns observed in earlier studies, where eastern Italian haplotypes approached Lithuania from the east and western Italian – from the west. The Balkan and German haplotypes were among most common all over the country. The eastern Italian haplotype was distinguishing by multi-stemmed umbrella-like crowns and bark type with small plates with horizontal cracks. The western Italian haplotype often possessed dichotomic stems. The German haplotype possessed commercially better stem morphotypes. We conclude that the postglacial migration continues at present bringing new genetic variants with discrete adaptive properties, such as the Italian haplotypes. Such organization of genetic diversity must be considered while designing gene conservation units.

Provenance trials of oaks in Austria: advancing forestry and forest management

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Oaks (*Quercus* spp.) are widely distributed across various countries and provide valuable ecosystem services such as high-quality timber but also high biodiversity levels. Projected changes in the climate system will lead to a significant shift from coniferous spruce forests to more drought-tolerant broadleaved forest ecosystems in central Europe. Oak species are specifically interesting due to their high resistance against summer drought and high phenotypic plasticity. Provenance trials offer a valuable opportunity to deepen our understanding of oak adaptability, growth characteristics, and performance under local environmental conditions, provide insights into selecting suitable seed sources, optimising silvicultural practices, and guiding evidence-based decision-making in sustainable forest management. The present study aims to present the results of a provenance trial with pedunculate oak (*Q. robur*) and sessile oak (*Q. petraea*), of which progenies were already used for establishing seed orchards. The trial includes five ecologically different experimental sites established in 2006–2007, where 22 provenances, originating from Austria and neighbouring countries, are being tested. We focus on assessing the genetic variation, growth performance, form characteristics, resistance to abiotic stresses, responses to changing environmental conditions in different climate regions, and the suitability of provenances for potential oak cultivation in Austria. Various tree traits were recorded at the age of 2, 5, 10 and 15 years. We assess the provenance plasticity across the tested sites by differences in tree volume and stem quality with the joint regression analysis (JRA). The application of the Weighted Average of the Absolute Scores (WAAS) as a stability parameter enables the classification of provenances into generalists and specialists. Provenances were also genotyped using nuSSR and cpSSR markers. The establishment of the oak provenance trial in Austria contributes to the development of guidelines for species and provenance selection, site preparation, and sustainable forest management. By considering the genetic variation and adaptive capacity of oak populations, the trial supports the cultivation of resilient forests that can withstand future challenges, including climate change impacts.

Regenerating Oak Trees in the Eastern Himalaya

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Regenerating Oak Trees in the Eastern Himalaya

Til Bahadur Subba

The eastern Himalaya is renowned for its verdant temperate oak forests whichprovide varied ecosystem services. The main genera in the Fagaceae family include Lithocarpus, Quercus and Castanopsis. However, natural regeneration of the Quercus and Lithocarpus genus is largely absent on the forest floor thereby raising serious concerns on the future of these forests. Conventional nursery techniques to artificially regenerate these trees is not successful as the acorns are attacked by weevils at the flower stage itself. Also, traditional forestry techniques focussed on replacing these forests with fast growing conifers, and hence there is limited knowledge in practice as well. In this paper, we present the process and findings of a field experiment taken up in the Sikkim State of India during 2022-23 to raise oak seedlings in the nursery. The techniques and methods for collection of acorns, seed separation, screening, pretreatment, substrate, germination chamber, planting, transplantation and weeding is explained in detail. A germination percentage of eighty percentage was achieved and it is hoped that the seedlings will attain a height of 60 cm by the end of the second year and will be ready for out planting. We hope that the learnings from this experiment will help to standardize the regeneration techniques of oak trees and contribute towards the restoration of these forests.

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Restoring Mediterranean Oaks: Enhancing Conservation and Management through Networked Plot Monitoring and Plot-based Analysis

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Sustainably managing forests as targeted in SDG 15 requires understanding the current state of forests, the factors that constrain or threaten this sustainability, and the factors or actions that facilitate it. Monitoring the dynamics of trees and forest development, as a whole, needs to be ensured to understand the most limiting factors and promote adaptive management actions to ensure the sustainability of the forests. In the case of oaks in temperate regions and those with Mediterranean influence, situations of fragility in guaranteeing sustainability have been reported for some species (e.g. *Quercus suber*, *Q. ilex*), with forests developing with a very low density or undergoing decline mainly due to biotic threats. Climate change may make this scenario even more complex, with an expected increase in summer temperatures and/or a potential reduction in rainfall, conditioning seed production, seedling development and tree survival. These forest systems' fragility often worsens when operated as intensive agro-pastoral or silvoagropastoral systems.

Assessing the existing oak forests' and monitoring the development of representative oak forest is therefore fundamental to diagnosing the current state and deciding on the appropriate practices to guarantee forests' conservation, restoration or improvement. With this presentation the authors summarize activities developed under the Mobilizing Agenda "TransForm- Digital transformation of the forest sector towards a resilient and low-carbon economy", supported by the PRR-Recovery and Resilience Plan and the European NextGeneration EU Funds, involving data collection and the establishment of a network of experimental forest plots to analyze and forecast forest dynamics. The network will facilitate the assessment of the development of the forests under different situations and practices, providing valuable information regarding current pressures and in the context of climate change. By implementing this plot-based analysis, it is aimed to ensure the long-term sustainability and productivity of oak forests, benefiting the entire forestry sector value chain. Additionally, the authors will explore measurement protocols for assessing natural regeneration, providing valuable insights into the restoration process. By leveraging the analytical power of plot-based analysis and combining it with expertise in oak forest management, we can develop effective strategies to enhance the resilience and productivity of Mediterranean oak forests.

Status and drivers of oak decline in Western European forests

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: In Western European temperate forests, oak (*Quercus petraea* and *Quercus robur*) covers vast areas, provide habitats for a wide range of organisms, deliver essential ecosystem services, and are often considered more resilient than other native species. Yet, oak populations are declining due to changes in forest management, ungulate herbivory, and interspecific competition. In this presentation, we will synthesize different research studies - that we published between 2010 and 2023 – on the status and drivers of oak decline in Belgium. According to the regional forest inventory, oak-dominated stands cover 23 % of the forest area (32% of the standing stock), often mixed with beech (*Fagus sylvatica*) and hornbeam (*Carpinus betulus*). Although oak is abundant, the lack of young oak trees with a diameter of less than 30 cm is obvious and concerning. In oak-beech forests managed with continuous cover forestry (CCF), we studied the interspecific competition between naturally regenerated oak, beech and hornbeam seedlings in 23 sites and 242 fenced plots between 2009 and 2011. We modelled and evidenced that oak seedlings grew significantly slower than beech and hornbeam across the whole range of light conditions studied. We also monitored regeneration in 734 pairs of fenced and unfenced plots between 2016 and 2021. Ungulates strongly reduced the growth of oak, hornbeam, birch and rowan seedlings whereas the growth of beech and spruce was little or unaffected. Nevertheless, oak seedlings grew more slowly than the mixed species regardless of herbivory pressure. We also found that oak regeneration may not benefit from being surrounded by palatable neighbors as the positive effect of browsing diversion would likely be offset by increased interspecific competition. To successfully regenerate oak with CCF, we then recommend maintaining a closed canopy (PACL < 5%) until oak seedlings emerge, then protecting seedlings from browsing, reducing overstory density (PACL > 20%) and manually releasing oak seedlings from competition. In the study area, oak can regenerate spontaneously outside the forests but is unlikely to regenerate in forest understory without manual intervention.

The impact of mammals on seed fate of Castanopsis indica in a subtropical forest

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: Mammals, particularly rodents, play important roles as both seed predators and dispersers for Fagaceae plants. Previous studies in temperate regions have revealed that mammals' impact on the regeneration of Fagaceae plants can vary between the mast and non-mast seeding years. However, there is limited research on the effects of mammals on Fagaceae plants in tropical and subtropical areas. To address this gap, we utilized magnetic tags to track the fate of *Castanopsis indica* seeds in an evergreen broad-leaved forest in Taiwan during the non-mast years of 2022 and 2023. We distinguished the effects of rodents and medium to large mammals on seed dispersal and regeneration based on the presence or absence of exclosures. We used camera traps to identify the species of seed predators. To test the "seed effectiveness hypothesis," we compared our findings with a previous study conducted in the same area during a mast year. Our results showed that without exclosures, all 160 seeds were consumed by Formosan macaques (*Macaca cyclopis*) within three days, which was not reported in the previous study. With the implementation of exclosures, *Niviventer coninga* emerged as the primary seed predator and disperser. Out of the total seeds, 70% (n=112) were consumed *in situ*, 19.4% (n=31) were dispersed, and 10.6% (n=17) could not be located. The dispersed seeds were found across various microhabitats, including 17 in the litter layer, five in the soil layer, five under fallen logs, and four among fern roots. Approximately 80.6% (n=25) of the seeds were dispersed within a distance of less than 5 m, while the remaining 19.4% (n=6) were dispersed between 5-10 m. Of the dispersed seeds, 19 were consumed after dispersal, seven were consumed after being cached, and five were successfully cached. Fifty days later, all cached seeds either fell victim to mammalian consumption, became infested by insects, or perished due to mold. Regrettably, none of the seeds were successfully established as seedlings. These findings contrast with mast years, showcasing a higher rate of seed consumption, shorter dispersal distances, and a lower rate of seed caching, which further support the hypothesis.

Using Strip Clearcutting to Facilitate Northern Red Oak Establishment in a Mixed Appalachian Hardwood Forest

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: The challenge of regenerating oak species (*Quercus* spp.) is well documented throughout eastern hardwood forests. Successful oak regeneration is often linked to the availability of competitive seedlings. In undisturbed Appalachian hardwood forests, the light levels (<5%) are often too low to allow oak seedlings to persist long enough to attain competitive sizes. While these stands are harvested, shade tolerant advance reproduction outcompetes newer oak seedlings, while fast-growing intolerant species overtop the slow growing oak seedlings on the higher quality sites. Manipulating light conditions ahead of regeneration treatments can make oak seedlings more competitive, but these treatments require 10 or more years to create competitive advance reproduction. Despite its demonstrated effectiveness, widespread adoption of such treatments (*e.g.*, midstory removal) is hindered by high costs, limited markets for small diameter stems, and the need for immediate landowner income. Therefore, alternatives that are low cost and provide meaningful harvest volumes are needed. A strip clearcut regeneration harvest, where 50% of the area is cut and the remaining 50% is harvested once regeneration is well-established (e.g., 5-10 yr), was conducted in a mature Appalachian hardwood forest as an alternative to tradition harvest techniques. Red oak seedlings were planted along a light gradient between cut and residual strips. After nine growing seasons, the northern red oak seedlings showed significant and contrasting responses to the light gradients created by the harvest treatment relative to survival and height growth—higher survival within the shaded residual strips and greater height growth in the cut portions of the stand.

Who is the winner? Effect of experimental fire and herbivory on early successional tree cover in grassland after five years

T3.3 Disappearing oak woods: conservation and management of global oak forests

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Abstract: The early history of silviculture was by and large a struggle to achieve unconstrained wood production, by active protection from both natural and anthropogenic disturbances, mainly fire or herbivory, usually in the form of grass-feeding livestock that in the past grazed on forest land. Today, fire has negligible influence on tree succession in Europe and cattle is either indoors or grazing on productive agricultural fields, with no influence on tree successions. Only browsers remain in the landscape, not capable of producing grazing lawns, but sometimes capable of slowing down successional rates into dense forest. Here, we imitated the disturbance regimes of pre-historical European landscapes by subjecting young tree successions in grasslands to fire and herbivory (both cattle and wild fauna). In many parts of NW Europe, these conditions were also characterising the reality of early foresters 200 years ago, when cattle-based economy was dominating large parts of Europe. In a full factorial experiment 2400 young trees were subject to Fire (annual spring grass fire), Herbivory, Fire+Herbivory and compared with ungrazed and unburned fenced control in a landscape scale experiment at Nordens Ark at the Swedish west coast. In 2015 we planted 480 seedlings each of oak, pine, spruce, birch and lime in 24 plots on previous forest plantation land, under a grazing restoration since 2012. After six vegetation seasons we evaluated tree cover from drone pictures. There was a strong effect of fencing on tree survival compared to both herbivory and fire. Herbivory had stronger effect than Fire on the growth of trees. We discuss our results in the, for silviculture, contrasting vegetation consumer approach, partly based on a previously published article (Amsten et al 2021) and looking at tree succession from a grassland perspective. We argue our results are of high relevance to the restoration of seminatural grasslands of NW Europe, harboring a large part of Europes biological heritage with high- value trees, especially oaks (Quercus spp) being an integrated component.

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

Biodiversity conservation of ash forest in the face of an alien species invasions

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Due to global change and human activity, forests are exposed to unprecedented threats from non-native pests and pathogens. The European ash (*Fraxinus excelsior*) is a commercially, ecologically and culturally important tree species in woodland and urban greeneries. Currently, irreversible economic and ecological losses of ash (*Fraxinus*) species related to ash dieback fungus (*Hymenoscyphus fraxineus*) in Europe and the emerald ash borer (*Agrilus planipennis*) in North America, both of which are indigenous to Asia. Recently, both of these invasive species were found in Ukraine, where they were overlapping in a forest area on the same trees of *Fraxinus exselsior* and *F. pennsylvanica*. Therefore, *Fraxinus* species, particularly *F. excelsior* and its associated species in Europe will be at a high risk for decline or extinction. Moreover, emerald ash borer-associated mycobiome could play a crucial role in ash mortality and structural failure of wood, at the same time beetles act as vector aggressive pathogens and pioneer wood degraders which contribute significantly to the tree mortality and loss of wood integrity in ash trees. Therefore, both invasive species may induce shifts in biodiversity in ash forests, but the direction of these shifts largely depends on tree resistance and fungal communities vectored by emerald ash borer. There are only a few fungal species, belonging to the phylum Basidiomycota have the capacity to degrade lignified polysaccharides, therefore, the study of the effect of new wood decomposers on local fungi is crucial. Most of the research on emerald ash borer has focused on its biology and management, and only a few studies have been published with a focus on the fungal community associated with the beetles in North America. However, tree-killing pathogens associated with xylophagous beetles represent one of the most significant contributors to forest health deterioration and may cause large-scale forest disturbances followed by loss of biomass and carbon storage, and degradation of ecosystem services Identifying the fungal community associated with emerald ash borer helps in understanding the importance these fungal species on European ash and whether new-coming species impact on local biodiversity before invasion spread through Europe.

Biological control of Ailanthus altissima based on Verticillium nonalfalfae isolate Vert56

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Invasive species pose significant ecological and economic challenges worldwide. *Ailanthus altissima*, commonly known as tree-of-heaven, is such an invasive tree species that has rapidly spread across various regions, outcompeting native vegetation and causing detrimental effects on ecosystem stability. *Ailanthus* usually spreads from urban heat islands into rural areas and it is expected to expand its range due to climate change. The search for effective control agents to mitigate the spread of *A. altissima* has led to investigations on the potential use of *Verticillium nonalfalfae*, a soil-borne fungal pathogen. The isolate Vert56, originating from Styria, Austria, has shown promise as a biocontrol agent due to its distinct adaption to *Ailanthus*. Successfully inoculated trees exhibit severe wilting symptoms within a short period of time leading to mortality lacking the undesired development of root sprouts or sucker shoots. Furthermore, the pathogen has the ability to spread within clonal root systems, that often develop after unsuccessful control attempts. However, the use of *V. nonalfalfae* as a control agent must also consider potentially occurring non-target effects. The genus *Verticillium* includes well-known plant pathogens, particularly in agriculture, that pose significant threats to infected plants as no directly effective plant protection measures are available to date. Therefore, risk assessment studies are essential to determine the feasibility and safety of using *V. nonalfalfae* isolate Vert56 for the biological control of *Ailanthus*. Until now, about 70 species, including the most important agricultural crops known to be susceptible, have been tested for susceptibility to isolate Vert56. So far, all tested ligneous plants proved to be tolerant or resistant to the pathogen, whereas three herbaceous plants, i.e. *Petunia x hybrida*, *Cucumis sativus* and *Spinacia oleracea,* displayed symptoms of wilting after artificial inoculation, but only *S. oleracea* was equally affected as *Ailanthus*. Based on the current results, an emergency authorization with limited indications regarding application period and area has been granted in Austria since 2017. Further investigations of non-target effects, the pathogen's persistence in the soil and potential pathways of transmission are currently ongoing with the goal to achieve an "active substance authorization" for *V. nonalfalfae* isolate Vert56 within the European Union.

Detecting the distribution of invasive plant Mikania micrantha in artificial forests using deep learning and UAV imagery

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: This study investigates the application of deep learning and Unmanned Aerial Vehicle (UAV) imagery in detecting the presence of the invasive plant *Mikania micrantha* in artificial forests. *Mikania micrantha* is a fast-growing invasive plant that can climb and cover other plants, damaging or killing them by intercepting sunlight and causing suffocation. In addition to affecting the growth of crops in orchards and farmland, it also poses significant threats to artificial forests and secondary forests. In this research, UAVs were used to capture images of artificial forest sites affected by *Mikania micrantha*. During the flowering period of *Mikania micrantha*, it exhibits clustered white flowers, making it easier to distinguish. Therefore, we conducted UAV imaging specifically during the flowering period of *Mikania micrantha* (from November to January of the following year). The spatial ultra-high resolution of UAV imagery was utilized to capture detailed images of *Mikania micrantha*. The deep learning module in ArcGIS Pro was utilized to analyze UAV imagery, and a deep convolutional neural network (CNN) was employed for the detection of *Mikania micrantha*. The UAV images were classified and segmented to identify the distribution of *Mikania micrantha*. The classification tests of Mikania micrantha, utilizing deep learning techniques, all achieved an overall accuracy above 90%. The study demonstrates that deep learning models yield high accuracy in detecting *Mikania micrantha*. This approach holds promising applications for effectively managing invasive plants in forestry operations. Accurate detection of *Mikania micrantha*'s distribution enables the development of appropriate prevention and control strategies, minimizing its ecological impact on artificial forests.

Management of invasive tree Broussonetia papyrifera using biochar technology

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Ecosystems are seriously threatened by the rapid and uncontrolled spread of invasive plants and innovative solutions are urgently required to control the invading plant population. Massive biomass production by the invasive plants and their impacts on adjacent ecosystems necessitates the development of innovative solutions to control and sustainably manage the plant invasion. Pyrolyzing invasive plants into biochar could be one of the suitable approaches in this regard, as biochar prepared from invasive plants can serve dual benefits, by improving crop growth and assisting in management of our invasive allies. *Broussonetia papyrifera* (L.) L'Hér. ex Vent. is a commonly found invasive tree native to Asia and the Pacific islands and has emerged as one of the leading plant invaders in the subtropical urban ecosystems of an urban city of India, Chandigarh (30°45′N; 76°45′E; 348 m above sea level). To prepare the biochar, litter fall leaves of *B. papyrifera* were collected, ground, and charred in an electric muffle furnace at 400 ºC for 30 mins hold time. The obtained biochar was characterized by Fourier-transformed infra-red (FT-IR) spectroscopy and Scanning electron microscopy equipped with Electron dispersive spectroscopy (SEM-EDS). The physiochemical attributes of biochar including pH, EC, moisture, and ash content were determined. The biochar was applied in soil at the rates of 0, 0.5, 1.0, 2.0 and 4%, and growth responses of *Cajanus cajan* L. was assessed after 30 days under greenhouse conditions. The results showed a significant ($P < 0.05$) improvement in crop root and shoot growth parameters, chlorophyll content, photosynthetic efficiency, and biochemical attributes after biochar amendment, compared to the control. Most of the crop growth and biochemical attributes were found maximum at 2% biochar amendment rate, thereafter a decline was observed. However, soil properties, viz., pH, EC, moisture, enzyme activities were found to increase with the increasing biochar amendment rates. Therefore, biochar prepared from *B. papyrifera* can be utilized in agricultural fields for uplifting the growth of food crops that will further assist in sustainable management of this invasive tree in urban systems.

Keywords: Biochar, urban ecosystem, leguminous plants, plant growth, biomass

Managing an invasive species affecting multiple key sectors of economy: The example of Prosopis juliflora in Kenya

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Biological invasions have become an important component of human-induced global change, along with other factors such as habitat transformation and climate change. Invasive species have negative impacts on biodiversity, ecosystem services and human well- being. Some of the invasive species have met the objectives for their introduction such as production of wood and non-wood products and control of soil erosion on one hand and devastation of ecosystems and habitats. Prosopis (mesquite) species epitomizes this conflict of interest dilemma in Eastern Africa. In Kenya, *Prosopis juliflora* covers over 1.5 million hectares and expands at the rate of 15- 20% every year, with a potential to cover 85% of land. From 2015 to 2021, the research project Woody Weeds (WW) was conducted in Kenya, Ethiopia, and Tanzania to assess the impacts of Prosopis on people and the environment, and to identify management practices that help mitigating negative impacts. Results from the project were shared with the Kenyan Ministry of Environment and Forestry and subsequently used as a rationale for developing a National Strategy and Action Plan for effective management of Prosopis (NPS) in Kenya. The Kenyan and Swiss partners of WW managed to secure additional funds to support Kenyan institutions in implementing the NPS in three pilot counties: Baringo, Isiolo and Tana River. This new project, Woody Weeds + (WW+) is working with stakeholders at national, county, and local levels to fast track the implementation of the NPS. The paper describes the process taken in the development of a national strategy and action plan to address an environmental problem affecting multiple key sectors of economy such as environment, agriculture and tourism among others. It further describes the establishment and roll out of a governance system and institutional arrangements to help institutions at the national, county, and local decision-making levels to concretize and operationalize the NPS by developing spatially explicit Prosopis management strategies and integrate them in land use, land restoration or integrated development plans. The model is envisaged to be useful in an African context and therefore an important guide for possible adoption by other affected countries in Eastern Africa and beyond.

On Robinia pseudoacacia L. impacts on biodiversity in Europe

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Black locust (*Robinia pseudoacacia* L.) is among the most frequent and widespread non-native tree in Europe. It is commonly found in many cities and town as well as in rural and forest landscapes; it was planted in the past as an ornamental and for forestry but it is also invading abandoned and semi-natural environments. A number of studies have focused on its impacts to biodiversity by comparing different forest types and conditions. These studies have mainly focused on plant diversity; however, comparisons exist also for other taxonomic groups (e.g. birds, insects). A variety of different effects, positive, neutral and negative, have been observed, raging from reduction in species richness to hosting species of conservation interest. This tree species is also important for the array of ecosystem services and goods that it can provide. Through the use of different case studies, implications for forest and semi-natural habitat management will be discussed by considering different silvicultural approaches as well as different landscape settings (e.g. urban vs. rural).

Patch size matters to oribatid mite communities impacted by garlic mustard (Alliaria petiolata, Brassicaceae) invasion in urban forests

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Investment in management of non-native species in forested ecosystems should be informed by knowledge of impact, including the consequences for native biodiversity and ecosystem functioning. Soil mites in the suborder Oribatida may be particularly useful to evaluate the impacts of plant invasions, since they are bioindicators of disturbance and soil ecosystem health, but more research is needed to understand how oribatid mites respond to plant invasion. The objective of this study was to determine the effect of invasion of urban forest understories by an allelopathic weed (garlic mustard, *Alliaria petiolata* (Brassicaceae)) on belowground oribatid mite (Oribatida) species and communities. We examined adult oribatid (> 300 µm) community assemblage data along with species richness, evenness, Shannon diversity, and abundance in central Alberta, Canada, in plots invaded with garlic mustard as well as uninvaded plots with native vegetation at two sites over two years. We also evaluated the impact of several environmental covariates. Results suggest that the impact of garlic mustard invasion on oribatid mite communities is mediated by the size of the invaded patch. No community-level impacts were detected when considering invasion as a binary variable, but garlic mustard patch area influenced oribatid mite community composition and was positively related to species richness and several abundance metrics. Site was also dominant factor influencing oribatid mite communities, influencing every community-level metric evaluated as a main and/or interactive factor. Significant impacts of year, litter depth, and canopy cover were also detected. Our results indicate that the impact of forest understory invasion by garlic mustard on oribatid mite communities depends on the size of the invaded area, and we discuss implications for management of invasive weeds in forested ecosystems.

Population predictive growth models: Invasive plant species in Natural and Established Forest Ecosystem

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Models can be used to predict population dynamics and assess various management options. Population dynamics description by matrix models provides powerful means of understanding the factors that affects population structures. This study aimed at developing population projection model for estimation of invasive structures distributions within forest ecosystems and agricultural lands. Mt. Elgon forest ecosystem blocks consisting of *Kimothon, Kiptogot, Saboti, Suam and Kitale* were considered for the study. Experimental design was adopted with transects (1km long) and plots 300m apart depending on the environmental variability within different forest blocks. The plots were 10 by 10m for assessing mature trees, 5 by 5m for sapling and 1 by 1m for seedling.Data on the invasive tree species were collected on height, diameter at breast height and also on the soil characteristics, mean temperature, mean rainfall, altitude collated and forest disturbances patterns due to grazing, logging, footpaths and roads of all the sampled plots. This study mapped invasive species distribution using occurrence data and distribution model to identify occurrence and project population using the growth rates. The variables used to predicts population distribution included: elevation, ecological factors like rainfall, soil, temperature and factors such as grazing, disturbances to forest through harvesting and deforestation.The model predictions shows that the distributions of *Cestrum aurantiacum* is on the increases under different climatic scenarios; with current extents estimation expected to increase at differential rate with growth values λ (Lambda) for different forest blocks of Kiptogot at λ=4.48, Kimothon λ=3.31, Saboti λ=3.37, Suam λ=2.89 and Kitale township area at λ=3.91. The forest is continued to be invaded by *Cestrum aurantiacum* with the five year assessment of Mt Elgon ecosystem forest blocks showing invasion of blocks at Kimothon currently covering 356.45 ha constituting 3.23% of the total area within the block, Kiptogot 307.74ha (3.0%), Saboti 295.38ha (2.94%) and Saum 16.75ha (0.70%). This study provides critical information that is useful to decision makers in rehabilitation and management of the current state of invasive species within the forest ecosystems, agricultural lands and in achieving the Sustainable Development Goals aimed at the protection, restoration, and promotion of sustainable use of terrestrial ecosystems.

Raccoon impacts in German forests – status quo and future prospects

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Predatory mammals are an integral part of ecosystems worldwide. Sustainable management of these species relies on sound knowledge of biological-ecological relationships. The North American raccoon is an introduced carnivore species in Germany and one of the most omnivorous mammals worldwide. These and other alien species can play a significant role in the eco-lo-gi-cal balance of their newly encountered biotopes, particularly if their habits overlap and com-pete with those of the native animals. Due to a vast in-crease of raccoon numbers over the last years and its continuous expansion, a controversial dis-cus-sion arose regarding the influence of the new inha-bi--tants on indigenous and especially protected species, as well as the poten----tial trans-mission of diseases and parasites.

Despite a high demand for management strategies and recommendations, the development of sustainable and efficient measures often fails due to insufficient knowledge about the species and extensive evidence-based know-ledge about the actual consequences of raccoon settle-ment, primarily in natural land-scapes, is still lacking. Aiming to elucidate the wildlife biology and potential impact of this intro-duced spe-cies, a long-term and integrated research project was conducted from 2006 to 2017 in the north-eastern area of distribution (Müritz National Park; Mecklenburg-Western Pomerania; www. projekt-waschbaer.de). In 16 different sub studies and by telemetric control of 69 raccoons, profound data on the population biology in the allochthonous distribution area was collected for the first time. Based on the hypothesis that raccoons may affect local stock of ecological relevant species through predation, raccoon faecal samples from this semi-natural lowland beech forest were analysed in terms of food ecology and endoparasite infestation, and linked to available resources in the study area, which is a prerequisite for assessing local impact.

The poster highlights the ecological background of raccoon settlement Germany and shows the potential influence as well as future management options.

Tree insect pests and pathogens: socio-economic and environmental impacts in urban areas

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Trees contribute greatly to urban environments and human well-being, yet relatively little is known about the extent to which a rising incidence of tree insect pests and pathogens may be affecting these contributions. To address this issue, we undertook a systematic review and synthesis of the diverse global empirical evidence on the impacts of urban tree insect pests and pathogens, using bibliographic databases. Following screening and appraisal of over 3000 articles from a wide range of fields, 100 studies from 28 countries, spanning 1979–2021, were conceptually sorted into a three-part framework: (1) environmental impacts, representing 95 of the studies, including those reporting on tree damage, mortality, reduced growth, and changes in tree function; (2) social impacts were reported by 35 of studies, including on aesthetics, human health, and safety hazards; and (3) economic impacts, reported in 24 of studies, including on costs of pest management, and economic losses. There has been a considerable increase in urban impact studies since 2011. Evidence gaps exist on impacts on climate-regulating capacity, including temperature regulation, water retention, soil erosion, and wind protection, but also on specific hazards, nuisances, human well-being, property damages, and hazard liabilities. As a knowledge synthesis, this article presents the best available evidence of urban tree insect / pathogen impacts to guide policy, management and further research. It will enable us to better forecast how growing threats will affect the urban forest and plan for these eventualities.

Using Unmanned Aerial Systems)Drones) to Monitor Invasive Species and Hazard Rate Urban Forest Trees

T3.4 Ecological and socioeconomic analysis of invasive species in forest ecosystems under changing environmental scenario

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Abstract: Unmanned Aerial Systems (UASs) or drones are increasing in technology and camera design. UASs were used to hazard rate urban forest trees for pests, including invasive species. By taking images directly above the desired species, an accuate position can be acquired. Both the image and the location can then be located in a Geographic Information System (GIS) for information on the host and the impact of species species. Data can then be saved in the GIS sysstem and shared via ArcGIS Online or saved into the Citizen Science base of iNaturalist or another archival data base. By using the UAS, multiple maps and images of change over time can be captured to monitor pest progression. UAS data can be collected in the visable spectral or uisng multispectral sensors to domcument impact. Using UASs for mapping produces both two dimensional and three dimensional images of the pest occurrence and change in the host plant. For increased accuracy of location, a base station or Ground Control Points can be used for mapping. Examples of monitoring include the occurrence and distribution of the crapemyrle bark scale and the associated sooty mold as an invasive species. In one case, severe investations were countered by removal of the crapemyrtle and replacing with spire oak. Following a cold snap, UASs were used to map out damage over time and the impact on the crapemyrtle. The invasive emerald ash borer can be mapped by UASs and utilized for removal and replanting of non-susceptible species. Using UASs to hazard rate urban forest pests indicated no differences compared to the stand visual method from the ground. For leafy mistletoe, twice as many plants were counted compared to traditional ground methods. During a severe ice storm, UASs were used to evalute each tree for damage and the information was used to remove damage limbs and improve the tree vigor from bark beetle pests. The use of UASs are increasing and the improved cameras and sensors expand the capabilty of of the urban forest pest managers to make informed decisions on both native and invasive speices in a changing climate world.

T3.5 Emerging socio-economic dynamics in Wildland-Urban Interface forest landscapes

A novel framework for wildfire risk management in touristic infrastructures

T3.5 Emerging socio-economic dynamics in Wildland-Urban Interface forest landscapes

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Abstract: Forest fires in Europe pose an increasing challenge to populated areas at the wildland-urban interface (WUI), where people and assets are exposed to fire and smoke hazards. This vulnerability is particularly evident in tourist destinations within WUI areas, especially in Mediterranean Europe, which heavily relies on nature and culture for its touristic appeal.

The impact of forest fires on tourism is multidimensional. It can affect the touristic population which includes groups of people having different background in terms of their culture, spoken language(s), risk perception, and past experience with fire. In addition, fire can directly damage tourism facilities, accommodations, infrastructure, and services, which can take a significant amount of time to replace. Furthermore, wildfires can lead both to a direct decrease in revenue within the tourism industry, as well as long-term consequences in terms of reduced tourism demand and loss of tourist expenditure.

Unfortunately, local authorities often lack an appropriate approach to managing the wildfire threat in tourist destinations and installations. Tourists themselves are generally unaware of the fire risks, while tourism-oriented buildings and facilities do not consistently incorporate fire preparation measures. There is hence a need of adopting common and coherent messages and recommendations for prevention and protection practices in this sector.

This communication introduces a novel framework for wildfire risk prevention and protection planning in touristic infrastructures. It encompasses new methods, tools, and guidelines for analysing fire exposure and vulnerability of assets and people, as well as proposing risk mitigation actions for specific touristic infrastructures (e.g., hotels, resorts, camping areas, etc.). The practical application of this framework is demonstrated in the cross-border touristic region of Cap de Creus, situated on the Spanish-French border within the province of Girona. Developed with the objective of establishing harmonized criteria throughout Mediterranean Europe, this approach offers a comprehensive solution that enables touristic areas across the European Union to increase their resilience against wildfires. By adopting this approach, these areas can effectively safeguard the well-being of both their visitors and the local communities that rely on tourism for their sustenance.

Assessing residents' tradeoffs between wildfire risk and environmental benefits in California's Wildland-Urban Interface

T3.5 Emerging socio-economic dynamics in Wildland-Urban Interface forest landscapes

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Abstract: Wildfires across the state of California are becoming larger, more frequent, and more severe. This shift has been primarily attributed to a global change in climate along with local changes in wildland fuel quantity. An expansion of the wildland-urban interface (WUI) has heightened the risks for communities and people living in the WUI. In California, 3 out of every 10 homes are in the WUI – a number that is expected to increase in the coming years. Further research is needed to better understand how to minimize the effect of wildfires on communities in California's WUI, especially for vulnerable residents.

This project investigates how the impact of wildfire might be reduced in diverse WUI communities across California by better understanding residents' perceptions of fuel treatments and their associated environmental benefits. A multimodal survey approach was conducted in 16 WUI communities, that represent a mix of wildfire risk, wildfire history, population size, geographic location, and social vulnerability. The survey included questions about the geography and vegetation around participants' residences and neighborhoods, preferred fuel treatment activities to reduce wildfire risk, and socio-demographic information.

The economic value of the trade-offs between wildfire and ecosystem benefits from fuel treatments was quantified using a choice experiment survey of residents. Through the choice experiment, survey respondents selected their preferred type of fuel treatment(s) (e.g., prescribed fire, mechanical thinning, etc.) and the level of benefits they and their communities could receive from ecosystem services (e.g., improved air quality, water quality, and greater recreation opportunities).

The survey results may help resource managers develop more research-based planning processes for the WUI. For example, the results may help stakeholders better understand residents' preferred fuel treatment activities and their potential ecosystem service benefits in WUI watersheds. Second, the results may help land and fire managers better target spatially-specific fuel management strategies by better accounting for vulnerable communities' preferences for their surrounding landscapes. Lastly, insights gathered from this project may provide critical information to improve policy uptake and decision-making such as the recent Climate 21 Memo's opportunities for the USDA to address development in the WUI and the increased use of prescribed fire.

Changes in forest structure and community composition in the wildland-urban interface of the northern United States

T3.5 Emerging socio-economic dynamics in Wildland-Urban Interface forest landscapes

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Abstract: Given the myriad ecological and social benefits of forest ecosystems, there is a need to better understand how development in the wildland-urban interface (WUI) alters the structure and composition of forested ecosystems. It has been asserted that the WUI concept is relevant for a broad suite of natural resource management challenges beyond fire risk, and yet little is known about how WUI expansion affects forest stand structure and composition, particularly in regions where fire is less prominent. In a space-for-time analysis we utilized US Forest Service Forest Inventory and Analysis (FIA) plots and housing density data to examine differences in forest characteristics of the northern US across three WUI change classes based on whether the WUI housing density threshold was reached before 1990 (old-WUI), between 1990-2020 (new-WUI), or not yet reached (non-WUI). Forest in the WUI had greater carbon storage, with greater aboveground biomass, relative stand density, and more live trees per hectare than non-WUI forest. WUI forest also had less structural diversity compared to non-WUI forest, with significantly fewer saplings, seedlings, and dead trees per hectare, suggesting a reduced capacity for forest regeneration. We found that WUI forest was more likely to be privately owned than non-WUI forest, but less likely to be under corporate ownership than non-WUI forest. However, we did not find evidence of differences in harvesting intensity between WUI classes. Using a longitudinal approach, we then examined two decades of remeasurement data from FIA plots in the northeastern US to identify changes in forest composition using four major forest communities identified via a Bayesian hierarchical model. We found that fir-spruce and maple-beech-birch occurred at higher mean proportion and were more often the dominant community type in non-WUI forest than ash-cherry or pine-hemlock communities. While individual communities consistently increased or decreased over time, rates of change did not vary substantially among WUI change classes. Longitudinal forest inventory data and space-for-time substitutions can shed light on processes of tree mortality, forest regeneration, and community composition change inside and outside the WUI, with implications for ecosystem services for surrounding communities and management-relevant advice for forest landowners and landscape planners.

Funding Forest Resilience in the Wildland Urban Interface with Environmental Markets

T3.5 Emerging socio-economic dynamics in Wildland-Urban Interface forest landscapes

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Abstract: Globally, there is a substantial need to improve the pace and scale of landscape management in order to conserve natural resources and limit the negative impacts of climate change. Many of the management activities occur in WUI areas in order to protect and preserve resources for human communities. However, the cost of performing such management is often restrictively large, resulting in needed work going unfunded. At the same time, active management of these landscapes is crucial for the provision of ecosystem services, including water, carbon sequestration, wood products, and protection from wildfire. There is a growing market for ecosystem services, whereby management is funded by benefiters of one or several of these services. As a result, the careful monetization of ecosystem services can help cover the funding shortfall of management and improve forest resilience within the WUI. In this study, we develop an economic model of environmental markets based on the ways in which the benefits of ecosystem services are internalized by potential investors. Several ecosystem services, including water provision, water quality, and wood products, are private goods whose benefits might be directly internalized or realized by investors. Others, such as carbon sequestration, biodiversity, or cultural amenities, are public goods which can be internalized by private investors only through their reputational or marketing benefits. Despite the fact that the private benefits can be directly internalized by investors, our model shows that the private reputational benefits obtained from funding non-excludable ecosystem services can be used to increase the financial attractiveness of the investment by lowering the cost of the project relative to the excludable private benefits obtained by investors. After demonstrating this, we apply it to a WUI landscape in Northern California. We utilize an ensemble of landscape models, including models of landscape processes, forest disturbances, hydrological resources, and management activities. We use the model ensemble to estimate the management requirements to achieve a pre-defined management target whereby disturbance return intervals match historic averages. Next, we calculate the costs of achieving this. We use our economic model to both value ecosystem services, and construct the optimal funding mechanism for the landscape.

Grazing amidst forests as Nature-Based Solution for wildfire risk mitigation

T3.5 Emerging socio-economic dynamics in Wildland-Urban Interface forest landscapes
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Abstract: Wildfire risk poses severe challenges to human lives and assets (particularly in the Wildland-Urban Interface), including forest investments, cultural landscapes and identities, and to the conservation of natural features. In response to those, substantial public (and in some areas also private) funding is devoted to fire suppression, yet their limited efficiency lately increases the interest towards interventions to reduce fire hazard, exposure and vulnerability. These fire risk reduction measures typically manage the vegetation mechanically to control the fuel load, and consequently hinder the chances for high intensity fires. However, these interventions are costly and not free from environmental impacts.

Nature-Based Solutions (NBS) rely on natural processes and inputs as alternative to grey, non-renewable-based alternatives. Two main NBS emerge in wildfire risk management suiting the WUI: use of crop belts, and controlled grazing around a security fringe.

This study analyses the controlled grazing agreements within the metropolitan area of Barcelona (Spain), based on existing experiences and prospective agreements in additional municipalities. We analyse socio-economic and governance aspects, to draw lessons learned for highly urbanised areas. Focus groups with main stakeholders, in-depth interviews and surveys constitute our data sources.

Our preliminary results show that shepherds working in the WUI are in a very delicate situation due to the highly anthropized territory, the numerous (often inconsistent) administrative requirements, and social conflicts with locals. These challenges add to their economic vulnerability -also present in extensive grazing elsewhere. The marketing of their produce jointly with the current incentives seem not to suffice in some areas, as shepherds tend to abandon the activity. Ensuring (e.g. with municipal funds) supporting infrastructure (e.g. water points, night shelter following all animal welfare and urban requirements) can overcome some of their productive function barriers. These findings call for a coherence review of the administrative framework to facilitate non-productive-focused activities (e.g. wildfire oriented) related to grazing, as well as to define a fair payment scheme to incentivise and socially recognise the shepherd's work. We also detected the larger acceptance among the local population of the grazing interventions when accompanied with educational and awareness campaigns.

Why can't they just burn it? Organizational barriers to implementing hazardous fuel treatments in the WUI

T3.5 Emerging socio-economic dynamics in Wildland-Urban Interface forest landscapes

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Abstract: In 2022, the Secretary of Agriculture and the Chief of the Forest Service in the United States charged the Forest Service with implementing a 10-year Wildfire Crisis Strategy (WCS) (Vilsack, 2022). In response, the US Forest Service has implemented a robust prescribed fire plan that aims to build a workforce capacity in the agency to treat and assist in treating millions of acres of forest land in the Wildland Urban Interface (WUI) across the western United States (USDA, 2022). One way to address the challenge of performing hazardous fuel treatments in the WUI is to investigate organizational barriers, knowledge gaps, and resource needs for successful implementation of hazardous fuel programs. While scholars in a variety of disciplines have investigated barriers to addressing wildfire risk and prescribed fire burning (Jakes 2002; McCaffrey 2006; Christianson 2015; Lake 2021), they have not investigated the everyday workplace and workforce organizational barriers to implementing large scale prescribed burning along the WUI. We employ a mixed methods approach through use of surveys, focus groups, and in-depth interviews to gather data for both developing quantitative statistical models and qualitative information that can provide greater coherence, depth, and density to questions related to organizational barriers, knowledge gaps, and resource needs for successful implementation of the WCS. Using a mixed methods approach, this study investigates and uncovers 1) innovative operational capacities being leveraged by US Forest Service to meet the heavy demands placed on the agency's fire service; 2) How the US Forest Service fire program is implementing prescribed fire treatments at the scale specified in the WCS; 3) real and perceived organizational barriers, and 4) innovations to implement the WCS over the next 10 years.

T3.6 Extent and ecological consequences of hunting in the forest ecosystems

Assessment and prioritization of threats to biodiversity in Benin

T3.6 Extent and ecological consequences of hunting in the forest ecosystems

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Abstract: Biodiversity loss is a pressing global issue, and understanding the specific threats faced by different regions is crucial for effective conservation efforts. Using literature review and survey of 32 conducted study to identify and prioritize threats to biodiversity in Benin, a country in West Africa. Data from the survey of 32 experts were analyzed to determine the frequency of citation for each threat, categorized by threat level and taxon or ecosystem. Benin is home to a diverse array of species, including approximately 2,807 plant species, 552 higher fungal species, 603 bird species, 157 mammal species (with two-thirds comprising small mammals), 103 reptile species, 221 freshwater fish species, 136 marine and brackish fish species, and 51 amphibian species. Despite the existence of protected areas and forest reserves, which cover approximately 25% of the national territory, the data indicated a decrease in species populations over time. The main threats identified in the assessment were associated with agriculture and aquaculture, resource exploitation (particularly in the forestry sector), and residential and commercial development. These threats consistently emerged across different sources, highlighting their significant impact on biodiversity in Benin. This assessment provides valuable insights into the threats faced by biodiversity in Benin and serves as a basis for developing targeted conservation strategies. It underscores the need for proactive measures to mitigate these threats and ensure the long-term sustainability of Benin's rich and unique ecosystems.

Impact of game browsing and hunting strategies on climate resilience and development of our forests.

T3.6 Extent and ecological consequences of hunting in the forest ecosystems

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Abstract: The predicted far-reaching climate changes make it necessary to adapt the management of forests. Investigations into the effects of different management strategies is the aim of the joint project WiWaldI. Maintaining functional diversity in forest ecosystems means being able to secure a minimum of adaptation options for forest development in the future.

The Chair of Forest Protection at the Technical University of Dresden is responsible for assessing the effects and potential of regulation measures with regard to the influence of game. For this purpose, the occurring game species, game condition, game management and habitat structures are considered. Strongly distributed herbivores such as roe deer and their influence on forest development are in conflict with human objectives. In this context, the results obtained from the investigations and the comparison of interdisciplinary data collections by the project partners are used to derive statements on ecological and economic assessment, forest development influenced by game, an adapted hunting and the implementation of a future-oriented development of forests. A multifactorial approach is the new approach in order to approximate dynamic processes. Biodiversity conservation is a decisive objective in politics and practice to prepare ways into the future under today's impacts on forest ecosystems.

The presentation will discuss the embedding of stability factors that can be influenced by humans, the experimental design and methodology for recording influencing factors and preliminary results for sustainable development.

SPECIES PREFERRED AND HUNTING TOOLS NORMALLY USED IN PROTECTED RAINFOREST AREAS IN GHANA

T3.6 Extent and ecological consequences of hunting in the forest ecosystems

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Abstract: Hunting in the rainforests protected areas has been a secrete business because the laws frowns on that yet, local people sneak into these areas to hunt for wildlife species. The goal of this study was to learn more about this illegal hunting, focusing in particular on the species that are hunted and the typical hunting techniques. Data was collected from 17 poachers who were arrested in the Kakum Conservation Area in Ghana over a period of 12 months. The data revealed that 69 animals were poached belonging to 12 species being recorded. Most of the animals were mammals, with primates being the most prominent species among the animals poached. Shotguns and wire snares were the main hunting methods used. The findings of this study can be used to inform conservation efforts in protected rainforest areas, as well as to develop strategies to reduce poaching and protect vulnerable species.

Wildlife trade at the interface between deep-rooted animal-based traditional medicine and unregulated harvesting of wild animals in West Africa

T3.6 Extent and ecological consequences of hunting in the forest ecosystems

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Abstract: Local/or domestic trade remains one of data poor components of wildlife crime that is essential to fill the gap for an enlightened combat against the illegal wildlife trade at national, regional and international scales. The study constitutes the first larger field-based sampling efforts that deciphered wildlife trade in West Africa through the distribution of wildlife markets, diversity of species traded and the extent of trafficking chain using the georeferencing of wildlife sale sites, and semi-structured interviews with 75 vendors in the 10 largest traditional medicine markets in Benin. GPS coordinates of wildlife markets were used to map their geographic distribution and assess their spatial patterns. We used a generalized linear model to determine the drivers underlying the spatial patterns of wildlife markets. A circular layout was designed to delineate the geographic extent of wildlife trade in terms of supplying sources. The wildlife trade took place through 121 sale sites including 15 and 106 bushmeat and traditional medicine markets respectively. The spatial analysis of wildlife markets exhibited an aggregative distribution pattern with a spatial temporality (permanent vs. periodic) that was significantly explained by the type of market, the number of stalls in the markets ($P < 0.001$) and the status of occurrence municipalities of markets ($P < 0.001$). Wildlife trade for traditional medicine affected 61, 96 and 268 reptile, mammal and bird species respectively, and included high concern conservation profile species on both the IUCN Red List, the Red List for Benin and CITES Appendices but also the fully protected species under the National legislation. Our study delineated a national wildlife trade that violated Beninese laws, contrary to international commitments, and that was substantially fed by all countries of the West African Economic and Monetary Union (WAEMU) except (Guinea-Bissau) and 12 out of the 15 countries of the Economic Community of West African States (ECOWAS) as source countries. It provided substantial data on wildlife trade structure and driving forces that could help informed decision-making for strict regulation to protect threatened species in Benin, an effective law enforcement in order to eradicate national and regional illegal wildlife trade.

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

Changes in tree diversity in response to elevation and climatic gradient

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Conservation of tree species and their diversity becomes the key concern in light of climate change. Nowadays, climate change implications are beginning to emerge even in tropical belts. As a result of that, species diversity and richness in tropical forests are shrinking. Species diversity patterns over the landscape scale are difficult to understand due to the complex integration of various factors. The link between the spatial distribution of the tree species and variability in climate and other abiotic factors is yet to be investigated at the country level of tropical Sri Lanka. Studying the variation of tree diversity along the elevation and climatic gradient will enhance our understanding of how species diversity and richness vary in response to various climatic and edaphic factors. The current study hypothesises that a critical biodiversity zone can be created and expanded along the gradient of climate and elevation. Therefore, our study aims to assess and analyze the diversity variation and distribution pattern of the plant species in forest cover along an altitudinal gradient of Sri Lanka and study the effect of elevation and climatic factors on species diversity and species richness.

Our study was extended from the Southern to the Eastern provinces along the transect. The area lies between 6° 4'38.40" N and 8° 6'8.68"N latitude, covering the cross section of the Sri Lankan landscape across three agroclimatic zones and three elevation zones. Tree-level data were adopted from the National Forest Inventory (NFI) database of the Forest Department of Sri Lanka, and Bioclimatic (BIOCLIM) data were extracted from Worldclim.org. Generalized Additive Models (GAMs) were used to explore the relationship between diversity and abiotic factors.

Results revealed that the lowest number of species was recorded at higher elevation areas. This implies that higher elevation areas should be conserved with necessary conservation measures. The highest species richness and Shannon diversity were recorded in the mid-elevation. The lower altitudinal areas preferred moderate species richness, Shannon diversity and related parameters. This study concluded that the high elevation was the critical point of species richness and Shannon diversity.

Key Words: Tree diversity, Richness, Elevation gradient, Climate change

Development and implementation of genetic and forest indicators for monitoring biodiversity in forest stands

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Over the past few years, anthropogenic activities and climate change are causing a substantial loss of biodiversity at ecological, specific, and genetic diversity level. Indeed, it has long been established that forests should be managed in an ecologically sustainable way. Given the fundamental role of forest ecosystems for life on earth, the genetic resources and biodiversity that characterize forest systems must be conserved because they are important resources from social, economic, and environmental perspectives. Biodiversity conservation is one of the main goals of ecologically sustainable forestry. In this regard, it is necessary to develop a predictive model for sustainable forest management (SFM). The objective of this work is to develop genetic and forest indicators in different European Forest Types (EFTs) to implement the predictive model for sustainable forest management. The indicators were developed considering two conditions, unmanaged forest and managed forest to identify the best silvicultural practice that presents higher biodiversity which is a powerful tool in response to climate change. To achieve this goal, genetic and forest indicators were calculated using collected data regarding trees species and the complex symbiont relationship between ectomycorrhizal and trees from the 20 demonstration sites of the project LIFE SySTEMiC located in Italy, Croatia, and Slovenia. Forest indicators such as stand structure, deadwood, species diversity, and species evenness were calculated. Whereas for genetic indicators, we decided to use the *Essential Biodiversity Variables* (EBVs) specifically genetic diversity, genetic differentiation, *inbreeding*, and effective population size (*Ne*) to synthesize complex biodiversity data obtained by mediating observations of genetic diversity within species, populations, and ecosystems. Both types of indicators represent an input to the predictive model by providing information on the best adaptive management of forest stands in response to climate change, considering both species and different silvicultural treatment conditions.

Diversity and Distribution of Caddisfly (Trichoptera) in Molawin-Dampalit Subwatershed in Mt. Makiling Forest Reserve, Philippines

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Caddisflies are one of the most diverse groups of aquatic insects and are members of the EPT (Ephemeroptera, Plecoptera, and Trichoptera) which are considered as important indicator species in freshwater ecosystems. The survey of immature stages of caddisflies was done in six sampling sites comprising the upstream, midstream, and downstream gradients of the Molawin-Dampalit Subwatershed in Mt. Makiling Forest Reserve, Philippines. A total of 336 caddisflies belonging to 12 morphospecies and three families (Hydropsychidae, Philopotamidae, and Rhyacophilidae) were assessed in the Molawin-Dampalit Subwatershed. The family Hydropsychidae or the net-spinning caddisflies were the most abundant comprising 86% of all individuals recorded. The highest occurrence of caddisflies was observed in the upstream sites. While the highest species diversity was recorded in sites situated in the downstream areas. High similarity values were measured in caddisfly assemblages in upper and midstream areas. The caddisfly assemblages can be useful in identifying differences in the level of disturbances in streams. The study serves as a baseline on caddisfly diversity in Mt. Makiling Forest Reserve. A more in-depth study should be done on their ecology which can be later crucial in environmental monitoring leading to proper management of their habitats and protection of other possible endemic caddisfly species in Mt. Makiling Forest Reserve.

Drought diminishes successional trajectories and aboveground biomass accumulation rate during secondary succession in a tropical forest of China

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Tropical secondary forests play an increasing role in biodiversity conservation and climate change mitigation, but the relative importance of biotic and abiotic factors and demographic progresses driving successional trajectory and biomass dynamics in these ecosystems remain largely unclear, especially under increasing drought intensity. We compared the variations in demographic rates, community composition, and aboveground biomass (AGB) dynamics among three successional stages, with four 1-ha plots each in young secondary forest (YS), old secondary forest (OS), and old-growth forest (OG) on Hainan Island, China, using ten years of census data (2010 – 2020). The result showed that the diameter growth, mortality, and recruitment rates were the highest in the YS and the lowest at the OG. Growth decreased and recruitment increased during the second census period (2015-2020) during which there were two extended droughts, but there was no significant change in mortality rate. The successional trajectories of YS and OS showed a slow but directional trend towards the OG, with a weak stochastic component. The five species groups made different contributions to the successional trajectory. Generalists contributed to the convergence of secondary forests to old-growth forests, while old-growth specialists contributed to divergence. Secondary species usually contributed to divergence with old-growth forest, and young-secondary specialists had a stronger effect than old-secondary specialists. The divergence effect of rare species on similarity occurred only when presence data were used. When based on abundance data, rare species had little effect on community similarity. The different drought frequency between the two intervals was the dominant factor predicting the net change of AGB. With high-frequency droughts, the loss of AGB intensified and the increment rate of AGB decreased, especially in old-growth forests. Successional stage was another major factor affecting AGB and its dynamics, showing a positive relationship with AGB stock and a negative relationship with net AGB change. Species richness and fungal richness had a significant positive association with AGB, while soil available nutrient had a significant negative relationship. Thus, with the intensification of global climate change, the effects of high-frequency drought events should be taken into account when studying the factors affecting recovery in tropical secondary forests.

Effect of microclimate on wood decay fungi

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Wood decay fungi play a central role in decomposition and carbon cycling. It has been hypothesized that fungal decay rates are affected by microclimate. So far, the effect of microclimate on fungal communities affecting decay processes have been shown in the lab environment, but not in natural conditions. Thus, by measuring inner-wood temperatures, calculating wood decay rates and sampling fungi communities, we test in this research project for the first time hypotheses related to this. We expect i) the highest decomposition rate in dense forests in southern Sweden and the lowest decomposition rate on clear-cuts in northern Sweden, and ii) that fungi communities vary on a latitudinal and on a shade gradient and thus, certain decayer profiles dominate in various microclimatic conditions. In 2020, 450 Norway spruce logs were distributed along a 1200 km long latitudinal gradient in Sweden and wood samples were taken from each log. The logs were set up under varying microclimatic conditions and their inner-log temperature was measured hourly. In 2023, we will take new wood samples to measure the decompositions rate and identify the fungi communities of the logs. Preliminary results will be presented at the conference.

Enhancing forest monitoring by biodiversity indicators - a case study in Britz, Germany

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: The loss of biodiversity - especially due to climate change and intensive land use - calls for effective solutions and targeted recommendations. For this purpose, comprehensive data-sets from existing monitoring networks like ICP Forests or the NFIs deliver information to describe state and change of biodiversity. Unfortunately, important character-species requiring specialist knowledge cost intensive equipment are not considered there. To gain a deeper insight it is therefore important to complement the existing monitoring systems with in-depth studies to understand links and feedback-systems and determine thresholds which later allow up-scaling.

To develop methods bridging the gap between widely available data and in-depth studies we use our intensive forest monitoring site “Britz” in Germany, a highly equipped site stocked with five different tree species. We encourage and facilitate research from colleagues collecting high-resolution biodiversity data like e.g. insect abundance, bird diversity, or pollen occurrence. This data can be combined with detailed ecological data following the internationally harmonised manuals of ICP Forests. Furthermore, we assess forest structure and vitality by UAV and remote sensing, measure light regimes, and provide meteorological and increment data.

Through this we create a data base for understanding the drivers on species and biodiversity and to define the linkages to parameters available at larger-scale. Here we present our approach of linking the long-standing ground-based monitoring to provide structural information as a basis for up-scaling high-resolution data to specialists working on our site. This poster is an invitation for using existing infrastructures and increase their value by adding further studies.

FOREST GENETIC MONITORING: PRELIMINARY RESULTS OF A MICROSATELLITE-BASED GENETIC STUDY OF SCOTS PINE AND PEDUNCULATE OAK IN LITHUANIA

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Scots pine and Pedunculate oak are among economically and ecologically most important forest trees species covering 36.8% of total forest area in Lithuania (34.5% and 2.3% respectively). Ongoing climate and environmental change, human activities have been recognised as one of the main threats to forest trees and its ecosystems. Thus, high genetic diversity of forest tree populations ensures that forests can grow, adapt and evolve under rapid environmental change. The objective of Forest Genetic Monitoring (FGM) is to assess the current state of forest genetic resources (FGR) (e.g. gene conservation units) and quantify relevant changes at a temporal scale, in order to preserve long-term adaptive evolutionary potential. At EU level several projects (FORGER, LIFEGENMON, GENTREE, etc.) and European forest genetic recourses programme (EUFORGEN) has emphasized the importance of FGM and presented various FGM methods. Moreover, EUFORGEN recognise FGM of the forest genetic conservation units as important tool for conservation and sustainable use of FGR. Therefore, our study is presenting DNA marker-based case study of FGM of Scots pine and Pedunculate oak in four forest genetic reserves (Marcinkonys and Braziūkai for Scots pine; Ignalina and Dzirmiskis for Pedunculate oak) in Lithuania. In total we genotyped 350 trees of Scots pine and 400 trees of Pedunculate oak (two generations adults and natural regeneration in each). Our results based on microsatellite (nSSR) markers (11 for Scots pine and 14 for Pedunculate oak) provides us a baseline DNA markers-based data and shows how nSSR's can be used for FGM system in Lithuania.

First results indicate that genetic diversity was distributed evenly from adults to natural regeneration in both species. Data regarding genetic variation and genetic differentiation among Scots pine and Pedunculate oak FGM plots and among adult trees and natural regeneration within the plots will be presented. Furthermore, continuation of FGM in future will allow us to draw conclusions about the population's evolutionary capacities through comparison to the recently assessed baseline data.

Impact of climate change on biodiversity and food security: an implications for challenges of feeding the future

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Abstract
Climate change is happening due to natural factors and human activities. It expressively alters biodiversity, agricultural production, and food security. Mainly, narrowly adapted and endemic species are under extinction. Accordingly, concerns over species extinction are warranted as it provides food for all life forms and primary health care for more than 60–80% of humans globally. Nevertheless, the impact of climate change on biodiversity and food security has been recognized, little is explored compared to the magnitude of the problem globally. Therefore, the objectives of this systematic review are to identify, appraise, and synthesize the link between climate change, biodiversity, and food security. Data, climatic models, emission, migration, and extinction scenarios, and outputs from previous publications were used. Due to climate change, distributions of species have shifted to higher elevations at a median rate of 11.0 m and 16.9 km per decade to higher latitudes. Accordingly, extinction rates of 1103 species under migration scenarios, provide 21–23% with unlimited migration and 38–52% with no migration. When an environmental variation occurs on a timescale shorter than the life of the plant any response could be in terms of a plastic phenotype. However, phenotypic plasticity could buffer species against the long-term effects of climate change. Furthermore, climate change affects food security particularly in communities and locations that depend on rain-fed agriculture. Crops and plants have thresholds beyond which growth and yield are compromised. Accordingly, agricultural yields in Africa alone could be decline by more than 30% in 2050. Therefore, solving food shortages through bringing extra land into agriculture and exploiting new fish stocks is a costly solution, when protecting biodiversity is given priority. Therefore, mitigating food waste, compensating food-insecure people conserving biodiversity, effective use of genetic resources, and traditional ecological knowledge could decrease further biodiversity loss, and meet food security under climate change scenarios. However, achieving food security under such scenario requires strong policies, releasing high-yielding stress resistant varieties, developing climate resilient irrigation structures, and agriculture. Therefore, degraded land restoration, land use changes, use of bio-energy, sustainable forest management, and community based biodiversity conservation are recommended to mitigate climate change impacts.

Indicators of habitat quality in a national inventory of deciduous forest

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Traditionally when monitoring forests field effort in different forest types is proportional to how common the forest is. It is a robust method to give an unbiased general view of forests. In a largely forested country such as Sweden however, with a high proportion of managed and coniferous forest, that gives inadequate information on the less common older deciduous forests. Therefore, the Swedish Environmental Protection Agency initiated a national inventory of deciduous forest in 2020 with the aim to collect data on older deciduous forests as a complement to the Swedish National Forest Inventory. The responsibility fell on the National Inventories of Landscapes in Sweden (NILS).

In a hierarchy of samples NILS now inventories older deciduous forests in dense samples focusing on forest habitats included in the Habitat Directive in EU:s Article 17 (Annex I-habitats), and forests that could be restored to such habitats. To further acquire information on aspects of quality in these forests a number of field variables are collected in a slightly larger area than the plot level with the more general aim to assess the quality of the forest for conservation, in addition to plot level variables on tree, shrub and field layers. A species inventory supplements the biotope aspects of quality.

Two indicators, biotope and species value, are combined from variables measured in the field. Together they provide categories that we use to estimate the proportion of area with good conservation status for different types of deciduous forest. A similar method could also be used to estimate proportion of areas in need of restoration. In both cases, using a monitoring program with field inventory gives an unbiased method to follow the development of forests with respect to these indicators over time.

Metapocyrtus Weevils: Potential Forest Biodiversity Indicator in the Philippines

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: *Metapocyrtus* is a genus of weevils belonging to the Tribe Pachyrhynchini and is endemic to the Philippines. These weevils have gained attention in recent years as potential indicators of forest biodiversity for effective forest management strategies. This abstract provides an overview of *Metapocyrtus* and highlights its significance as a forest biodiversity indicator. These weevils are small in size, measuring approximately 5 to 15 millimeters in length, and are characterized by their distinctive body shape and coloration. They exhibit a wide range of morphological variations within the genus, making them an interesting subject for taxonomic and ecological studies. *Metapocyrtus* species are mainly found in forested areas, particularly in lowland and montane tropical forests across different islands of the Philippines. These weevils are documented in association with 46 species of host plants belonging to 31 families, primarily flowering plants and ferns, which are dominant in Philippine forests. The presence and abundance of different *Metapocyrtus* species can indicate the overall health and diversity of these host plant communities. As weevils are sensitive to environmental changes, their population dynamics and species composition can reflect alterations in forest structure, disturbance levels, and habitat quality. Forest management practices often require efficient monitoring tools to assess the impact of management interventions on biodiversity conservation. *Metapocyrtus* weevils have the potential to serve as reliable indicators due to their specificity to certain host plants and their sensitivity to forest disturbances. By conducting surveys and monitoring the presence and abundance of *Metapocyrtus* species, forest managers can gain insights into the success or failure of conservation efforts and make informed decisions regarding sustainable forest management practices. Further research and collaborative efforts are needed to fully understand the ecological role of *Metapocyrtus* weevils and their potential for practical application in forest management. Such studies will provide a solid scientific basis for incorporating these weevils into comprehensive forest monitoring programs and conservation strategies, ultimately enhancing the sustainable management and preservation of the rich forest biodiversity in the Philippines.

Monitoring biodiversity impact of reforestation: insights from a pilot project to assess the potential of soil environmental DNA metabarcoding

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Monitoring the impact of reforestation projects on biodiversity is essential to assessing the effectiveness and ecological benefits. Traditional methods for measuring biodiversity often rely on time-consuming and resource-intensive approaches, which makes them difficult to scale up for large-scale reforestation projects. Advancements in environmental DNA (eDNA) metabarcoding hold great potential to circumvent that limitation.

To explore the potential of eDNA metabarcoding to assess the biodiversity impact of reforestation projects, we conducted a pilot project focused on soil biodiversity. Soil communities are ubiquitous, respond rapidly to changes in the environment, and are a vital component of ecosystems, making them potentially suitable indicators for reforestation monitoring. The pilot, conducted in Spain, compared fungal, bacterial, and invertebrate biodiversity of a degraded area set aside for reforestation with a mature coniferous and a mature broadleaf forest. Biodiversity indicators related to species composition, species richness, and functional and evolutionary diversity were compared between the different sites. Most soil biodiversity indicators were found higher in the mature forests, marking a potential reference for soil biodiversity for the reforested site.

We found that the advantages of soil eDNA metabarcoding as a biodiversity metric are numerous. Firstly, it provides a non-invasive, relatively easy, and cost-effective alternative to traditional sampling methods, reducing the need for labor-intensive field surveys by experts. Secondly, it provides a robust and standardizable method to monitor biodiversity across large spatial scales and over extended periods, providing valuable insights into long-term biodiversity dynamics. Despite its potential, we found the application of soil eDNA metabarcoding as a biodiversity metric has some challenges. These include protocols for selecting reference forests, identification of the most informative soil biodiversity indicators to assess reforestation success, and analyses and reporting methodologies.

We think the application and acceptance of eDNA as a biodiversity metric would benefit from standardized and internationally agreed methodologies. By sharing experiences from this pilot, we aim to discuss potential solutions to the above-named challenges to accommodate the applicability of soil eDNA metabarcoding as a method to measure the biodiversity impact of reforestation projects.

Options and scenarios for voluntary commitments to biodiversity in the ASALs of Kenya: A case of Kajiado County

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Approximately 80% of Kenya is arid and semi-arid with land degradation being a major threat to biodiversity. There is a need to reverse biodiversity loss in ASALs by mainstreaming biodiversity in the key economic sectors. The BIODEV2030 project, funded by the French Development Agency (AFD) and implemented by the International Union for Conservation of Nature (IUCN) and the Ministry of Environment, Climate Change and Forestry (MECCF) assessed options for mainstreaming biodiversity in the livestock, forestry, and crop production sectors for sustainable and resilient economies. We assessed possible scenarios for voluntary commitments to biodiversity by private sector actors in Kajiado County, Kenya. The Species Threat Abatement and Restoration (STAR) metric was used to identify key economic sectors with a potential to drive degradation in Kenyan ASALs while the Drivers, Pressures, State, Impact, and Responses (DPSIR) framework was applied in conceptualizing the study. A desktop review of literature, key informant interviews (KII), and focus group discussions (FGDs) were used for data collection. Value Chain Analysis (VCA), weights and scores, and participatory ranking techniques were used for data analysis. Target respondents for the assignment included value chain actors, government agencies, and Civil Society Organizations (CSOs). The main drivers of degradation were overgrazing and overstocking (44%), deforestation (24%), conversion of land to crop production (17%), and intensive horticulture production (15%). Possible voluntary commitments to biodiversity in the livestock sector were building the capacity of actors, adherence to grazing management plans, adoption of sustainable stocking rates, and use of certification schemes for livestock inputs and products. In the crops sub-sector, capacity building, adopting efficient farming technologies, and use of sustainability standards were ranked highest. Promotion of alternative energy sources, efficient charcoal production and utilization, adoption of nature-based enterprises, payment for ecosystem services, and forest certification were recommended by actors in the forestry sector. These commitments could be promoted to mainstream biodiversity in the three sectors thus improve on biodiversity conservation and the livelihoods of ASAL communities.

Keywords: Biodiversity, Conservation, Voluntary Commitments

ORF: an operational framework to assess resilience in forest social-ecological systems

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Resilience is addressed from multiple perspectives dealing with the planning and management of forest social-ecological systems. However, we lack a unified framework for the operational application of related indicators for resilience quantitative assessment. We show a framework aiming to provide (i) a common terminology and procedure to be used across different perspectives, and (ii) an operational approach to assess forest resilience in front of disturbances or stressors challenging biodiversity and climatic emergences.

The proposed resilience operational framework (ORF) is built upon several elements: *system variables* (e.g., ecosystem services and elements of the ecosystem-related value chain), *disturbances and stressors* acting at given spatio-temporal scales, *reference state* whose characteristics are intended to be maintained or achieved, and *metrics* that compare the observed values of the system variables with the reference state. These elements fit into a rationale devoted to identify co-drivers and manageable predictors that reflect the mechanisms involved in the resilience of the selected system variables. So, system variables represent indicators describing forest social-ecological systems, while resilience predictors correspond to indicators predicting resilience performance. In both cases biodiversity-related indicators play a major role to resilience assessments.

To validate and ensure the consistency of ORF, we conducted a review of studies assessing resilience in forest social-ecological systems. We screened 524 papers for identifying the use of the abovementioned ORF elements. This review demonstrated that ORF elements were commonly acknowledged in most studies. Additionally, most studies identified resilience predictors, a key element for planning and developing actions to promote resilience. Nevertheless, the complete rationale behind the framework was not always evident, particularly in socioeconomic-focused studies, in which quantification was infrequent. Therefore, this exercise identified major gaps in the current assessment of forest resilience.

The proposed ORF allows to standardize terminology and facilitates the measure and the promotion of resilience in forest systems, by providing a common procedure for its assessment. This procedure permits comparability and identification of key factors that determine resilience, and therefore the establishment of targets for decision-making and management.

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Phenology, seed conservation improvement and moisture sorption isotherms of the endangered African rosewood (Pterocarpus erinaceus).

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Phenological observation enables us to understand and predict the response of species to climatic changes. Generating information on phenology, seed propagation and storage improvement techniques of threatened species, remain critical for their long-term conservation. African rosewood (*Pterocarpus erinaceus*), is, highly exploited and endangered tree species in arid and semi-arid forest zones of West Africa. This study assessed the timing of the reproductive life cycle of the species relative to local climatic variables for 3 year period within the forest and savannah zones of Ghana. The effects of four pretreatments on seed germination, and seedling vigour was also evaluated. We further examined varying temperature, duration and packaging material on seed storage deterioration. Period and intensity of leaf flushing, flowering, fruiting and seed dispersal among individual trees were monitored, scored and analysed with drone-captured images. Seed moisture sorption isotherms at 20, 25 and 30°C were characterized by equilibrating seed samples on series of lithium chloride (LiCl) solutions. Data were fitted to four mathematical models to determine the most suitable for describing phenology seed moisture sorption isotherms. Results indicate that fruiting and seed dispersal phenophases occurred between November -February, with a strong positive correlation ($r = 0.93412$) with mean monthly maximum temperatures. Moisture sorption isotherms showed a sigmoid (*S*-shape) profile, characteristic of orthodox seeds, and best described by the Henderson equation. Our findings show ideal ideal seasons for seed collection and we recommend the adoption of orthodox seed storage protocols for effective *P. erinaceus ex-situ* conservation.

Remote Sensing Based Forest Indicators in Support of Restoration Monitoring

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: The UN decade on Ecosystem Restoration has put the need for ecosystem monitoring high on the political agenda. The European Commission has reacted by putting forward a proposal for a European Nature Restoration Law (NRL), which is currently in consultation stage. This and other biodiversity targets heavily rely on indicators to measure the policies' impacts and to allow for enforcement measures. Suitable indicators need to be accurate and meaningful, they should be cost-effective and quickly accessible, transparent in their generation, and provide spatially explicit information – ideally all at once. One of the problems with most indicators is, that they are typically either not specific enough or not easy to generate because they require very specific data. Remote sensing (RS) is a way to provide indicators in a spatially explicit manner and over larger areas than field assessments.

Here, we analyzed different forest related indicators (forest area, forest fragmentation, species distribution, canopy height and vertical structure) over time for the assessment of restoration progress in both forest areas and wetlands. We evaluated multi-temporal assessments of forest restoration after severe disturbance (e.g. from bark beetle) and for bog restoration monitoring. We found that LiDAR is especially important for monitoring restoration success, i.e. for identifying areas of shrub and tree encroachment in a bog, where apparently the water table was not increased sufficiently or still had an unwanted drain. LiDAR can also be used to detect drainage infrastructure such as channels and dams. For the forest restoration, we found foliage height diversity to be a useful indicator to monitor progress, as it includes the vertical forest structure. Satellite-based disturbance detection further helps to keep up with changes. With regards to the NRL, the technology for monitoring using a combination of remote sensing and in-situ tools is available, but there is still a significant lack of clarity in terms of targets. Assessing the naturalness of forest ecosystems is based on the comparison of structure and tree species composition of the current forest with a natural forest of the same type.

Resilience Indicators for Assessing Resilience of Forest Biodiversity: A Multi-Criteria Analysis Approach

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Forest ecosystems play a crucial role in maintaining biodiversity and providing essential ecological services. However, the increasing pressures from human activities, environmental changes and climate change emergencies necessitate effective forest management strategies to ensure their long-term resilience. In our study we aim to develop a comprehensive set of indicators suitable for assessing forest resilience, with a particular focus on biodiversity. The indicators chosen should be sensitive to maintenance or enhancement of forest biodiversity through active forest management.

To accomplish this objective, first, an extensive preselection of potential indicators and parameters relevant to forest resilience was conducted. These indicators encompass a wide range of ecological, social, and economic aspects, reflecting the multifaceted nature of forests and forestry. In a next step we applied a multi-criteria analysis together with relevant stakeholders. By integrating multiple quantitative and qualitative criteria, we have identified the most pertinent indicators to assess forest resilience through forest management planning and decision-making.

Our study aims to generate a concise set of key indicators that can effectively capture and monitor changes in forest resilience. These indicators will serve as easily applicable tools for assessing the fitness, functionality, and adaptive capacity of forest ecosystems, particularly in terms of biodiversity maintenance and enhancement. The concise set of indicators will provide a practical framework for monitoring and evaluating forest resilience, enabling informed decision-making and the formulation of targeted management strategies. By aligning active forest management practices with the identified indicators, it becomes feasible to optimize management interventions towards fostering resilient forest ecosystems.

Status and dynamics of deadwood in Austrian forests

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: The positive correlation between deadwood occurrence and dependent species richness of a forest is widely recognized, which is likely a reason that deadwood volume is often used as an indicator for forest biodiversity or naturalness. However, it's important to note that an evaluation of forest biodiversity by using the amount of deadwood has to take into consideration forest type. A comparison between different forest types may not be reliable, as values do not account for varying growing conditions at different sites. Moreover, while the deadwood amount is an important metric, it's not sufficient for assessing the conservation value and naturalness of forests. The compositional diversity of deadwood is equally important as it determines the potential habitats for dependent species. Accordingly, shaping the compositional diversity of deadwood, e.g. in terms of species, diameter, decomposition, and position, can enhance the conservation status of certain saproxylic species that require high structural diversity. In many managed and but even also in currently unmanaged temperate forests of Europe, especially standing deadwood is occurring in small quantities. To date, few studies have examined how environmental factors, forest management, and changing climate affect the availability and dynamics of standing deadwood. This presentation provides critical insights into how tree-, forest stand- and landscape-level parameters, forest management, and climate affect the characteristics and dynamics of deadwood in different forest types of unmanaged and managed forests of Austria. Understanding the impact of various factors on deadwood availability and dynamics is crucial to ensure the continuity of deadwood supply and the conservation of deadwood-dependent species.

SUSTAINABILITY INDEX OF BIODIVERSITY AND CARBON RESOURCES FROM SELECTED REHABILITATION AREAS IN QUEZON PROVINCE, PHILIPPINES

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: The forest landscape of the Philippines is subject to intensive rehabilitation through the national greening program and carbon sink Initiatives due to years of deforestation that contributed to biodiversity loss, climate change, and sustainable development goals. This study focused on the evaluation of the sustainability index (SI) regarding biodiversity and carbon resources in monitored and assessed rehabilitation from Pagbilao and Padre Burgos, Quezon Province. Rehabilitation from mangroves (Ilayang Polo, Marao, Ibabang Kinagunan) and upland (Binahaan, Ilayang Palsabangon, Ilayang Bagumbungan) was selected. Bioindicators (species composition, diversity, conservation, biodiversity, growth, regeneration, biomass, and carbon) were described and indexed using a Likert scale to correlate values with the natural ecosystem. All bioindicators of biodiversity and carbon resources defined the progress of rehabilitation. SI of regeneration was very high in mangroves (525-5,850 seedlings ha^{-1}) than in upland (1,150-11,425 seedlings ha^{-1}) and positively correlated ($r<1$) with natural forest, indicating succession. Carbon aboveground was higher in upland than in mangroves with high scale and positively correlated similarly with diversity, conservation, and biometrics with the natural forest which indicates a more functional upland ecosystem that mimics natural forest. Overall, success in mangrove and upland rehabilitation can contribute to biodiversity conservation to mitigate climate change. Monitoring biodiversity and carbon hence can ensure the sustainability of ecosystems for generations but should further study other factors to improve the index.

The Foamy World of Spittlebugs: Indicator of a healthy environment in the Philippines

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: The Cercopidae is the largest family of Cercopoidea and form the largest group of xylem-sap sucking insects. They are commonly known as froghoppers or spittlebugs. Mostly land-dwelling worldwide, their juveniles can live in spumous frothy excreta sometimes called ‘bubble nest’ or ‘crachat de coucou’ (cockoo spit) in French. The presence of the protective frothy excreta has been traditionally identified as a protection against predation, parasitism and it creates a microclimate that reduces the risks of overheating and desiccation. This group of insects including its counterpart familyfrom the new word region, the family Ischnorhinidae, has been reported to be a serious pests of some economically important crops in some parts of the world. However, in the Philippines, all the 70 species recorded in the country werenot reported to be attacking the crops. Philippine Cercopids are sensitive to any changes in the environment or any disturbances, as indicated by very few to almost no species observed in the human intervened area. Most of the species are found in the forest ecosystem. The higher the number of Cercopidae in a particular ecosystem, the less disturbance in the ecosystem. This makes Cercopidae a good candidate as tool in monitoring the status of the environment. For the last 7 to 9 years of studying the taxonomy and systematics of the Philippine Cercopidae through collection trips and expeditions, a series of taxa new to science were described. Along with their taxonomy, their ecology, associated hosplants from different families were also observed, mostly are only found the in the found in the undisturbed forest ecosystem. Despite these available data about their taxonomy, host plants and ecology, knowledge remains very limited and further research is relevant to fully understand the value of Cercopidae in the Philippine biodiversity. These informations could then be used in formulating effective management strategies in protecting our forest ecosystem and also conserving the species, which are forest dependent and are used as bioindicator.

The FOrest Biodiversity Index (FOBI): monitoring the biodiversity potential of Britain's public forests over space and time

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: A third of British forests are owned or managed by public forest agencies. In adherence with the UK 25-year environment plan and international, legally binding treaties and targets, such as the post-2020 Global Biodiversity Framework, these government bodies have a statutory duty of care to safeguard and enhance the biodiversity value of these areas. However, they often lack the information and tools with which to evidence progress towards meeting these obligations and to justify their decision making. To help fill this information need, we have co-developed the FOrest Biodiversity Index (FOBI), a quantitative, transparent and repeatable approach for assessing the biodiversity potential of Britain's publicly owned forests. This index is a composite of several extent, condition, connectivity and diversity 'metrics', or proxies of forest biodiversity, which are measured using forest survey data and other spatially explicit landcover information. Scores are assigned to individual forests and are aggregated using a stepped approach to provide FOBI indices at Local and Landscape levels, and four sub-indices levels. These can be interrogated and reported at annual intervals, at all levels of the index and at a range of scales (for individual forest, regionally and nationally). The results can therefore inform locally targeted action, as well as national long-term monitoring and reporting. We will provide insights from the co-development of this approach and application to several annual time stamps in England and Scotland. We discuss the steps taken to ensure the statistical robustness of the index, the use of benchmarks to assess changes over time, and the provision of online, interactive tools for visualising and exploring results over space and time. Opportunities and challenges for future enhancements and applications will be also considered, such as the potential to extend the approach beyond the public forests to relatively data-poor private forests.

The role of leaf phenology in the carbon and biodiversity cobenefits in a tropical forest

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Second-growth tropical forests offer important carbon and biodiversity cobenefits (i.e., positive aboveground carbon stock (AGC) and species richness relationship), and different leaf functional types of tree species. Leaf deciduousness is an important functional trait that can contribute to seasonal and spatial changes in carbon balance. In this context, we investigated the distribution pattern of AGC, species richness, and functional dominance among trees with differing leaf phenology as well as the carbon and biodiversity cobenefits of tree communities in contrasting topographical conditions in a second-growth tropical Atlantic forest. We sampled fourteen 20 m x 40 m plots established in the forest and classified tree species into three categories groups with respect to the leaf phenology (deciduous, semideciduous, and evergreen species) according to field observations and literature. The AGC were estimated from the allometric equations for forest biomass. We calculated community-weighted mean metrics based on mean functional traits related to AGC capacity in tropical forest: wood density and maximum tree height. We found that evergreen species showed higher richness, while the deciduous species had a greater contribution to AGC. Our tested models showed a significant positive relationship between AGC and species richness. Thus, the variation in AGC had the strongest positive effect on species richness of evergreen, and semideciduous trees. Furthermore, when analyzing the interaction between predictors, it is observed that evergreen and semideciduous trees are responsible for a strong and positive relationship between AGC and species richness. However, no effects of deciduous trees were observed. Thus, the leaf phenology groups can affect the relationships between species richness and AGC. For example, deciduous species are key to maintaining higher carbon stock with smaller numbers of species; meanwhile evergreen species are important to maintain a higher species richness. Thus, leaf phenology groups could be responsible for important cobenefits in tropical forests. Therefore, this study showed a relevant result on the relative contribution of leaf phenology groups in the carbon and biodiversity cobenefits along topographic gradients. This study can allow the selection of key tree species to improve the management, conservation, and restoration practices in tropical forests.

The role of riparian buffers for biodiversity in boreal forests: does one size fit all?

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Forest harvesting can have abiotic and biotic impacts on adjacent aquatic ecosystems, ranging from nutrient leaching to an extra input in sediments, which may permanently alter aquatic communities and food webs. Riparian buffers are strips of forest left uncut along water bodies and wetlands following harvests. These buffers have been used across the world as the only silvicultural tool aiming to mitigate the impacts of forest harvesting on aquatic ecosystems. Furthermore, it has been suggested that riparian buffers may play an important role in landscape connectivity, hence in preserving biodiversity. As they make up a large proportion of residual forests following a clear-cut, riparian buffers could offer key habitats to forest dwelling species. However, the long-term role of riparian buffer strips in the maintenance of boreal forests' biodiversity and connectivity is poorly understood, as it has never been investigated before.

Therefore, this study aims to assess the role of riparian buffer strips in preserving biodiversity and habitat in boreal forests. This study will be carried out in Eastern Canada (Québec), in the MRC of Abitibi, in the balsam fir white birch bioclimatic region, in stands dominated by jack pines (*Pinus banksiana*) or black spruces (*Picea mariana*), on either clay or sand substrate. In Québec, buffers 20 meters wide have been applied for over three decades. In these 20 meters wide riparian buffers, larger buffers, as well as natural riparian zones, we will evaluate diversity and species composition, 15 to 20 years after logging. Following a multi-taxa approach, plants, birds and mammals will be surveyed using, respectively, transect and microplot surveys, acoustic recorders and camera traps. A total of 60 sites will be surveyed over the summer of 2023. Riparian connectivity will later be assessed using spatial analyses.

Ultimately, this study will provide silvicultural prescriptions for the implementation of riparian buffers in boreal forests, acting as a guideline for forest management. In addition, it will determine the long-term effects of forest harvesting on riparian biodiversity and address knowledge gaps regarding aquatic-forest interactions.

Thresholds for biodiversity in boreal forests: how structural indicators affect the diversity and richness of epixylic and saproxylic species

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: In forests, diversity and amounts of structures such as deadwood, broadleaved trees, and large trees are often used as biodiversity indicators. Such indicators are commonly used to determine which forests should be preempted from forestry. Hence, it is of great interest to understand if there are certain amounts of these indicators that are required to significantly promote biodiversity, i.e., if it is possible to identify thresholds, and if such thresholds vary across different environments, taxonomic species groups, and spatial scales.

To explore this, we set up a multi-taxon study covering Finland and Sweden along a gradient of forest management intensity. In total, we established 240 plots situated in set-asides (unmanaged in recent decades), retention plots (tree groups left unharvested), and old clearcuts (harvested 25-30 years ago). These plots were surveyed for epixylic and saproxylic bryophytes, lichens, and fungi. Simultaneously, detailed data on every tree in these plots were collected pertaining to tree condition, size, species, and decay stage. With threshold analyses, we studied tree- and plot-level thresholds for individual species and various biodiversity measures.

We uncovered tree-level thresholds for many species. For these species, we obtained knowledge on the requirements these species have from trees in terms of sizes, species, and decay stages and were able to compare the threshold values between threatened and non-threatened species, and between species with different functional traits and taxonomic classifications. On a plot-level basis, we showed the threshold values relating to the amount and variety of deadwood, tree species composition, and amount of large living trees for various biodiversity measures including (threatened) species richness, the Shannon-Wiener index, and functional diversity measures. Differences between forest management types were also elucidated in terms of the tree-level thresholds for species and the plot-level thresholds for the various diversity measures across sites.

In conclusion, understanding threshold values above which species become increasingly present and biodiversity rises significantly is important in our consideration of forest biodiversity indicators. Our findings improve our knowledge of individual species' needs and set clear goals on how to increase taxonomic and functional biodiversity across differently managed forests for stakeholders involved in forestry and conservation.

Tree-related microhabitats on retention trees as biodiversity indicators in Fennoscandian planted forests

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: In Sweden, forests cover 70% of the land area, and the majority are intensively managed using even-aged silviculture. Over recent decades, retention forestry has emerged as a conservation tool to counteract the effects of clear-felling on biodiversity, particularly in the short term. However, there is an increasing necessity to assess how and to what extent retention trees contribute to biodiversity in planted forests throughout the rotation period. In this sense, tree-related microhabitats (TreMs) have been proposed as a meaningful indicator of the state of biodiversity at the stand scale. TreMs are structures such as cavities or injuries occurring on trees that constitute an essential habitat resource for numerous species during at least part of their life cycle. TreMs have been widely studied in the temperate forests of central Europe, but are only just beginning to be considered in Fennoscandia. In this study we: 1) identify archetypes of TreMs on retention trees in coniferous planted forests; 2) evaluate the role of different retention tree species (*Quercus robur, Populus tremula, Betula sp,* and *Fagus sylvatica*) to provide TreMs; and 3) evaluate the effect of forest management (i.e. stem density or distance to the retained trees) on the abundance and richness of TreMs. To do so, we measured TreMs on 114 broadleaf retention trees located within 20 Norway spruce (*Picea abies*) production stands in southern Sweden. We observed that older trees, particularly oaks (*Q. robur*), within this production context do host a higher abundance and richness of TreMs, and that a higher density of production stems surrounding the retention trees is associated with the development of some TreM groups (e.g. exposed sapwood, crown deadwood). Outcomes may be explained by shade-induced dieback and the closer proximity of management interventions creating TreMs via artificial disturbance. However, this management can also prevent the development of other types of TreMs. TreMs could play a more central role in deciding which trees should be retained in planted forests, and we discuss using this approach as a biodiversity indicator for setting conservation targets in Fennoscandian forests.

Untapped Treasures of Forest Biodiversity Indicators in the UNECE Region: Unlocking their Potential for Monitoring Biodiversity in Climate Emergencies

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: The urgent need to address biodiversity loss in relation to climate emergencies necessitates the development of effective monitoring tools to assess the pressures on and state of forest biodiversity. This research explores the untapped potential of forest biodiversity indicators within the UNECE region, focusing on their applicability for monitoring forest biodiversity facing these pressing environmental challenges. A comprehensive review was conducted, analyzing 56 national reports on forests and forestry from all UNECE countries to identify existing national biodiversity indicators utilized or applied within these reports. A wealth of indicators was found not depicted in international reporting efforts. We aim to assess their potential for international reporting on forest biodiversity in Europe and beyond. Additionally, our objective is to evaluate indicators identified, considering their availability, replicability, and reproducibility. This evaluation will enable us to gain inside into the existing data gaps within forest biodiversity monitoring. By assessing these aspects, we seek to strengthen the robustness and reliability of future biodiversity assessments. The findings from this study have profound implications for forest management, conservation strategies, and international reporting frameworks. By uncovering and evaluating previously underutilized indicators, we can enhance our understanding of forest biodiversity dynamics and adopt a more comprehensive approach to assessing its status. Additionally, this research will shed light on crucial considerations for selecting indicators in the face of future biodiversity scenarios under increasing climate emergencies, ensuring that monitoring efforts remain relevant and effective in addressing the challenges ahead.

Variation among ghaf (Prosopis cineraria) trees within one square kilometer in the United Arab Emirates

T3.7 Forest biodiversity indicators: supporting our response to the biodiversity and climate emergencies

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Abstract: Ghaf (*Prosopis cineraria*) is an evergreen tree that inhabits the dry and hot regions of the Middle East and South Asia. It is a useful tree that generously supplies food to humans, livestock, and wild animals. The green canopy of the *Prosopis* also provides cool shade from the blistering desert heat to a wide range of wildlife. Given its importance to the people, domestic animals, and wildlife of the country, it is the national tree of the UAE. In some of its natural range areas, it is an important agroforestry species. The exploitation of its genetic variation in other regions may bear fruit. With this in mind, a study was undertaken by the Plant Genetic Resources Program of the International Center for Biosaline Agriculture (ICBA) to find the diversity of all ghaf trees (82 total) within an area of one square kilometer in the UAE. For this purpose, different morphological characteristics of the tree, including angle/shape of the tree crown, leaf color, number of leaves per 30 cm of branch, leaf area, leaf dry weight, date of flowering, maturity date of the pod, inflorescence color, inflorescence length, inflorescence weight, pod length, pod weight, number of seeds per pod, number of seeds infected with insect, seed width, seed length, seed thickness, seed color, and seed weight have been studied in detail. Initial results indicate the presence of considerable genetic variability within the local ghaf trees. The sizeable genetic diversity of *P. cineraria* can be exploited for different breeding purposes, including introducing it to other non-natural range areas.

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

A candidate gene association analysis identifies SNPs potentially involved in several abiotic stress tolerance in European beech (Fagus sylvatica L.)

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Local adaptation is one of the essential evolutionary mechanisms that allow species to thrive in heterogeneous environments. Understanding the dynamics and mechanisms of local adaptation in natural populations provides the basis for predicting responses to environmental changes, including those associated with global climate change. Local adaptation is expected to alter the allele frequencies of genes that influence fitness in particular environments. Local adaptation is best studied in long-lived sessile organisms with large effective populations covering large and variable environments such as forest trees. European beech (*Fagus sylvatica* L.) is one of the most economically and ecologically important deciduous trees in Europe, yet little is known about its genomic adaptive diversity and its adaptive potential. The adaptation potential of beech to climate change has been widely discussed. Although beech is considered a sensitive tree species in the context of projected environmental changes, some authors conclude that beech will not lose its importance and adaptive capacity in the future. However, changes in beech marginal populations have already been observed, and several modelling studies predict range shifts of this species in the context of global warming. Therefore, a deeper understanding of its potential to adapt to changing environmental conditions is needed. In this study, using a candidate gene approach, we investigated the association between SNPs and environmental factor variation in 12 beech (*Fagus sylvatica* L.) populations located in 5 different biogeoclimatic regions and subjected to different silvicultural regimes. This work presents for the first time the results of the study of genetic differentiation among European beech populations in different management conditions, presumably associated with adaptation to different climatic conditions, based on a pooled analysis of many bioclimatic variables, together with a large number of genetic markers, single nucleotide polymorphisms (SNPs). In total, 5,143 SNPs were genotyped in 194 individuals. Among them, both climate region-specific and population-specific polymorphisms were observed. Association analyses are currently in progress. Four different methods (PCAdapt, LFMM, BayeScEnv, and RDA) were used for the analyses to observe a correlation between SNPs and variation in some environmental factors and presumably associated with local adaptation.

A journey through the inside: exploring the endophytic microbial biodiversity of ancient beech forests in central Italy

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: The World Heritage Forests composed mainly by beech forests (*Fagus sylvatica*) located in the Mediterranean Basin are considered an hot spot of both climate change and biodiversity. This ecological biodiversity is currently threatening by global warming, deforestation and tree decay, which would lead to habitat loss and even extinction. Immediate actions are needed to better identify forests natural mechanisms of adaptation to environmental changes and thus, a careful monitoring of the biodiversity shifts at local level could give insights on the forests health status. The biodiversity and abundance of the endophyte community is strictly linked to the plant health, environmental conditions and plant organs. We investigated the endophyte communities of two unmanaged ancient beech forests recognized by UNESCO World Heritage and located in central Italy "Faggeta Vetusta del Monte Cimino" (UNESCO site) in Soriano Nel Cimino (VT), "Faggeta Vetusta di Monte Raschio" (UNESCO site) in Oriolo Romano (VT), together with a third beech forest located in Monte Terminillo (RI). In each site, seeds and leaves were collected from five different trees and at two different sampling area. Microbial biodiversity was then investigated throught classical culture-based isolation methods to be compared with metabarcoding analysis of both fungal ITS and bacterial 16S amplicons sequenced in Illumina platform. Given that not all the endophytes are cultivable, the metagenomic analysis will provide a more detailed picture of the microbial community. We aim to identify the "**core microbiome**" composed by endophytes constantly associated with beech, independently from any external condition or geographic location, the "**resiliome**" composed by the endophytes present in healthy and vigorous plants that contribute to the resilience of plants living in difficult condition, and the "**weakness pathobiome**" composed by those endophytes that could shift from a neutral behaviour to a pathogic habitus, especially when plants are weakened by different stress conditions. Since the influence of these organisms in shaping the adaptability of the species is more than a hypothesis, these outcomes will represent a basis for a pioneering natural approach to understanding of the endophytic community under specific conditions for a more precise preservation and conservation of European beech forests.

Application of genomic methods in moso bamboo biodiversity

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Moso bamboo (*Phyllostachys edulis*) is the most representative bamboo in China, which forest area exceeds 5.2 million hectares. Due to long-term adaptation to different habitats, natural selection and artificial selection, many forms of moso bamboo with various morphological characteristics have been generated. However, the association of phenotype with heredity in those bamboo forms is too limited. Here, the main difference of phenotype among those forms were subdivided into 15 indicators. The correlation matrix and R-type cluster analysis of morphological character markers showed that several marker pairs were significantly related, among which color variation and node or internode shape variation were the main markers differentiating one variant from another. To explore the genetic differences among the forms, 20 forms were collected for genome sequencing on the Illumina platform, and a total of 1.26 Tb sequences were generated, with an average sequencing depth of 30.04× per variant. Totally, 3,230,107 high-quality single nucleotide polymorphisms (SNPs) and 742,564 InDels were identified. Interestingly, the density of SNP and InDel distributed on the different chromosomes were highly consistent. Most SNPs (84.04%) were distributed in intergenic regions. There had 4496 SNPs located in 3676 genes were annotated with high level effecting variation, which were uneven distributed on the chromosomes. Moso bamboo forms were characterized with high genotype heterozygosity, 30 low and 40 high long continuous heterozygous regions (LCHRs) were identified, respectively. Based on gene functional enrichment analysis, the genes located in high-LCHRs were related to the zeatin biosynthesis and brassinosteroid biosynthesis. According to the established phylogenetic tree and morphological characters, moso bamboo forms were divided into node/internode variation group (VG) and node/internode normal group (NG). Moreover, 1512 genes were identified as candidate genes responsible for the differentiation between VG and NG groups during evolution. Most of the candidate genes were related to plant hormone signal transduction and MAPK signaling pathway. These results provided a comprehensive insight of SNP markers into moso bamboo genome, which would facilitate further research related to moso bamboo evolution, marker-assisted selection, diversity conservation and functional identification of genes related to agriculturally important traits.

Assessing genome-wide patterns of hybridization among members of Fraxinus section Melioides in the Great Smoky Mountains National Park

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Since its introduction in the 1990s, emerald ash borer (EAB) has extirpated over 100 million ash trees (*Fraxinus* spp.) across the eastern United States (US). The sudden endangerment of US-native ash, primarily within *Fraxinus* section *Melioides*, has prompted extensive efforts to characterize and breed resistance to EAB, however, substantial knowledge gaps still remain in the fundamental ecology and diversity of this lineage. Specifically, recent genomic evidence suggests that species delimitation due to polyploidy and cryptic hybridization may be obstacles to the efficient application of conservation effort within *Fraxinus* section *Melioides*. Due to the rapid decline of this lineage in the US, a more precise understanding of gene flow among congeners within ecologically intact populations may be critical to future restoration efforts, while little time remains to characterize these dynamics due to EAB-induced mortality. In this study, we assess whether green and white ash (*F. pennsylvanica* and *F. americana*, respectively; two sister taxa within *Fraxinus* section *Melioides*) show patterns of admixture and introgression in the Great Smoky Mountains National Park, a UNESCO world heritage site and temperate biodiversity hotspot. Furthermore, we explore how local environmental conditions may impact gene flow among green and white ash across fine spatial scales. Extensive surveys reveal that the mountainous terrain within the Great Smoky Mountain National Park harbors not only stark environmental clines over short distances, but rare, mountain alluvial forests, presenting an uncommon opportunity for green and white ash to thrive proximally along stark elevational gradients. We propose that hybrid genomic mosaics arising from recent admixture and/or historical introgression events may have had lasting effects on the genomic architecture of these taxa due to differential fitness across microclimates. Using traditional botany, whole-genome sequencing, computational hybrid detection, ecological modeling, and landscape genomics approaches, we assess the genomic and ecological diversity of green and white ash to inform the conservation management and future restoration of two critically endangered forest tree species.

Assessing the effects of adaptive responses of black spruce (BS) on future carbon sequestration through genomic approaches and dendroecology

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Forest ecosystems around the world can help mitigate climate change (CC) through reforestation, afforestation, and restoration, but these ecosystems, particularly the boreal forest, will also be significantly impacted by CC. To achieve their aims, these nature-based solutions will have to rely on the selection of species and seed sources adapted to future climates. Yet, predicting the long-term response of trees to climate change is a major challenge, and such predictions rarely consider the adaptive genetic variation of species. Taking advantage of four black spruce (*Picea mariana*; BS) common gardens established in the early 1970s, we leveraged genomics and dendroecological data collected from over 2,100 trees (61 provenances) to determine how intraspecific genetic variation may influence BS growth response to current and future climates. We determined: i) the number of distinct genetic clusters present within BS from 50,000 SNPs; ii) the most important climatic variables and genetic variants underlying local adaptation and iii) the association between climate and genetic variation. Genomic analyses revealed three major genetic clusters dividing populations in western, central, and eastern Canada. In parallel, we modeled BS growth as cumulated biomass using a random forest algorithm trained with dendroecological data and genetic cluster information. This model was then used to project growth until 2100 within a climate change context. The genetic clusters were then shown to have an influence on local adaptation and on responses of BS populations to climate change, with the western cluster being more impacted than the others. Among climate variables, mean annual climate moisture index, total annual precipitation, and total annual temperature range were best associated with genome-wide variation, and overlapped a major allelic transition between Central and Eastern genetic clusters, as shown by a gradient forest analysis. However, the random forest model also revealed that mean summer and autumn temperatures were the most relevant climate factors to consider for future adaptation to climate change, as high temperatures were detrimental to growth. Therefore, BS appears headed toward a general climate maladaptation, which may negatively impact the carbon sequestration potential of the species.

Characterization of organellar genomes in Santalum album L. (Indian sandalwood) to understand parasitism

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: *Santalum album* L. (Indian sandalwood) is an economically and culturally important species belonging to the Santalaceae family, and is valued for its essential oil and fragrant heartwood. It is a facultative root hemiparasite parasitizing on vast spectrum of angiosperms. While several studies have dealt with the functional attributes of *S. album*, presently, the genomic footprints of parasitism in the genus *Santalum* is absent. In this study, organellar genomes of *S. album* were characterized to understand the effect of parasitism on these extra nuclear genomes. Chloroplast (cp) genome of *S. album* (NC_048953) was annotated with *Osyris alba* (NC_027960) cp genome as reference and was compared with previously published Cp genomes of 27 plants including autotrophs, hemiparasites and holoparasites. A total of 109 genes were predicted including 4 rRNAs, 31 tRNAs and 74 protein coding genes, with total GC content of 38.0%. Comparative analysis revealed considerable shrinkage of Cp genome caused by loss of five genes (*ndhA*, *ndhF*, *ndhH*, *ndhI, trnR-UCG*) and pseudogenization of 7 genes (*infA*, *ndhB*, *ndhC*, *ndhD*, *ndhE*, *ndhG*, *ndhK*), all of which are known to be involved in photosynthetic activity Phylogenetic analysis revealed three distinct clades with *S. album* being placed in hemiparasitic clade with phylogenetic relatedness to *Osyris alba* and *O. wightiana,* both belonging to the family Santalaceae. Mitochondrial (mt) scaffolds were assembled from leaf transcriptome of *S. album*, annotated and compared with complete mt genomes of three autotrophs and two hemiparasites under order Santalales. The annotation results revealed pseudogenization of three tRNAs and loss of protein coding genes *atp*9, *ccm*B, *ccm*Fc, *mat*R, *mtt*B, *rpl*2, *rpl*10, *rps*1, *rps*2, *rps*10, *rps*11 and *rps*12. Traces of Cp genes (*rpo*C2 and *ndh*H) were found in the mt genome, suggestive of possible horizontal gene transfer between the organellar genomes. The present study revealed that the lifestyle transition from autotrophy to parasitism led to gene loss, pseudogenization and horizontal gene transfer of photosynthetic genes in the organellar genomes of *S. album*. It also provided an insight into the probable effect of parasitism on reconfiguration of organellar genomes, specifically the chloroplast genome in parasitic plants.

Characterizing the Genome-Wide Impact of Tree Improvement in Scots Pine

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Tree breeders aim for improved trees that grow better, are well adapted to local conditions (e.g. Berlin et al. 2016 Silva Fenn 50), have sufficient variability, as it increases resilience to environmental changes and pathogen resistance, and will not suffer from inbreeding depression. To meet these goals, all stages of breeding and seed production (breeding populations and seed orchards) are to be carefully designed. Further, possible effects on diversity at different stages of the process should be monitored. To understand the effects of early stage breeding and selection on Scots pine in Finland, we compare the genetic composition of natural populations, plus trees, and an early breeding generation across the genome, using the newly developed SNP genotyping array for Scots pine, the Axiom PiSy50k. Further, we explore potential effects of different management and selection strategies on the genetic diversity of Scots pine with simulations. We find in general weak differences in genetic diversity between natural and plus trees. Likewise, we found little to no loss of overall genetic diversity in our simulated selections based on several traits. However, our findings highlight the importance of carefully accounting for ascertainment bias when assessing overall patterns of genetic diversity with a genotyping array. In our results, the small effects we found may be largely due to this bias, but, importantly, ascertainment bias has a smaller relative effect when apparent differences are larger as we illustrate with simulations. Overall, our study emphasizes the usefulness of the PiSy50k to monitor genetic diversity in Scots pine.

Forecasting through the lens of landscape genomics: local adaptation in the foundation species Nothofagus pumilio

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Climate change will alter relationships among genetic factors and environmental conditions, and thus it has the potential to change the selection pressures acting upon adaptive gene variants. The southern Andes mountain range presents an ideal study site because it contains two distinct orthogonal environmental gradients: temperature and day length (South-North) and precipitation (West-East), which allows us to disentangle environmental effects on genetic adaptation. We used the foundation tree species *Nothofagus pumilio* as a model because it inhabits a 2,000-kilometer-long range within these gradients. We assessed local adaptation patterns using a landscape genomic approach that encompassed a paired site sampling design, population structure analysis, and association analyses among genetics, environment, and phenotype for 493 adult trees within 20 sampling sites. Data sources include current and future projected environmental conditions, phenotype variables derived from annual increment tree rings, and over 47,000 SNPs from candidate genes related to growth, circadian rhythm, and stress response. Among our main results, we found that genetic groups were oriented along the north-south latitudinal transect, likely due to past glacial-interglacial cycles. Outlier tests and genotype-environment association analyses showed that *Nothofagus pumilio* has notable signatures of adaptation to current climate. Namely, 457 SNPs were strongly differentiated among subpopulations and/or associated with environmental covariates related to temperature, day length, and, to a lesser extent, precipitation. We extrapolated these findings across space and time to assess genomic offset and thereby predict the impacts of coming change. Since *N. pumilio* populations are adapted to current geographic configurations of environmental conditions including the static variable of day length, any new combinations created by climate change could have dire consequences for both natural adaptation and the practices of conservation and forest management.

Generation of genomic resources in Pterocarpus santalinus, an endemic high value tropical timber species for conservation of its genetic resources

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: *Pterocarpus santalinus* Linn. f., popularly known as Red Sanders is a medium sized deciduous tree endemic to Southern parts of Eastern Ghats of India and is known for its deep red color, fragrant heartwood and wavy grained texture. Due to unsustainable harvesting, slow regeneration and habitat loss, the genetic resources have drastically reduced and the species has been classified as 'endangered' by IUCN and listed in Appendix II of CITES. Conserving the available genetic resource in this endemic species is essential to minimize the risk of extinction under future environmental change. With the aim to generate genomic resources in *P. santalinus*, near-complete chloroplast genome was assembled from leaf transcriptome dataset and phylogenomic analysis revealed closest relation with *P. dalbergioides*, a species endemic to Andaman Islands in India. The analysis could also demarcate the African and Asian species of *Pterocarpus.* The chloroplast genome was mined and five novel barcodes including *ndhF-rpl32, atpA-trnR, trnH-psbA, psbA, psa1-ycf4* were identified and validated for species discrimination. Concurrently, a high quality draft genome was assembled using short and long reads generated from Illumina and Oxford Nanopore Sequencing platforms and the hybrid assembly showed 99.60% genome completeness. The haploid genome size was 541 Mb with high proportion of repetitive sequences (29%). The. A total of 51,713 consensus gene set was predicted and 31,437 were functionally annotated. The age of whole genome duplication event was dated at 30-39 mya, indicating genome duplication event during the Eocene period. Subsequently, whole genome re-sequencing of 36 diverse genotypes spanning the complete distribution range of the species was conducted and more than 20 million variants were predicted, with maximum SNPs in the intergenic regions. Understanding the spatial genetic structure and adaptive diversity of *P. santalinus* populations using genome-wide SNP markers is in progress. The unprecedented genomic information generated in the study is expected to provide deeper insight into the population divergence in relation to its endemic nature. The genome-scale markers will accelerate trait based breeding program, facilitate development of conservation strategies and aid in development of diagnostic tool for timber forensics.

Genetic diversity, population structure and demographic history in Fagus crenata

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Nowadays, by applying the population genomic data generated by next generation sequencing, evolutionary history and the genetic background associated with local adaptation in non-model species can be studied more easily than in the past. Japanese beech (*Fagus crenata* Blume, Fagaceae) is dominant in tracts of the cool temperate deciduous broad-leaved forest in Japan. Although its current genetic diversity and population structure have been evaluated using allozymes, organelle DNA and microsatellites (SSR), the evolutionary history of populations, i.e., population demographic history, remains unclear. In this study, by applying the SNP data generated using RAD-seq and a new reference genome of *F. crenata*, we first re-evaluated genetic diversity and population structure in *F. crenata* populations distributed across the species' range. As revealed by the previous study with SSRs, two genetically divergent lineages, Japan Sea and Pacific were detected, and the latter was further divided into northeastern and southwestern lineages. The clinal decrease from southwest to northeast in within-population genetic diversity, revealed by the SSR study, was not detected with the SNP data. Next, to infer the population demography of *F. crenata*, we constructed four population divergence models with parameters based on the population structure we found. The best fit model was decided by the maximum likelihood estimation of parameters using coalescent simulation and the calculation of Akaike information criteria. According to the best fit model determined by coalescent simulation, it was inferred that the ancestral population diverged into two lineages, Japan Sea and Pacific, before the Quaternary, and the Pacific lineage then diverged into northeastern and southwestern lineages during the Pleistocene. The probable vicariance due to the global cooling occurred during the Pliocene to the Pleistocene may have resulted in the present three lineages. The estimated parameters suggest that population sizes were generally increasing and that secondary contacts that occurred among the three lineages resulted in significant increases in gene flow rates after the late Pleistocene. These findings are the baseline for understanding vulnerability, resilience and adaptation to climate change and addressing conservation and sustainable management, for *F. crenata* and beech forest ecosystem.

Genetic effects of continuous cover forestry

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Promotion of uneven-aged forestry with selective cuttings in Scandinavia have raised questions on the genetic consequences of CCF (Continuous Cover Forestry) practices. The long history of high grading, exploitative timber harvesting practice, resulted in regionally poorly growing, sparse forests and a worry of negative effect of the methods to genetic composition of forests, and to future forest health, productivity, and stem form of trees. While modern methods of CCF practices deviate strongly from high grading, it is still important to study genetics of this management method, e.g., for recommendations on selection harvesting practices.

We study the degree of inbreeding, spatial genetic structure and kinship structure of experimental uneven-aged forest plots (ERIKA sites) that have undergone three cuttings of selective harvesting between 1980-2020 and where e.g., growth, demography, and flowering of the trees have been followed. Three cohorts: all reproducing trees, and samples from understory and saplings were genotyped with a 50K snp chip.

The degree of inbreeding was low in all cohorts. However, substantial spatial genetic structures were found with rather high degree of kinship between individuals within and between cohorts and study plots. With the genetic information, and other existing data from ERIKA plots, we assess the possible effect of selection harvesting to growth characteristics of trees and genetic composition of CCF forests. Detailed genetic analyses will help to assess sustainable methods in selection harvesting for contemporary continuous cover forestry.

Genetic Isolation in a high-elevation marginal population of Sakhalin fir: implications of pollen immigration revealed by nuc- and cp-SSRs

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Global temperatures are rising, despite some fluctuations, and the rate of increase is particularly large in the high-latitude regions of the Northern Hemisphere. The effects of potential climate change that may occur in the near future have already been observed in alpine ecosystems. According to climate change prediction models, habitats suitable for alpine vegetation will disappear or decrease substantially along with changes in subalpine forest vegetation. However, these predictions, based on wide-ranging climatic conditions, do not take into consideration certain practical factors that limit vegetation change. As for the establishment of forest vegetation, there are various constraints such as seed dispersal distance, time required for seedlings to grow and mature, biotic and abiotic competition, and emergence of new diseases and pests. In particular, the low genetic diversity of marginal populations can be critical. In order for a population to adapt and evolve to a new distribution area, it is necessary to maintain genetic diversity in the source population. However, a decrease in genetic diversity is often detected in populations at the edge of a distribution limit; i.e., the forefront of distribution expansion, and this is considered to be one of the factors that limit distribution. Sakhalin fir (*Abies sachalinensis*) is a major component of mixed coniferous and broad-leaved forests in northern Japan. This species has a wide vertical distribution range and the species traits such as growth, morphology, physiology, and phenology, vary with altitude. The distribution limit of the species reaches the subalpine zone, where it forms a small low-density patch population adjacent to the alpine zone. In this study, population differentiation was analyzed among populations of Sakhalin fir at different elevations by nuclear and paternally inherited chloroplast microsatellite loci. The results showed that the high-elevation marginal population was genetically distinct from populations at lower elevations. This could be due to certain restrictions in gene flow in the subalpine zone. Our findings also include paternal identification of seeds at the high-elevation margin. Along with flowering phenology, we discuss the maintenance and acquisition of genetic diversity in Sakhalin fir populations at the high-altitude distribution limit.

Genetic variation within and among populations underlies adaptation to climate in a Mediterranean pine species

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Genetic variation is the raw material for population adaptation to climate change. Although forest trees often exhibit extensive genetic variation within and among populations, they may be particularly at risk under climate change due to their long generation times and slow migration rates. We studied the genetic variation within and among 34 rangewide populations of maritime pine (*Pinus pinaster* Ait.) using about 10 000 single nucleotide polymorphisms (SNPs) and phenotypic traits from five clonal common gardens located within the species natural range. Within-population quantitative genetic variation for early height growth, a fitness-related trait, was lower in maritime pine populations from climates with cold winters. This reduced genetic variation may result from adaptation to harsh climates but may also hinder future adaptation to novel climates. Genetic variation among populations was also associated with large-scale climatic gradients, and we predicted the extent to which the current gene-environment relationships will be disrupted under climate change for each population, using a proxy of potential maladaptation, often referred to as the *genetic offset*. As the genetic offset predictions were highly dependent on the modelling approach used to generate them, we evaluated which approach best explained phenotypic data from common gardens and mortality rates from natural populations, using National Forest Inventory Data from France and Spain. Approaches to predict potential maladaptation in natural populations are still under development, in particular for species with strong population structure such as maritime pine, and our results confirm that their predictions should not be used in conservation or management strategies without validation steps based on independent data.

Genetics of adaptive seedling traits in Scots pine - views from natural and breeding populations

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Seedling traits in many tree species show systematic clinal variation, which implies important adaptive roles for these traits. Seedlings with northern origins set their bud earlier, grow less, and have higher frost tolerance than seedlings from southern origins. We study timing of bud set, cold tolerance and seedling height in Scots pine, a widespread conifer species with important economical role in nordic countries. Data is derived from both natural and breeding populations mainly in Southern Finland.

GWAS (Genome Wide Association Study) analyses are utilized to find the genetic loci controlling the trait variation. Multilocus analyses are best fitted for this data, as strong single locus effects are not found in a sample of unrelated trees in Southern Finland. Earlier multipopulation analysis shows genetic heterogeneity between northern and central European areas in timing of bud set.

Genetic prediction (GP) models are built and evaluated to assess the feasibility of inclusion of adaptive seedling traits into genomic selection models in Scots pine breeding. We do not find strong trade-offs with traditional breeding targets such as growth and external stem/branch quality. Phenotypic comparisons between natural and breeding populations show that artificial selection for better growth and exernal qualities in breeding population has not affected the distributions of seedling traits so far.

Analyses of natural selection in the seedling traits show that within population selection pressure is moderate by the age of 9 years, and that earlier bud set and taller status (compared to population average) are favored. Within population distribution, and therefore selection pressure, is likely affected by gene flow from south. Seedling traits seem genetically mostly independent, as correlations within population are rather weak despite strong between population correlations.

Genome-wide association of water use efficiency traits in Puerto Rican populations of Pterocarpus officinalis to better inform riparian restoration

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Tropical wetlands are some of the most threatened ecosystems in the world due to climate change, projected sea level rise, agriculture and other land development practices. Tropical wetlands are also some of the most productive ecosystems in the world and offer many essential ecosystem services. *Pterocarpus officinalis* creates swampy wetlands in riparian and coastal areas across the neotropics. While *P.officinalis* forests create habitat for a variety of species and offer many essential ecosystem services; it is an understudied species and the IUCN lists the species as near threatened. Restoration efforts are key to preserving this species along with the habitat and ecosystem services it provides. In order to better inform restoration efforts, the species' physiology and genome-wide diversity needs to be better understood, because the limited studies in *P.officinalis* have mostly examined salinity tolerance and genetic diversity using a small number of microsatellites. The goals of our study were to examine, and identify candidate loci for, water use efficiency and leaf traits across 12 locations of *P.officinalis* located in Puerto Rico, so that future restoration efforts can be better informed and more successful. Seed stock from 9 mother trees was collected from each of our 12 locations across Puerto Rico and planted in a nursery in San Juan, Puerto Rico. DNA was extracted from 7-10 individuals from each of the 12 locations and sequenced using a whole-genome sequencing platform with an observed coverage of 15-20X per sample. 13 Water use efficiency traits were collected from individuals in 11 of the 12 locations. A de-novo genome assembly was created and used to call single-nucleotide polymorphisms (SNPs) for each sample. Trait differences and associations were examined at a multivariate and univariate level. A high amount of trait variation was observed within and among locations for each trait. A significant effect of longitude, elevation and isothermality was observed for physiological traits, indicating that restoration effects may need to use seed sources specific to their longitude, elevation and that have similar temperature ranges.

Genome-Wide Identification and Expression Analysis of GDP-D-mannose pyrophosphorylase (CYT) and KATANIN (KTN) in Corymbia citriodora

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: The vascular cambium serves as the primary source of wood production, with GDP-D-mannose pyrophosphorylase (GMP, or named CYT) and microtubule severing enzyme KATANIN being present in its cells. GMP provides GDP-D-mannose for cell wall carbohydrate biosynthesis, protein glycosylation, and ascorbic acid (vitamin C) biosynthesis, while KATANIN is responsible for maintaining ordered microtubule structures within cells. In this study, we performed genome-wide identification and comprehensive analysis of CcCYT&CcKTN genes in *Corymbia citriodora*, a eucalypt species, by bioinformatics methods, and the expression of the CcCYT&CcKTN genes was specifically analyzed by qPCR. As a result, 8 CcCYT and 4 CcKTN genes were identified. Among them, CcCYT4 and CcKTN4 genes exhibited highly homology with AtCYT1 and AtKTN1, respectively. Our findings indicate that, with the exception of CcCYT1, 8 and CcKTN2 genes, the expression levels of all other genes exhibited a positive correlation with diameters at breast heigh (DBH). This suggests that these genes play a crucial role in secondary xylem synthesis, particularly the CcCYT4 and CcKTN4 genes. The findings will enhance our comprehension of the intricacy of CcCYT&CcKTN across diverse DBHs and furnish valuable insights for future functional characterization of specific genes in *C. citriodora.*

Genomic Imprinting in Scots pine (Pinus sylvestris)

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Scots pine has an excellent ability to adapt to local environments, proven by its wide distribution across Eurasia. Genomic imprinting could be one of the factors behind its local adaptation. Genomic imprinting is an epigenetic phenomenon where the expression level of a gene depends on the parental origin. It is caused by epigenetic modifications ("imprints") made to genes, regulatory regions, and histones. These imprints can completely silence the expression of a gene or repress it. Imprinted genes have been found in angiosperm, mammal, and insect species. Numerous theories have been developed for the origin of this phenomenon, but none is widely accepted. According to the popular kinship theory, genomic imprinting is caused by competition between the parents for the allocation of resources to the development of offspring. This competition mainly takes place in the tissues in charge of resource allocation for the developing offspring: endosperm in angiosperms and placenta in mammals.

We investigate whether genomic imprinting also exists in gymnosperm species, using Scots pine as our model species. Gymnosperms have a haploid maternally inherited endosperm. The parental conflict, described in the kinship theory, cannot take place in the haploid megagametophyte. Alternative theories for the origin of genomic imprinting do not require parental conflict. As conflict could exist in systems where coadapted maternal-offspring traits have large fitness effects. Imprinted genes have also been found in embryos in both angiosperms and mammals, thus hinting at the possibility of another reason behind it.

Reciprocal crosses, required for the identification of imprinted genes, were performed for selected Scots pine pairs and seeds collected. RNA-seq was performed for the embryonic tissues and exome capture for the megametophytic tissues of the same seeds. Haploid megagametophyte allows the identification of maternal and paternal alleles. We can then compare the expression levels of a gene when it has been inherited both paternally and maternally. Previous results of allele-specific expression in Scots pine indicate abundant allele-specific expression in embryos. This ongoing study aims to provide information on whether genomic imprinting has evolved convergently in angiosperms and animals or has a shared history.

Genomic variation of European beech across its distribution range reveals patterns of local adaptation and future maladaptation

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Local adaptation is key for ecotypic differentiation and species evolution. Understanding the underlying genomic patterns allows the prediction of future maladaptation and ecosystem stability. We used whole-genome resequencing to analyze more than 1000 individuals from 100 range-wide populations of European beech (*Fagus sylvatica*), one of the most important forest tree species in Europe. We show that genetic variation closely mirrors geography. Putatively adaptive variation identified by genotype-environment and genotype-phenotype associations exhibits highly polygenic architectures, involving thousands of associated sequence variants across the genome. By modelling the 'genomic offset' of these sequence variants under projected future climate conditions, we identify broad- and fine-scale variation highlighting geographic regions as well as populations at potential elevated risk of mortality or local extinction. Our results emphasize the importance of considering natural genetic variation within species for forest conservation under climate change.

New insights into the population structure and evolutionary history of two closely related Picea species from a large hybrid zone

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Geographic patterns in genetic diversity are the result of the complex interplay of demographic and evolutionary history of populations with local adaptation. Gaining insight into the forces that shaped genetic diversity is of paramount importance if one wants to be able to predict species' responses to climate change. Norway Spruce (Picea abies) and Siberian spruce (P. obovata) are closely related species which dominate the boreal forests in Eurasia. Following main glacial cycles, the two species probably did not evolve independently but entered into contact several times. Studies based on mitochondrial DNA or on nuclear DNA suggest a recent introgression from P. obovata into the eastern range of P. abies. However, this pattern can be due to a lack of sampling in the westernmost range of P. obovata, precisely on the hypothetic hybrid zone between the two species. In the present study, we collected Picea individuals from 55 populations, ranging from the European mainland and Fennoscandia to the Yenisei River far east, including a dense sampling in the North-Baltic and western Russia to cover the main hybrid zone between P. abies and P. obovata. A total of 546 individuals from P. abies, P. obovata, and putative introgressed individuals were genotyped at 480K SNPs using exome capture for the past demographic and admixture history inference. Nine well-separated clusters were identified despite extensive current gene flow between the two species. Estimated effective migration surfaces (EEMS) identified multiple migration barriers as well as corridors, suggesting a biased gene flow from P. obovata toward the northern range of P. abies and a significant contribution of P. abies genetic background into P. obovata southern domain. Demographic history inference suggested multiple historical contacts between the two species and two cryptic refugia in the current hybrid zone during LGM. The expanded diversity through introgression possibly increases the capacity of the two species to cope with changing environments. This study sheds light on the complex dynamics between the two species and paves the road for further analyses on the potential role of adaptive introgression contributing to long-term adaptation to climate change.

Probing the Role of Adaptive Introgression in Timberline Ecosystems' Response to Climate Changes Using Exome Capture Sequencing

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Living species have adapted to climate changes through migration, mutations, genetic diversity, and genetic introgression. Adaptive introgression, which involves acquiring advantageous traits from closely related species, enables faster environmental adaptation. Understanding this process is crucial to assess adaptation to future global warming.

Timberline ecosystems, as highlighted by the Intergovernmental Panel on Climate Change (IPCC), are known to be vulnerable to global warming. Japanese stone pine (*Pinus pumila*), which grows in timberline zones in Japan and the cold regions of northeastern Eurasia, is expected to have faced the challenge of adapting to climate changes, particularly warming.

In Japan, organellar DNA introgression is observed between *P. pumila* and the closely related *P. parviflora*, which grows in warmer environments. Introgression from *P. parviflora* may have contributed to *P. pumila*'s adaptation to past climate changes, however, previous studies lack nuclear genome-level analysis due to the large genome size of pinus species.

To compensate for this issue, we extended the HyRAD-seq method and implemented a new cost-effective probe design for exome capture. First, we collected leaves of *P. pumila* and *P.parviflora* from mountain areas in Japan and extracted DNA and RNA. RNAs were used to construct probes for exome capture sequencing, while DNAs were used to prepare next generation sequencing libraries, then target regions were captured with the probes.

The population structure and the admixture status of the two species exhibited signs of introgression, aligning with expectations based on species divergence and population distances. These results indicated the effectiveness of exome capture using cost-effectively designed probes for population genetic analysis of species with large genomes.

Further analysis will focus on identifying admixed genomic regions and their correlation with environmental variables. The findings from this research will provide valuable information to assess the adaptability of timberline ecosystems to global warming.

Rapid differentiation, ecological stasis, and edaphic adaptation during the temperate to tropical transition in Mexican firs

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Understanding and disentangling the main drivers of local adaptation within and between species is a pre-requisite of any forest breeding, management, and conservation plan. Insights from past adaptive events may indeed help predicting future evolutionary trends and fine-tunning specific management actions. However, differentiating between adaptive and non-adaptive processes may be complex, particularly for long-lived and slowly-evolving species, like conifers. We explored which evolutionary processes occurred during the migration and diversification of firs (*Abies*, Pinaceae) between the Southwestern United States and Central America at various geographic and evolutionary scales. Using genomic data, we inferred a well-resolved phylogeny that showed four main fir lineages that fitted a North-South isolation by distance framework. Such lineages further had diminishing values of *Ka/Ks* towards the Equator, indicating reduced purifying selection efficiency. Groups showed a strong phylogenetic signal for morphological and climate variation, suggesting a random walk model of differentiation. However, early adaptation to tropical conditions was inferred in the ancestor of the southernmost firs, as all modern southern taxa were climatically differentiated from the northernmost species (*A. concolor*). Interestingly, autapomorphic traits were observed for soil properties, suggesting possible species-specific adaptations. We explored such adaptations in *A. religiosa* at the range-wide and local (within-population) scales. Genome-soil association analyses revealed a series of candidates correlated to various soil traits. Multilocus clines indicated a significant contribution of geographic proximity to both soil and candidate gene variation, which is consistent with the geological history of the mountains where this species is distributed. Altogether, our results show that a combination of non-adaptive and adaptive processes operated along different environmental and phenotypic axes during the southward migration of this plant lineage from North America, and its subsequent radiation in the Neotropics. Looking beyond climate change is thus advised when planning future forest management plans. For instance, integrating soil variation and the accumulation of partially deleterious variants should be a priority for such plans.

Reassessing the role of local seed sources in climate change - Exploring the genetic structure and adaptive potential of white oak species in Europe

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: As climate change progresses, it is likely that the pace of forest tree adaptation will lag behind changing environmental conditions. Therefore, the transfer of forest reproductive material (FRM) from seed sources that are well-adapted to the anticipated conditions (known as assisted migration) has been proposed as a promising strategy to ensure future forest resilience. However, each large-scale transfer of FRM alters the natural genetic structures within populations, potentially even augmenting the lag in adaptation through selective consideration of specific adaptive traits while neglecting others. Consequently, the consideration of regional-scale environmental variation in studies concerning the local adaptation of tree species is crucial, as it holds the potential to unveil pre-adapted seed sources at a localized scale. Hence, it is particularly meaningful to explore the genetic variation of species with wide ecological amplitude and distribution ranges, such as the three closely related white oak species *Quercus robur*, Q. petraea, and Q. pubescens. Within the framework of the BiodivERsA project 'ACORN', an extensive sampling was conducted, encompassing over 120 populations of the aforementioned oak species. The sampling strategy was designed to encompass a wide geographic range from Central Europe to the Eastern Mediterranean Basin as well as contrasting site conditions on a regional level of the sampled populations. Using a comprehensive set of genetic and genomic tools, our objective was to identify populations that exhibit a high adaptive potential in a changing climate. We performed genome-wide environmental association analyses, aiming to uncover signatures of local adaptation. Specifically, we investigated the association of certain genes and genomic regions with drought-related environmental parameters, as well as the presence of a shared signature of drought adaptation among the populations. Our study provides valuable insights into the genetic diversity and adaptive potential of the three white oak species, which can serve as a guide in identifying potential candidates for future seed selection and breeding programs. Furthermore, our research underscores the significance of considering genetic variation and local adaptation in the development of effective conservation and management plans for white oak species, but also for other tree species facing similar challenges in the face of climate change.

Resilience of genetic diversity in forest trees over the Quaternary

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Past environmental changes have shaped the demographic history and genetic diversity of natural populations, yet the timescale and strength of these effects have not been investigated systematically and simultaneously for multiple, phylogenetically distant species. We performed comparative population genomic analyses and demographic inference for seven widely distributed and ecologically contrasted European tree species across their natural ranges, namely *Picea abies*, *Pinus sylvetsris*, *Pinus pinaster*, *Quercus patraea*, *Fagus sylvatica*, *Populus nigra* and *Betula*

pendula. While patterns of genetic diversity and differentiation were species-specific and best explained jointly by geographic range and dispersal ability, ancient population expansion events were shared and largely synchronous across species. Effective population sizes increased or remained stable over time, indicating that despite major changes in their geographic ranges and extents, dominant forest tree species have been remarkably genetically resilient to the drastic environmental challenges of repeated glacial cycles. Our results suggest that forest trees with large geographic distributions might be able to cope better than initially thought to current climatic change and therefore have important implications for the management of genetic resources. This study is major contribution from GenTree consortium through a European Union's Horizon 2020 project "Optimizing the management and sustainable use of forest genetic resources in Europe".

Role of hybridization in plastic and heritable changes leading to adaptation to warming climates in Douglas-fir

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Hybridization and environmental stress may produce widespread genomic and epigenomic changes that can be transmitted to subsequent generations and may contribute to the ability of plants to persist in variable environments. This research project investigates the contribution of hybridization to genomic and epigenomic changes that could lead to increased growth and drought tolerance in hybrids between the two varieties of the economically important timber species Douglas-fir (*Pseudotsuga menziesii var. glauca and var.menziesii*). Warming temperatures and more frequent heat events will reduce the growth capacity of the commercial, less drought tolerant, Douglas-fir coastal variety. In contrast, the DF interior variety is more drought-tolerant, but grows slowly therefore is not ideal for commercial purposes. Our studies suggest extensive asymmetric introgression in two main contact zones in the US and Canada. Intervarietal hybrids between varieties show increased drought and heat tolerance than pure varieties, which could be due to transgressive segregation or adaptive introgression. The effects of hybridization across the species' geographic distribution range are also discussed.

The role of open chromatin in local adaptation of Scots pine (Pinus sylvestris) and silver birch (Betula pendula)

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: As sessile organisms, plants depend on their ability to respond to environmental cues. Adjusting the timing of growth and reproduction will be essential in the changing climate as the combinations of light, temperature, and biotic conditions change. Forest trees are excellent model species for understanding the genomic determinants of local environmental adaptation because they are often widely spread, occupy diverse conditions, and have hereditary, adaptive phenological differences among populations. On the molecular level, regulatory regions have been shown to be important for adaptation to different environments because they regulate gene expression according to internal and environmental cues. Regulatory regions are often found in non-coding open chromatin parts in the genome. The location of open chromatin is a heritable trait and therefore a potential subject to natural selection which indicates its importance in local adaptation.

Interestingly, despite being separated by 300 million years of divergence, Scots pine (*Pinus sylvestris*) and silver birch (*Betula pendula*) display similar clinal patterns of growth cessation timing across a latitudinal gradient in common garden studies. The genomes of the species, however, are vastly different with Scots pine having a 22 Gbp genome, of which only 0.2% is coding sequence, and silver birch having a 440 Mbp genome with roughly 10% of coding sequence. The disparity indicates possible differences in the size of non-coding open chromatin locations between the species and thus differences in evolutionary responses to environmental selection pressure.

ATAC-seq is a method that allows genome-wide identification of open chromatin location, and nucleotide-level regulatory variation coinciding with the open chromatin. In this study, we will use it to sequence the open chromatin and to identify population level differences in the open chromatin amount and location as a response to day-length changes. When coupled with RNA-seq data on differential gene expression, the information on regulatory variation obtained with ATAC-seq allows the linking of the regulatory variation to genes that confer the phenotypic response as a result of local adaptation. The results are important for understanding the molecular basis of forest tree adaptation as well as key differences in adaptive dynamics between conifers and broadleaved forest tree species.

Understanding the genetic basis of silver birch adaptation to local environments and disease in Britain

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Bold annual targets have been set for planting new woodland in Britain by 2050, within the context of a more extreme climate and increasing pathogen prevalence. The genetic diversity of existing native tree populations represents an invaluable resource to mitigate these threats, although a limited understanding exists of the scale and pattern of this adaptive differentiation.

Here, we present data from two different - but complementary - approaches to investigate genetic adaptation in UK silver birch (*Betula pendula*) to environmental stress. The first method utilised common-garden experiments for silver birch (ie. forestry provenance trails) first established in 2003. Whole genome sequence data was generated for approximately 2000 trees, and performance and adaptive traits such as tree growth, tree health (prevalence of dieback), and water use efficiency (C^{13} discrimination) were recorded. The second experiment examined the genomes of natural populations of *B. pendula* sampled by the UK National Tree Seed Project (UKNTSP), identifying genetic loci that exhibited patterns of polymorphism that correlate with environmental variables (ie. a genome-environment association study, or GEA).

Combining genomic analyses of provenance trials with GEAs on natural populations provides a two-pronged approach to determine the genetic basis of adaptation. This project, conducted by Royal Botanic Gardens Kew and Forest Research as part of the Centre for Forest Protection, sought to harness both methods to discover the extent and pattern of genetic diversity in silver birch in Britain. Cross-validating provenance trial and GEA approaches will allow adaptive trajectories to be predicted at a wider scale and inform seed sourcing for new plantings, and test the efficacy of both methods to help understand the utility of applying them to other British tree species.

Variable maladaptive outcomes characterize responses of southwestern white pine populations to changing climates across southwestern North America

T3.8 Forest genomics as a vantage point to biodiversity and adaptation under global change

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Abstract: Populations of forest trees are often adapted to local climates. As local climates change, mismatches occur as rates of climate change usually outpace evolutionary changes to adaptive genetic architectures. The magnitudes of these mismatches quantify accumulated degrees of maladaptation, which can inform future modelling and management activities. Here, we use a genotype-phenotype-environment correlation framework to quantify standing and predicted levels of maladaptation for southwestern white pine (*Pinus strobiformis* Engelm.). More specifically, we quantify levels of maladaptation across 51 pairs of high-low elevation plots of southwestern white using 70,000 SNPs, predicted dendrophenotypes based on a previous genome-wide association study, and past, current, and future climate models. We document southwestern white populations as locally adapted to climate, although current patterns are confounded with accumulated degrees of maladaptation relative to past climates. Predicted degrees of maladaptation to future climates vary drastically across the sampled range, with mismatches based on allele frequencies differing from those based on predicted dendrophenotypes. In general, however, there appears to be sufficient genetic diversity to sustain evolutionary responses to changing climates across populations of southwestern white pine, especially with active and informed management of connectivity across adaptive gene pools. We leverage these results to examine best practices for use of genomic offsets in forest management across the southwestern United States.

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

A policy mix for achieving ambitious goals on forest landscape restoration: Analyzing coherence and consistency in forest related policy.

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: Due to the increasing global trends of land degradation and deforestation, the concept of forest landscape restoration (FLR) has gained recognition worldwide as an approach that complements cross-sectoral integration and aims to restore multiple forest ecosystem services across a broader landscape. Within this context, numerous studies have emphasized the significance of aligning policies across different sectors and integrating them effectively. However, existing studies often fail to adequately capture the intricate and dynamic nature of integrated policy goals and instruments across various policy domains. This study argues that addressing this gap requires a deeper understanding of the elements and characteristics of policy (mix). This involves scrutinizing policy instruments in various domains to gain insight into complex policy design problems. In this regard, we present a new methodological approach, the Cross-Impact Matrix (CIM), to analyze the interaction between goals and instruments as a specific characterization of policy mix in FLR related policies. We demonstrate the proposed concept and methodology by utilizing the example of Ethiopia's policy aimed at achieving comprehensive restoration targets. The results reveal varying levels of coherence based on 121 interactions among eleven goals in the CIM. Additionally, the consistency of instruments was analyzed through 2116 interactions among 46 instruments. Based on these interactions, certain regulatory instruments, such as the acquisition and use of agricultural land, exhibited a negative ripple effect throughout the system. On the other hand, the 'Reducing Emissions from Deforestation and Forest Degradation' (REDD+) creates a positive and conducive environment for implementing other instruments. In conclusion, this paper emphasizes the importance of examining the connections between policy integration and policy mix within the context of FLR, to envision congruent outcomes.

Forest and Landscape Restoration Opportunities Assessments for Mt. Kulal Biosphere Reserve and Mukogodo forest in Kenya

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: Forest and landscape restoration has been a national priority of many countries in the context of climate change and the rapid reduction of forest areas in the last few decades. By enhancing carbon sequestration and boosting carbon sinks, forest restoration is a key strategy to reduce climate change. In Kenya, initiatives are being made to restore the country's natural forests and landscapes, which are essential for delivering environmental services like carbon sequestration, biodiversity preservation, and watershed protection. In addition, forest restoration will play a key role in achieving Kenya's commitment of restoring 5.1-million-hectares by 2030 under the Bonn Challenge and AFR100. Successful restoration is achieved by strategically addressing the drivers of land degradation and analysing feasible restoration opportunities suited for each landscape. It is against this backdrop that Sub-National Forest Landscape Restoration Assessment (SNFLRA) was undertaken for Mt. Kulal biosphere reserve and the Mukogodo forest landscapes in Kenya using the Restoration Opportunities Assessment Methodology (ROAM). The SNFLRA process took into cognizance of the importance of stakeholder engagement throughout the process. The results of the SNFLRA identified the following as feasible restoration options and area within the two landscapes: Rehabilitation of degraded natural forests (46,687 ha); Agroforestry on Cropland (7,072.2 ha); Tree-based Buffer Zones along roads (6,710.44 ha); Tree-based Buffer Zones along Water Bodies and Wetlands (1,965.4 ha); and Rangeland's restoration (360,118 ha). In terms of economic analysis of the restoration options, the findings revealed that the transition for each option is economically viable since they have the ability to pay for themselves within a 30 -year time period. This analysis provides information necessary to design Forest and Landscape Restoration Interventions that can be implemented with specific attention paid to the severity and type of degradation in these areas, and the contributions landscape restoration can make to food security, resilience against climate change, and biodiversity conservation.

Forest landscape restoration (FLR) policy program in a developing country: Ecosystem vs community development discussion

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: The United Nations has declared 2021- 2030 as the decade of forest landscape restoration (FLR). Globally, there are over two billion hectares of degraded forests that need to be restored. Like other tropical countries deforestation and forest degradation is an issue in Bangladesh too, hence the forest ecosystem restoration with native species in degraded forest areas in Bangladesh has emerged as an essential policy program of Bangladesh forest sector. This study is focusing on the restoration policy programs implementation success, which is measured by how well the ecosystem functions and its synergy with livelihood context of the forest people. The study was carried out in the Cox's Bazar Forest division of Bangladesh. Content analysis was applied to analyze policy program documents. The research involved site assessment using the site survey method to collect the information regarding degraded sites. Additionally, the study applied individual interview and focus group discussion to identify forest people's perception on the FLR policy program. The study finds that the restoration effort has initial success in terms of replanting and enrichment planting. However, the forest people's perception on the restoration species choice is not in synergy with the interest of the forest administration. There is an interest conflict among the community and the forest administration regarding the policy program outcome. 70% of the forest people are in favor of fast-growing timber species against the slow growing native species which are chosen for habitat restoration. From the policy program dimension, the study finds that there is lack of policy coordination among the different sectors, especially the forest land scape restoration policy program is facing challenges from the country's foreign policy agenda of that region along with economic development agendas.

FOREST LANDSCAPE RESTORATION IN HIMALAYA COMMUNITY FOREST: BRIDGING FOREST MANAGEMENT AND SUSTAINABLE DEVELOPMENT GOALS

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: The Himalayas, a region of enormous ecological significance, reflects a dynamic and complex landscape that requires immediate attention for constructive Forest Landscape Restoration (FLR) efforts. This mountainous terrain harbors diverse forest ecosystem crucial for climate regulation, biodiversity conservation, and wellbeing of local communities. However, the Community managed Forests (CFs) pertinent to Himalayan region plays a significant role in the landscape formation, its management and sustainable conservation.

In our study, we examined the status of Forest Landscape Restoration (FLR) and its interrelation with Sustainable Development Goals (SDGs) role in six CFs (commonly known as Van Panchayats - VPs) in Himalayan state.We employed participatory approach, involving local people through village level governance (head of the village- Pradhan) and forest level governance (president of community forest-Sarpanch), while also considering the involvement of forest department.

The study is focused on identifying and developing various indicators for selected SDGs for wellbeing of the dependent community on the basis of management status of CFs, health, social, economical and, environmental wellbeing through selected frameworks, focused group discussion and semi-structured questionnaire-based interview using Participatory Rural Appraisal techniques like listing and ranking.

The major governance challenges restricting FLR in CFs were property right conflict, decision-making, sharing of cost and benefits, community ownership and land-use fragmentation. Acknowledging and addressing these challenges and managing it through natural resources based solutions adopted by the local community and their coupled relationship with ecosystem services and human well-being for the future by strengthening community land tenure and forest rights, with involving them in CFs restoration via indigenous species plantation, provisioning of socio-cultural conservation based incentives, accrued benefits and implications to develop some amalgamated solutions to assist the policy and governance interface for the CFs is also essential towards eco-centric approach for the local and global acceptance.

In general, outcomes of the study have potential to ameliorate the effect of FLR through restoring degraded forestland, aligning with the Bonn challenge commitment, attaining nation’s INDCs (Intended Nationally Determined Contributions) and subsequent SDGs targets.

Key words: Community based restoration, nature-based solutions, ecosystem services, Forest and land tenure, socio-cultural values

Forest Landscape Restoration interventions for conservation and sustainable development in Sri Lanka: a case study

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: Severe shortage of land resources to fulfil the demand for various needs particularly for development work is a main threat on available natural forests in Sri Lanka at national level. Further, present economic crisis of the country demands to assure food security through increased food production. Poverty alleviation and increased national income are crucial to address the economic crisis.

Forest Landscape Restoration (FLR) provides an opportunity to integrate conservation, production, poverty alleviation and increased national income to achieve SDG.

A case study was conducted to analyze the issues and possible solutions in a forest landscape, which consists of different forest types, water streams and water tanks associated with adjacent agricultural communities. A part of forest landscape is degraded due to anthropogenic disturbances, and it is being developed for ecotourism which is a main target of government policy. This landscape lies within a popular tourist area featured by attractive wildlife, cultural heritage and natural beauty.

Primary data and secondary data were collected using formal and informal discussions with various stakeholders. The issues were identified in relation to different land-uses, and stakeholders suggested potential solutions to restore the landscape. The main issues in conservation were timber felling, excessive firewood and forest products collection, encroachment, fire, waste disposal in forest, and scarcity of food and water for wildlife. In terms of livelihood maintenance, water scarcity for agriculture and homegardens, low diversity in homegardens, food and water shortage for livestock and unsustainable harvesting of fish were identified as main concerns. Low diversity of tourism activities, poor interpretation service, insufficient facilities, and unequal benefit sharing were identified as issues for developing sustainable tourism.

Rehabilitating small tanks, Wildlife habitat improvement, Degraded forest restoration, Improving irrigation facilities, Diversification of homegardens, Intensifying livestock management, Agroforestry, Diversifying tourism activities, Training interpreters were among the potential activities identified for landscape restoration to regain ecological functionality and enhance human wellbeing.

The selected activities will contribute to at least 4 SDG goals: 1-No poverty, 2-Zero hunger, 8-Decent work and economic growth, and 15-life on earth.

Protecting an artificial savanna as a nature-based solution to restore carbon and biodiversity in the Democratic Republic of the Congo

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: A large share of the global forest restoration potential is situated in 'unstable' mesic African savannas, contributing about 23% to the global mismatch between potential and actual terrestrial carbon stocks. However, uncertainty on Central African forest recovery rates impedes science-informed implementation of forest restoration efforts. Here, we quantify the forest restoration success of 17 years of fire exclusion within a mesic artificial savanna patch in the Kongo Central province of the Democratic Republic of the Congo. Since 2005, the local community of the Manzonzi village has conserved an 88-ha artificial savanna with support from World Wildlife Fund. In 2010, we established 101 permanent plots (total area of 40.4 ha) and remeasured them (at the threshold of 10 cm DBH) in 2014 and 2022, by considering two species categories: savanna and forest specialists. Between 2010 and 2022, mean stem density switched from 122.3 ± 9.0 to 27.0 ± 3.8 tree/ha and from 45.8 ± 7.5 to 178.6 ± 10.1 tree/ha for savanna specialists (*e.g. Hymenocardia acida* and *Maprounea africana*), and forest specialists (*e.g. Xylopia aethiopica* and *Albizia adianthifolia*) respectively. We found that aboveground carbon (AGC) recovery of forest specialist after 17 years was on average 11.9 ± 0.2 Mg C ha^{-1}. Using a model fitted to the data, we predicted that AGC stocks take 110 ± 3 years to recover to 90% of AGC stocks in old-growth forests. Applying this recovery trajectory, we show that 'unstable', artificial savannas across DRC, Congo, and Angola have a total carbon uptake potential of 13.5 ± 1.6 Gt C by 2100. Species richness recovered to 33.1% after 17 years and we predicted a 90% recovery at 57 ± 1 years. In contrast, the recovery of species composition was much slower, with an estimated 90% recovery after 125 ± 3 years. We conclude that carbon and biodiversity recovery trajectories are indispensable to developing policies promoting forest restoration in artificial African savannas. However, more long-term, *in situ* monitoring efforts are needed to quantify variation in carbon and diversity recovery

owing to resource availability (rainfall and soil fertility), prior vegetation and land-use history, and surrounding forest cover.

Small-scale farmers' preferences for the adoption of tree-based restoration systems: Empirical evidence from a discrete choice experiment

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: Despite the recognition of tree-planting and agroforestry systems as effective forest restoration practices, their adoption remains low among small-scale farmers. To increase their participation, it is crucial to understand farmers´ preferences and the factors influencing their decision-making. Therefore, this study assesses small-scale farmers´ willingness to adopt tree-based restoration systems on degraded forestlands, investigates their preferences for characteristics of these systems, and identifies the possible sources of preference heterogeneity. For this, we conducted a Discrete Choice Experiment (DCE) embedded in a survey among 400 small-scale farmers equally distributed over two districts in the northern Peruvian Amazon, a region that is experiencing high pressures of land use change. In the past, several bottom-up projects, with limited farmer participation during the planning and design, were implemented in this area. This caused a mismatch between project objectives and the needs of farmers, resulting in low adoption rates of restoration systems. Based on the DCE, we evidence that generally small-scale farmers were willing to enroll in the proposed scheme and showed positive preferences for the attributes proposed. They generally preferred higher monetary incentives, agroforestry systems (providing food and cash income) over tree plantations, technical assistance and implementing the system on a fraction of their degraded forestland (instead of their total degraded area). Furthermore, two groups of small-scale farmers with contrasting preferences related to two attributes were found. Specifically, one group (73%) was highly interested to engage in the proposed scheme and significantly preferred agroforestry systems over tree plantations, while the other group (27%) had a negative preference for adopting the proposed scheme and was indifferent to the type of tree-based system. Respondents not willing to enroll in the proposed schemes have participated significantly more in organizations in the past, had a significantly higher area of permanent crops but lower area of annual crops and primary forest, were engaged more in agriculture and were less forest dependent. These findings provide useful insights to design community supported policies promoting agroforestry systems that ensure small-scale farmers´ land rights to increase participation and for achieving land restoration while improving rural livelihoods (through food security and cash income).

Sustainable forest landscape restoration and management within Rohingya refugee camps in Bangladesh

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: Bangladesh hosts the world's largest refugee population— over one million Rohingya people residing in heavily congested conditions across 34 camps in the Cox's Bazar District of southeastern Bangladesh. Consequently, approximately 3,244 hectares of forest were lost, including 2,500 hectares for camp construction and 744 hectares for woodfuel and bamboo harvesting. Since 2018, FAO, Bangladesh Forest Department and humanitarian agencies have restored about 720 hectares within the camp and another 2,000 hectares outside the camp areas aimed to restore and regenerate the forest coverage in the region. This study in Kutupalong-Balukhali Mega Camp interviewed 430 Rohingya refugees from 11 out of 23 camps. The study revealed that forest landscape restoration (FLR) activities consisted of four components: forest restoration, land stabilization, reforestation, and capacity building. For producing quality planting materials, seeds and vegetative propagation were distributed for seedling raising in nurseries outside the camps. The FLR approach prioritizes the revival of multiple vegetation layers, including bamboo and fast-growing exotic and native tree species, for extensive plantation and soil stabilization. Both skilled and unskilled male and female Rohingyas participated in the restoration activities under a 'Cash for Work' program for site preparation, plantation, management, and site maintenance. Agencies promote a collaborative restoration management approach through community engagement, awareness campaigns, and capacity building for sustainable FLR management. About 91% of Rohingyas reported that restoration efforts empowered women and youth, and 85% reported that restoration improved the sense of community and solidarity among Rohingyas. Although Rohingyas are not given ownership and benefits of planted trees, 81% continued to participate in or support the restoration work in the future, while 88% perceived the long-term sustainability of the restoration program. The findings of this study will help develop a sustainable FLR management plan that takes into account the cultural, ecological and social aspects of the Rohingya refugees.

Towards Good and sustainable forest governance in Kenya- A Water-Energy-Food nexus security approach

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: In Kenya, forests are estimated to contribute 3.6 per cent of the Gross Domestic Product (GDP). Apart from climate regulation, forests support various other production and consumption services. Policies within the forest sector have greatly impacted the country's development goals and agenda. The current target is to increase tree cover to 15 billion by the year 2050. This, without a doubt, will have a great impact, especially on the 15 Sustainable Development Goals enshrined within the United Nations Agenda on sustainable development. These policies and targets have helped the country and households to improve consumption and production patterns, especially for non-timber forest products (NTFP). Other impacts include empowering rural women, increased food production through the shamba system, climate regulation, and biodiversity protection among others. However, unsustainable consumption and production may conflict with the achievement of such other development goals as clean energy, climate action, peace and justice brought about by illegal logging activities. The linkages that exist between the forest industry and the SDGs are complex. Past studies have typically considered individual economic sectors in isolation, lack temporal depth, and focus on a single SDG dimension. This study fills this knowledge gap by integrating a long-run economic analysis within the Policy Coherence for Sustainable Development (PCSD) framework to capture the impact of forest policies in Kenya on the SDGs over time and before they were formally adopted. A key focus will be on the Water, Energy, and Food (WEF) nexus security indicators. PCSD ensures the implementation of one goal does not impede the achievement of other goals. A historical perspective that considers the broader policy environment and evolution in Kenya over the past 50 years, will enable a more embedded understanding of current developments in the sector. More so, forest policies can have positive (synergies) or negative effects (trade-offs) on the realization of different SDGs, as well as interact with policies in other sectors of the economy across time. A long-run economic analysis using a range of indicators liked to the SDGs will help identify these interactions as well as pathways to minimize the trade-offs and maximize the synergies.

Village relocation: an approach to Forest Landscape Restoration

T3.9 Forest landscape restoration (FLR) and SDG Goals from the lens of forest policy and governance

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Abstract: Forest landscape restoration is considered as a process in which the soil is allowed to regain its ecological potential which was on continues pressure by different anthropogenic factors. In the current scenario, landscape approach is vital in case of conserving the Protected Area. Relocation of villages which are located in the Protected Area is carried out in order to restore the natural forest ecosystem. Eastern Vidarbha Landscape comprises of 3 National Parks and 8 Wildlife Sanctuaries which harbors a wide range of wildlife. The existence of villages inside the Protected Area is naturally prone to Human Wildlife Conflicts. Keeping the immense value of human and as well as the wildlife, rehabilitation of villages is carried out with the consensus of the community. Sixteen villages at different locations were relocated to nearby townships. The relocated forest landscape was treated with Assisted Natural Regeneration which includes native fruit bearing tree species, climbers and grasses. For a period of 3 years, the area was monitored consistently. The relocated villages in the landscape are now regenerated into a natural forest and grassland with distribution of native species. This landscape acts as a corridor for movement of wildlife. The intervention made by the government with specific guidelines made a win-win situation for both the community by means of compensation package as well as for the wildlife and ecosystem by means of restoration.

Keywords:

Eastern Vidarbha Landscape; assisted natural regeneration; relocation

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

Age estimation algorithms of living trees in natural mixed forest based on the micro-damage measurement of drilling resistance

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: Age estimation of standing trees is the most important and basic problem in forest production and research. We studied the algorithm of tree age estimation with the series of drilling resistance as the object, so as to provide the method and basis for the tree age determination.Three kinds of algorithms for measuring the living trees age were proposed in this paper, which could be used to estimate tree age by the series of drilling resistance values.(1)When the appropriate parameter rat was selected according to their DBH, the stationary Kalman filter applied in 323 groups of drilling resistance of Larix principis-rupprechtii had better denoising effect, so that the algorithm estimating tree age closed to the actual age. (2) The algorithm frequency spectrum analysis was applied to Larix, the window parameters were selected according to the DBH of living trees, and the algorithm estimating tree age was closed to the actual age. The results showed that the accuracy of spectrum analysis algorithm for estimating the age of Larix rupprechtii was better, and the accuracy of tree age estimation by resistance was improved. (3) Peak valley analysis algorithm was applied to 113 groups of drilling resistance sequences obtained from three tree species in natural forest including Larix olgensis, Pinus Koraiensis and Abies nephrolepis. When the appropriate threshold value (Det)was selected according to the tree real age, The tree age was estimated by the peak-valley analysis, and the results showed that it was close to the real tree age. The results showed that According to the tree diameter distribution, the algorithm parameters Rat and window parameters Wid were determined, and the estimation of the age of Larix rupprechtii by using the algorithm of stationary Kalman filter and the algorithm of spectral analysis were better, in which the error of the algorithm of spectral analysis was slightly lower than the algorithm of stationary Kalman filter; Using peak valley analysis algorithm to estimate the age of Korean larch, Pinus Koraiensis and Abies nephrolepis was better. The next step was to apply the algorithm to age estimation of more kinds of natural forest living trees.

Clonal multiplication from seedlings of Cordia trichotoma, Calophyllum brasiliense and Cariniana legalis

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: Many alternative native and exotic forest species have potential for commercial exploitation, but to establish production systems with these species, research in silviculture is necessary, mainly in genetic improvement and biotechnology. Therefore, tests were proposed for the optimization of vegetative propagation via cuttings of three native species of great economic, social, and productive importance: Cordia trichotoma (Vell.) Arráb. ex Steud., Calophyllum brasiliense Cambess e Cariniana legalis (Mart.) O. Kuntze. For the development of vegetative propagation protocols, rooting tests were performed with six different doses of indolbutyric acid (IBA) and a control. The IBA concentrations tested were: 0, 500, 1.000, 3.000, 5.000, 7.000 and 10.000 ppm. Therefore, the experimental design used for three species was complete randomized blocks with 7 treatments, 16 blocks and one plant per plot. The trait was evaluated: root length. The mini-cuttings were from seminal seedlings. Statistical analyzes were performed using the program R. In rooting tests with mini-cuttings, statistical differences were observed between IBA concentrations for C. brasiliense, C. legalis and C. trichotoma for root length at the 1% probability level. The best IBA concentrations for root length were 3.000 ppm for C. trichotoma, and 5.000 ppm for C. legalis and C. brasiliense. The mean root length was 2.59 cm for C. legalis, 1.71 cm for C. brasiliense and 1.45 cm for for C. trichotoma. The coefficient of variation was high for C. trichotoma, C. brasiliense and C. brasiliense (45.67%, 43.18% and 69.28%, respectively), which can be understood and expected since the mini-cuttings were used from several ministumps, which still bring great genetic variability. The established concentrations of AIB determined for the two studied species will be used to produce clonal seedlings for commercial plantings and genetic improvement.

Keywords: AIB, planted forests, wood products, genetic variability.

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Effects of fertilization on growth increments, reproduction and photosynthetic physiology of Pinus koraiensis plantations

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: Global climate change place increasing great pressure on world forest, which leading to reduced stand productivity, delayed harvests and forest decline. Reasonable intensive management can improve forest productivity, promote growth increments, reproduction and shorten production rotations. Fertilization is one of the important measures of forest intensive management. In the past, intensive management of fast-growing tree species (e.g timber) was commonly practiced, but there were few reports on intensive management of long-lived tree species, especially those with dual commercial value (such as seeds and wood of *Pinus koraiensis*). To determine the impact of intensive management on its growth and reproduction needs further research. In this study, 25-year-old Korean pine plantation in Hancongling Forest Farm of Jilin Province was selected as the research object to explore the effects of different fertilization treatments on the growth increments, reproduction and physiological parameters of Korean pine. This investigation aims to understand and quantify the promotion patterns of intensive management on growth increments and reproduction. The results showed that the photosynthetic physiological characteristics and nutrient concentration of *Pinus koraiensis* showed a positive response to fertilization, and its growth and seed setting were significantly increased. No matter the single application of N, P, K fertilizer or the combined application of NP and NPK significantly promoted the DBH, crown width growth of Korean pine, significantly increased the seed setting rate and cone yield per tree. The effects on the growth and fruiting of Korean pine were NPK > NP ≥ N > P > K > CK. Compared with the control, the DBH, seed setting rate and cone yield of Korean pine treated with NPK increased by 27.7%, 121.2% and 158.3%, respectively. Fertilization significantly increased the contents of Pn, Gs, Tr, Wue and chlorophyll, as well as the concentrations of soluble sugar, starch, nonstructural carbohydrates and nutrients in Korean pine. Fertilization significantly increased the concentrations of corresponding nutrient elements in needles, branches and trunks, indicating that *Pinus koraiensis* was sensitive to fertilization.

Genotype-by-environment interaction in Khaya senegalensis provenance and progeny tests

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: The genus *Khaya* (African mahogany) have aroused interest in hardwood production in tropical countries. This study aims to generate information and tools for the development of a breeding program for one African mahogany species (*K. senegalensis*) in Brazil, focusing on solid wood production. The goal is to estimate the genetic parameters and genotype-by-environment interaction (GEI). Thus, provenance and progeny tests were established between 2017 and 2019 in six edaphoclimatic conditions in the municipalities of Garça (GAR), Porto Seguro (PSB), Selvíria (SEL), Teresina (TER), Currais (CUR), and Alvorada do Guguéia (ADG). All tests were established in randomized blocks, with 22 progenies and five provenances and one plant per plot. The total height, diameter at breast height (dbh), commercial height, and stem shape were evaluated until 2023. Then, the average annual increment was calculated for diameter and total height (AAIdbh and AAIht). Statistical analyzes and genetic parameters, including the GEI, were estimated using the REML/BLUP method. The deviance analysis was used to verify the significance of genetic and GEI effects. The MHPRVG procedure was used to estimate the productivity, stability and adaptability of the progenies and classify them according to these criteria. Regarding the growth, we observe a higher AAIdbh in PSB (2.71) and for AAIdbh in TER (1.90), showing the adaptation of the species to warm climate regions. Significant differences were found between the performances of progenies in each test for diameter or height, with heritabilities for AAIdbh ranging from 0.01 in CUR to 0.22 AAIdbh in PSB. The GEI effect also was significant on the AAIdbh trait with a correlation between sites of 0.26. This result confirms the complex nature of the GEI effect on the species. Therefore, to establish a broad breeding program for the species in Brazil or another tropical country it is necessary to balance the selection of progenies based on stability and adaptability criteria. Following the MHPRVG method, the most stable and productive progenies in diameter are 10, 14, and 13. These progenies can be indicated in a wide range of environments to increase the productivity of commercial stands of the species. Acknowledgments: FAPESP process 2020/09216-0.

Optimizing In Vitro and Cutting Culture Techniques for Asexual Propagation of High Economic Value Trees

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: Forest plantations and tree improvement breeding programs in Thailand traditionally depend on efficient asexual propagation methods such as cutting culture. Recently, *in vitro* culture methods have been introduced, offering advantages including controlled environment and rapid proliferation, although success with commercially valuable timber tree species remains limited. This study investigated the effectiveness of these propagation methods in eight tree species with commercial value: *Dalbergia cochinchinensis*, *Pterocarpus macrocarpus*, *Xylia xylocarpa* var. *kerrii*, *Afzelia xylocarpa*, *Hopea odorata*, *Dipterocarpus alatus*, *Millettia xylocarpa*, and *Toona ciliata*. The focus was on the use of plant growth regulators such as 6-benzylaminopurine (BAP), kinetin, zeatin, naphthaleneacetic acid (NAA), and indole-3-butyric acid (IBA), to boost adventitious shoot or root formation. The findings highlight differential responses among species, with *D. cochinchinensis*, *P. macrocarpus*, and *M. xylocarpa* exhibiting successful shoot induction in *in vitro* cultures and effective root induction through cutting. *In vitro* cultures remained unsuccessful for *X. xylocarpa* var. *kerrii*, *A. xylocarpa*, and *H. odorata*, while root induction through cutting was successful. *D. alatus* and *T. ciliata* showed limited responsiveness to both methods. These findings shed light on the comparative effectiveness of *in vitro* and cutting methods in propagating different tree species. Further research is imperative to identify efficacious propagation methodologies for *D. alatus* and *T. ciliata*, and to refine *in vitro* treatments for species such as *X. xylocarpa* var. *kerrii*, *A. xylocarpa*, and *H. odorata*. Understanding the exact plant growth regulator combinations could lead to effective asexual propagation techniques. Such knowledge would be instrumental in enhancing the effectiveness of forest plantation establishments and tree improvement breeding programs.

PREDICTION OF SECONDARY CORK INDUSTRIAL QUALITY AND POROSITY BASED ON VIRGIN CORK CHARACTERISTICS

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: The primary aim of this work is to research the possibility of using physical characteristics accessed in virgin cork samples, as predictors of secondary cork industrial quality and porosity. If this hypothesis is confirmed, thinning of young high tree density plantations may be based on specific selection criteria, a relevant improvement to the current forest management practices.

Virgin cork samples (n=66) were obtained from 3 different stands. Nine years after the first debarking, the same trees were resampled for secondary cork. Secondary cork samples were classified regarding industrial cork quality classes by an experienced operator. Cork color was determined in virgin and secondary raw cork samples, based on CieLab color space, in the radial and transversal directions of the samples, and also in the cork sample back and belly. Virgin and secondary cork porosity was determined also in the raw samples.

The data analysis was carried out in order to considering: i) t-test carried out to the average values of L*, a* and b* color parameters from virgin cork samples, for comparing groups of distinct cork quality classes, classified by secondary cork samples ii) the Spearman correlation coefficient (ρ) between virgin and secondary cork porosity.

Results showed that color parameters, in particular *L** (lightness) and b* (blue versus yellow) measured in transversal or radial sections of the raw virgin cork, allowed to distinguish cork quality groups from secondary cork. The L* parameter measured in the back surface was able to differentiate good cork from average and low quality cork, but was nor able to distinguish the two latest groups.
A ρ=0.40 was obtained between the porosity values of virgin cork and secondary cork, showing a moderate positive monotonic relationship. The final model for the forecast of secondary cork porosity as a function of virgin cork porosity was formulated as an hyperbole. The model parameters were expressed as a function of color L* and b* values measured in the transversal direction of the cork. No additional color parameters were added since this would imply high multicollinearity. The final model presents a R^2 = 0.445 and a MSE = 0.00086.

Prospects of Organic and Inorganic fertilizer use in Commercial forest Plantations in Kenya

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: The use of fertilizer in commercial forestry is one of the key technologies for achieving fast growth and high yields of forest products. This practice has been adopted by many forestry enterprises around the world. However, there are mixed reports as to the actual levels of output achieved by the use of fertilizers. Some reports show a significant improvement, and others show marginal or no improvement in tree growth. In Kenya, the use of fertilizers in forestry has not been widely adopted and there is little information about their usefulness. To understand the impacts of fertilization in forestry in Kenya, a study was conducted at the Forest Research Institute of Kenya to determine the effects of application of organic and inorganic fertilizers during tree establishment, on survival, growth, and yield of one of the main commercial plantation species, *Eucalyptus grandis*. A randomized complete block design with four replications was used to evaluate the effects of four treatments namely, organic fertilizer – cow dung manure, inorganic fertilizer – Triple Super Phosphate, a combination of the two, and a control treatment of no fertilizer. Growth traits assessed were percentage survival, height, and stem diameter at breast height DBH, of trees in different treatments. The results of tree survival after one year of establishment showed no significant difference among the treatments. However, there was a significant difference in height and DBH growth among the treatments in the early growth upto age of six years, where the highest growth was by trees under organic fertilizer which achieved mean height of 14.25 m and mean DBH of 14.4 cm. However, by age 16, there was no significance difference in growth of the trees under different treatments. Results of this study, suggest that faster growth and higher yield can be achieved with the use of organic fertilizer only when the tree are raised for a short growing period of upto six years. Beyond this age, tree growth do not seem to benefit from fertilizer application.

Pruning Intensity and Spacing Impacts on the Growth of Terminalia brownii in the Lake Victoria Basin Eco Region, Kenya

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: Pruning Intensity and Spacing Impacts on the Growth of *Terminalia brownii* in the Lake Victoria Basin Eco Region, Kenya

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Indigenous tree resources play a major socio-economic role in the lives of rural communities that depend on them for the supply of fuel, medicine, and shelter among others. *Terminalia brownii* Fresen (Combretaceae) is one such species that is native to the greater eastern Africa region. *Terminalia brownii* has been used successfully in agroforestry, afforestation and reforestation programmes in the drylands of Kenya. Despite the economic benefits associated with *Terminalia brownii* in Lake Victoria Basin Eco-Region, its exploitation continues unabated. However, there is no or little information known on the management practices.

A study was conducted to investigate the effects of pruning regimes and spacing on the growth of *Terminalia brownii* in the Lake Victoria Basin Eco-Region in Kenya. The treatments consisted of three pruning regimes (severely pruned, pruned and unpruned) and four spacing types (1 x 1, 2 x 2, 3 x 3 and 4 x 4) in a randomised complete block design. Severely pruned and pruned trees recorded significant variation in basal area ($p=0.0377^*$), stems per hectare ($p= 0.036598^*$) and diameter at breast height ($p= 0.010^*$) while there were no significant differences in tree heights ($p=0.2266$) among different pruning regimes within different sites when compared to unpruned trees. Significant differences existed in diameter at breast height ($p<0.001^*$), tree height ($p=0.003^*$), mean stems per hectares ($p<0.001^*$), basal area ($p=0.0147$) and volume ($p=0.0168^*$) among the different spacing types. However, no differences were reported between 4 x 4 and 3 x 3 spacing. Tree diameter at breast height and crown expansion increased with wider spacing (4 x 4) and reduced with closer spacing (1 x 1). We concluded that tree spacing of 3 x 3 and pruning intensity (pruning) are significant management options in *Terminalia brownii* to maximize the increase in volume productivity.

Recent Advances in Nondestructive Evaluation of Wood: In-Forest Wood Quality Assessments

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: Recent research and development on nondestructive testing technologies has brought the in-forest assessment of wood and fiber properties of standing trees into tree breeding, forest management, resource evaluation, and harvesting operations. Significant values are associated with the wood and fiber quality of our forests for the production of structural lumber, engineered wood products, and pulping and paper. Rapid and nondestructive measurements on trees allow this value to be captured through genetic improvement and better silvicultural practices, as well as the allocation of resources to highest value users and application of best processing methods. This presentation provides an overview of recent research and development on in-forest wood quality assessments using emerging nondestructive and precision-based technologies such as SilviScan™, near infrared, DiscBot, acoustic waves, and resistance drilling. A brief discussion is followed on how these technologies and the knowledge obtained from them can support the development of the next generation of forests, e.g. through tree breeding and silviculture.

Relationship of standing tree strength with tree height and diameter based on site productivity: toward estimating standing tree strength

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: Stronger Japanese cedar logs yield stronger sawn wood, while stronger standing trees yield stronger logs. Stronger logs also have a smaller average annual ring width, indicating slow tree growth. Tree growth, particularly height growth, is an important indicator of site productivity in forestry. As a result of the aforementioned tendency, it is possible that site productivity affects standing tree strength. In this study, we aimed to better understand the relationship between standing tree strength and tree height or diameter based on site productivity. A site productivity estimation model based on a 5 m mesh site condition map was used to assess the productivity (divided into three classes: A for high to C for low) of a 43-year-old Japanese cedar experimental site (Mukai et al., 2023). Trees of varying diameters were selected from sites with different productivities, and tree strength, height, and diameter at breast height (DBH) were measured. Positive site classes such as A^+ and B^+ were assigned to trees taller than the average height of site productivity, while negative site classes such as A^- and B^- were assigned to trees that were shorter than the average. A weak negative correlation ($R=-0.69$, $p<0.01$) was observed between tree strength and tree height. Trees were grouped into site productivity classes of A^+, A^-, B^+, and B^-, from the weakest to the strongest, indicating a specific relationship between tree strength and site productivity. However, there was a strong negative correlation ($R=-0.81$, $p<0.01$) between tree strength and DBH. Trees from different site productivities were mixed, and no correlation was found between tree strength and DBH with respect to site productivity. This implies that the indicators influencing diameter growth are more relevant to tree strength than those influencing height growth. Therefore, indicators influencing diameter growth, such as tree density and crown volume, may be critical for predicting standing tree strength.

Response of growth and wood properties of Populus to different climate zones

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: Poplar (*Populus spp*.) is a genus providing important plantation tree species allowing the production of a fast growing wood resource mainly in temperate climatic regions, among which the *Sect. Aigeiros, Sect. Populus* and *Sect. Tacamahaca* are the main poplar species. These trees are present in many countries, they are easy to regenerate vegetatively, and the increasing demand for wood makes this an excellent tool to meet many sustainable development goals. The industrial production of wood products relates to the climate zone, meaning that the performance of poplars needs to be verified in relation to their multi-environment. Hence, determining the variation of wood properties and growth due to environment is a key task. Yet, the traditional wood property research methodology is complicated and takes a long time. The application of the X-ray CT scanning of wood cores has effectively saved workload, and hence research based on collecting a large number of samples has become possible.

This research has been carried out in 14 Köppen-climates zones from China and Europe. At each location poplars are selected from the above three sections for drilling wood cores. Historical meteorological data and parameters of the plantation are acquired for 'environment-poplar' modeling. The focus will be on the observational properties dealing with tree growth in combination with mechanical and physical properties as well as chemical composition to reveal the wood quality. In terms of responses to the environment, all the indexes acquired will be correlated with site and climate factors. Ecological zones suitable for the production of various clones will be divided according to the performance of poplar wood characteristics to provide strategies and experience for the forest industry chain based on plantation production systems.

Selected references

Scots pine breeding and wood quality

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: Scots pine (*Pinus sylvestris* L.) is a commercially important forest tree species in many Eurasian countries. Its wood has been commonly utilized for production of construction timber. In Sweden, a breeding program was launched in 1950s to improve Scots pine trees to better suit industrial requirements. The emphasis was mainly put on improving stem volume, vitality, stem straightness and branching characteristics whilst wood quality was neglected. However, since some of the important wood quality traits are negatively correlated with the prioritized volume production, the continuation of such an approach could in a long run lead to irreversible deterioration of wood quality.

In our study, we focused on wood quality traits that are relevant for construction timber – wood density, stiffness, strength, grain angle and sawn-board shape stability (crook, bow and twist). We linked wood quality traits that were nondestructively assessed on standing trees with those measured on sawn boards. We estimated narrow-sense heritabilities, genetic correlations and correlated responses to selection with the aim of identifying reliable techniques for wood quality assessment on standing trees and proposing suitable strategies for incorporating wood quality traits into the breeding program.

We have concluded that standing-tree drilling resistance, acoustic velocity and grain angle are good predictors of wood density, wood stiffness & strength, and sawn-board twisting, respectively. Taking into account the long-term development on wood market, we are proposing an inclusion of wood density in the breeding program, in the way that it will be retained at the current levels rather than increased, which would also positively affect wood stiffness and strength. Furthermore, we are suggesting to consider grain angle as a breeding trait although more research is needed to unravel its underlying biological mechanism.

Selected coastal Douglas-fir under global change: the effects of silvicultural interventions on forest resilience

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: As an important commercial tree species in British Columbia, coastal Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) has been subject to recurrent selection to enhance productivity. However, it is currently not known if this selection process has affected Douglas-fir's susceptibility to extreme weather events and how such effects are modulated by competition. As climate projections for coastal Douglas-fir forests in the Pacific Northwest predict more frequent and extreme weather events such as heat and drought, maintaining resilience is critical. In 1996, the British Columbia Ministry of Forests established five replicated realized gain trials comprising four initial planting densities and three levels of genetic gain for timber volume. By comparing tree-ring widths across all factorial combinations of site, genetic gain and planting density, we evaluate the effects of selection and competition on growth resilience following years with extreme weather events. Moreover, we compare tree-ring widths with remotely sensed spectral values and structural attributes at the individual tree level. This will allow us to determine if remotely sensed indices are a good indicator of drought stress, and can therefore be used as a faster and more extensive method of assessing forest health under climate stress. Lastly, we use microsections to characterize wood quality properties such as cell wall thickness and lumen diameter, to see how these properties vary across genetic levels and spacing densities under global change pressures. We predict that genetically selected individuals are less resilient to extremes, and that increased competition has a negative effect on resilience. We therefore expect that in these less resilient trees, impacts of extreme droughts will be higher and can be tracked on short temporal timescales using the photochemical reflectance index obtained via remote sensing. We expect higher resilience to be correlated to better wood qualities such as thicker cell walls and smaller lumens. With climate and planting density as the primary drivers of Douglas-fir growth variability, selection of the best adapted trees for reforestation and flexibility in operational planting densities can ensure that future Douglas-fir forests are resilient to climatic extremes and can continue to provide their ecological, economic, and cultural functions.

Species-optimal management of group-mixed Norway spruce and silver birch for sustainable bioenergy biomass supply

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: The Swedish Forest sector has the potential to provide biomass to produce renewable energy if forest management can ensure sustainable production of biomass for bioenergy and other materials. The presence of native broadleaves with conifer (silver birch and Norway spruce, respectively, in this study) has been advocated to increase sustainability. This study aimed to compare production and economy in monocultures of the two species with group-mixtures, either managed according to the mean values of the two species, or optimized management of the individual species.

The development of planted Norway spruce and silver birch forests in eight different sites in Sweden was simulated for three management alternatives, either monocultures of the two species, or group-mixtures managed with two management intensities. The decision support system Heureka was used to generate optimal treatment schedules. For monocultures, Norway spruce or birch was simulated for the whole stands. For group-mixtures, both species were either simulated together with the same timing of interventions or individual treatments of the tree species according to the timing of interventions found optimal in the simulations of monocultures. The rotation age of monocultures and group mixtures with average timing of interventions was decided by the highest land expectation value. The rotation age of the alternatives with group mixtures with individual tree-species treatment was selected based on the combined maximised land expectation value of the two monocultures.

Three scenarios were generated for all the management alternatives. In the base scenario, the felled trees in all operations were considered pulpwood and sawlog. In the second scenario, the first thinning was considered biofuel thinning. In the third scenario, logging residue was extracted in the final felling in addition to the base scenario. We analysed the impact of bioenergy biomass procurement from young stands on the overall profitability of a mixed forest, the economic return of the species-optimal management regime and the broadleaf growth compared to the conventional management. Initial results suggest that the species-optimal approach increases broadleaf growth compared to conventional group-mixed stand management and can be a sustainable source of biofuel. However, increased management interventions will increase the total management cost.

Whole-tree wood properties mapping of Eucalyptus pellita: toward a predictive model for wood quality

T3.10 Forest management solutions under global change: connections between tree breeding, intensive silviculture and wood quality

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Abstract: *Eucalyptus pellita* holds significant commercial value in the tropical region, mainly due to its application in the pulp and paper industry. This species has also been considered as an ideal source for producing high quality solid wood and veneer products. Wood quality assessment is crucial aspect to determine the end-product's performance, and consequently the value of the wood products. For the best utilisation of wood as a raw material and to develop an understanding of the effects of tree growth on wood formation, it is essential to have a knowledge of how wood quality changes within trees. Hence, this study aims to determine within-tree wood properties and develop whole-tree wood quality maps of even-aged plantation-grown *E. pellita* in the dry tropics of Australia. We selected 30 trees which represent five distinct genotypic backgrounds of *E. pellita* across two different sites on the Tiwi Islands. An IML Resistograph PD-400 was used to measure bark to bark wood properties at seven longitudinal points along the stem. Disc samples with 2 cm thickness were extracted from the base, middle and top part of each tree for assessing pith to bark wood properties using SilviScan and Near-Infrared Spectroscopy (NIRS). The results provide a comprehensive set of radial and longitudinal information on wood properties such as wood density, MFA, modulus of elasticity (MoE), fibre coarseness, cell wall thickness, fibre diameters, cells specific surface area, acoustic wave velocity (AWV), kraft pulp yield, lignin, cellulose, and extractive content of *E. pellita*. Whole-tree wood properties mapping was undertaken using Akima's interpolation method in R statistical programming environment with the RStudio interface to compare cambial age-related pattern of wood properties variation. The interrelationship between the various wood properties at different positions across the stem will also be explored. Wood properties mapping in this study will be used to develop wood quality predictive models based on non-destructive testing (NDT) that can inform plantation management practices and wood processing operations.

T3.11 Forest resilience: the vision from belowground

Arbuscular Mycorrhizal Fungi Spore Density of Nursery soil and Root Colonization Level of Seedlings in Tigray, North Ethiopia

T3.11 Forest resilience: the vision from belowground

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Abstract: In natural ecosystems, the root system of successful plants has microbial partnerships to survive and grow even in harsh conditions. Arbuscular mycorrhizal fungi (AMF) are among the mutual beneficial partners to plants in the drylands. Seedlings prepared for the restoration of degraded drylands need to be inoculated and colonized in the nursery for successful survival and growth at the planting site. The objective of the paper was to analyze the status of AMF spore density and root colonization in raised nursery tree seedlings and nursery soils in lowland, midland and highland agroecology in Tigray Ethiopia. Both soil and root samples were collected from seven private, four community and nine state nurseries using stratified random sampling method. AMF Spore enumeration and root colonization analysis were done using 204 seedling containers having nine species from lowland, fourteen species from midland and six species from highland. All the 22 species found in the 20 nurseries were colonized by AMF. The highest average spore density and root colonization were enumerated in lowland ($p<0.001$) followed by mid land and highland. State nurseries had recorded higher average spore density (43.60 spores 100 g^{-1} dry soil) and percentage of root colonization (39.51%) followed by community nursery and private nursery. The spore density of the nursery soils and root colonization of seedlings was low. Seedling raised in nurseries better requires inoculation from a non-disturbed soil sources.

Biodiversity mitigates drought and disturbance stresses in the decomposer system

T3.11 Forest resilience: the vision from belowground

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Abstract: Multiple facets of global change affect the Earth System interactively with complex consequences for ecosystem functioning and stability. Simultaneous climate and biodiversity change are of particular concern, because biodiversity may contribute to ecosystem resistance and resilience and may mitigate climate change impacts. Yet, the extent and generality of how climate and biodiversity change interact, remain insufficiently understood, especially for the decomposition of organic matter, a major determinant of the biosphere – atmosphere carbon feedbacks. Decomposition depends on the characteristics and diversity of plant-produced organic matter as the primary energy source, and is further regulated by an astounding diversity of soil organisms ranging from prokaryotes to macro-invertebrates that are organized in highly complex food webs. With an inter-biome experiment, we tested here how biodiversity in the multi-trophic decomposer system drives decomposition in forest ecosystems under drier conditions. Our results show at a relevant spatial scale covering distinct climate zones that forest floor biodiversity across trophic levels has a strong potential to mitigate drought effects on C and N dynamics during decomposition. Furthermore, by choosing seven locations along a climatic gradient that is invaded or non-invaded by a clonal species (*Phyllostachys heterocycle*, moso bamboo), we conducted both in situ and reciprocal decomposition experiment and manipulated soil biota community. We reported a tradeoff mechanism of soil microorganisms with litter traits and showed that macrofauna play important role in modulating decomposition under plant invasion disturbance. Preserving biodiversity at multiple trophic levels contributes to ecosystem resistance and appears critical to maintain ecosystem processes under ongoing climate change.

Keywords: Climate change, Carbon cycling, Drought, Ecosystem function, Biodiversity; Litter decomposition; Plant-soil interactions; Soil nutrient cycling; Soil fauna

Climate legacy interacts with wildfire to alter rhizosphere microbial communities in a Mediterranean climate-type forest

T3.11 Forest resilience: the vision from belowground

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Abstract: Mediterranean forest ecosystems will be increasingly affected by hotter drought and more frequent and severe wildfire events in the future. However, little is known about the longer-term responses of these forests to multiple disturbances and their capacity to maintain ecosystem function. This is particularly so for below-ground organisms, which have received less attention than those above-ground, despite their essential contributions to forest function. We investigated rhizosphere microbial communities in a resprouting *Eucalyptus marginata* forest, southwestern Australia, that had experienced a severe wildfire four years previously, and a hotter drought eight years previously. Our aim was to understand how microbial communities are affected over longer-term trajectories by hotter drought and wildfire, singularly, and in combination. Fungal and bacterial DNA was extracted from soil samples, amplified, and subjected to high throughput sequencing. Richness, composition, and putative functional groups were then examined. We found a monotonic decrease in richness and diversity with increasing disturbance with the greatest changes resulting from the combination of drought and wildfire. These changes were more apparent for fungi than in the bacterial community. There were distinct responses in community composition and putative functional groups to the disturbance types, with key mycorrhizal fungi and cyanobacteria being found at lower proportions in sites affected by drought plus wildfire. Our results suggest that microbial communities, in particular key functional groups, are highly responsive to wildfire following drought. Thus, a legacy of past climate conditions such as hotter drought can be important for mediating the responses of soil microbial communities to subsequent disturbance like wildfire.

Complementary belowground strategies underlie species coexistence in an early successional forest

T3.11 Forest resilience: the vision from belowground

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Abstract: Pure coniferous plantations are widely distributed globally and generally associated with low ecosystem services, low stability, and vulnerability to disturbances. Replanting broadleaf seedlings under pure coniferous plantations is an important measure to optimize the structure of monospecific forests. Unravelling belowground strategies is critical for understanding species coexistence and successional dynamics and would have important implications in the selections of broadleaf species; yet, our knowledge of nutrient acquisition strategies of forest species at different successional stages remains limited. We measured morphological (diameter, specific root length, and root tissue density), architectural (branching ratio), physiological (ammonium, nitrate, and glycine uptake rates) root traits, and mycorrhizal colonisation rates of eight coexisting woody species in an early successional plantation forest in subtropical China. By incorporating physiological uptake efficiency, we revealed a bi-dimensional root economics space comprising of an 'amount-efficiency' dimension represented by morphological and physiological traits, and a 'self-symbiosis' dimension dominated by architectural and mycorrhizal traits. The early pioneer species relied on root–fungal symbiosis, developing densely branched roots with high mycorrhizal colonisation rates for foraging mobile soil nitrate. The late pioneer species invested in roots themselves and allocated effort towards improving uptake efficiency of less-mobile ammonium. Within the root economics space, the covariation of axes with soil phosphorus availability also distinguished the strategy preference of the two successional groups. These results demonstrate the importance of incorporating physiological uptake efficiency into root economics space, and reveal a trade-off between expanding soil physical space exploration and improving physiological uptake efficiency for successional species coexistence in forests.

Controlled germination and inoculation of holm oak (Quercus ilex L.) with two species of the genus Tuber

T3.11 Forest resilience: the vision from belowground

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Abstract: Truffles (genus *Tuber*) are hypogeous **ectomycorrhizal (ECM) fungi** that enter into a mutualistic symbiosis with the roots of higher plants. Truffles are intensively cultivated due to their gastronomic value and the decline of natural production. Modern truffle cultivation is based on planting inoculated seedlings on suitable soils of appropriate ecological conditions to complete the life cycle of the fungus.

The purpose of the research is to find the optimal inoculation method that will ensure a satisfactory degree of mycorrhization. Holm oak was chosen as the host plant because it is a natural symbiont of black and summer truffles, our indigenous specie and ecologically suitable for the habitat of planned plantations. Black (*Tuber melanosporum* (Vittad.)) and summer truffles (*Tuber aestivum* (Wulfen) Spreng.)) were used as fungal symbionts, which are the most prized black truffles. In addition, the technology of plantation cultivation is known for them. The research tested three methods of storage and germination of acorns, two methods of inoculation (inoculation with substrate and inoculation by injection into substrate) with different doses of mineral fertilizer and different treatments with fulvic acid. 19 different experiments were set up with a total of 1 320 holm oak seedlings. So far, we have confirmed mycorrhiza with both truffles species. The results obtained by the end of 2023 will be presented on a poster.

The use of inoculated seedlings with truffle mycelium is very wide, such as raising plantations, reforestation and recuperation of degraded habitats or their free sale. It has been proven that mycorrhized plants grow faster and better than individuals of the same species that are not mycorrhized and have a significantly increased leaf surface. This is especially pronounced in soils with a low nutritional composition. Cultivation of inoculated seedlings would also help preserve natural truffle populations, which are increasingly under pressure due to anthropogenic influence and climate change.

Does forest age affect root-associated fungal carbon flow, soil organic matter turnover and nitrogen cycling?

T3.11 Forest resilience: the vision from belowground

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Abstract: Microorganisms mediate biogeochemical processes in soil, including nutrient and carbon cycling, and stewardship of ecosystem services provided by soils in boreal forests requires understanding of these processes. In these ecosystems symbiotic ectomycorrhizal fungi influence build-up and decomposition of soil organic matter, providing trees with nitrogen, but during succession, primary production is increasingly limited by nitrogen availability. However, the role of free-living microorganisms in organic matter turnover and inorganic nitrogen cycling, and the role of moss-associated N-fixation during forest succession, which may impact both carbon sequestration and forest productivity, are poorly studied. Forest clearcutting and site preparation in conjunction with replanting disrupt the soil profile and shift the competitive balance between free-living and root-symbiotic microorganisms. Here we study the development of microbial-mediated soil processes after clearcutting and replanting.

We hypothesized that priming of soil organic matter decomposition via ectomycorrhizal fungal exudation and inorganic nitrogen cycling is more important in younger forests, and that priming via ectomycorrhizal enzymes and diazotrophic nitrogen fixation is more important in older forests where nutrients become immobilized in organic matter. We also hypothesized that dead mycelium in older forests is more recalcitrant, contributing to build-up of soil organic matter stocks. We analysed the composition of the fungal, bacterial and archaeal communities in mosses and soil layers. Genes coding for specific nitrogen transformations and abundance of bacteria and fungi were quantified using quantitative PCR to examine inorganic nitrogen cycling and fungal:bacterial ratios, and N fixation rates were quantified. Soil solution was sampled sequentially and analysed for aliphatic and aromatic acids to quantify labile carbon fluxes. Decomposition was studied by incubating mycorrhizal mycelia in soil, measuring weight loss, and characterizing chemical composition. Preliminary results indicate presence of the gene *amoA*, encoding ammonia oxidation, in all stand ages and soil layers, implying a higher risk for N loss, and bacterial and fungal community data differed significantly depending on soil layer and stand age. Mycelial decomposition was significantly affected by fungal species, stand age and incubation time, with an average mass loss of 54%. Decomposition likely varied depending on chemical composition and mass loss was highest in the 80-year-old forest stand.

Ectomycorrhizal fungal succession in naturally regenerated silver birch (Betula pendula Roth) stands on post-agricultural land

T3.11 Forest resilience: the vision from belowground

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Abstract: Silver birch (*Betula pendula* Roth) is a pioneer species that often naturally regenerates on post-agricultural land. The quantitative and qualitative composition of mycorrhizal fungal communities changes with stand age. The succession of ectomycorrhizal fungi depends on many factors, including local environmental conditions, particularly soil conditions. Therefore, the objective of this study was to analyze the mycorrhizal fungal communities in four young silver birch stands regenerated by self-sowing on post-agricultural land. The stands' ages were: 1-2 years old (class I), 2-7 years old (class II), 6-11 years old (class III), and 11-16 years old (class IV). Soil samples were collected from each stand for soil and mycorrhizal analysis. Soil properties in all age classes significantly differed from forest soils. The high proportion of non-mycorrhizal root tips in age classes I and II (10.8% and 20.4%, respectively) may result from limited inoculum availability. The high proportion of non-vital root tips, up to 55.7% in age class IV, indicates that soil conditions were not conducive to mycorrhizal functioning. A total of 23 taxa of mycorrhizal fungi were detected, with *Inocybe moravica* being the most abundant and frequently occurring species (relative abundance – 34.6%). Another species present in all age classes was *Paxillus involutus*. Most taxa (14) were found exclusively in one age class. The youngest stand had only three ectomycorrhizal fungal species, while a higher number of fungal taxa was observed in the three older stands (12, 11, and 13, respectively). Dominance, Shannon-Wiener, Simpson, and Evenness indices showed similarity among fungal communities in the three older stands, differing from the first age class. The ectomycorrhizal fungal communities of the three older age classes of stands were characterized by similar biological diversity, while they differed in terms of species composition, as confirmed by the low Jaccard similarity index. These findings suggest that soil properties and mycorrhizal inoculum availability influenced the results more than stand age.

Effect of birch afforestation of post-agricultural soils on key soil macrofauna

T3.11 Forest resilience: the vision from belowground

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Abstract: Birch occurs throughout most of Europe, with the highest frequency in northern countries. In Western Europe it reaches 0.5% to 15% of all hardwood standing volume. In Poland, birch trees occupy 7.0% of the forest area and contribute 4,5% to the growing timber stock on forest land. Although currently not very important to the wood industry, they perform many ecological functions. Furthermore, in the face of climate change and the associated devastating phenomena birch might be relevant pioneer tree species in forest restoration, as it adapts easily to a wide spectrum of climatic and site conditions. Therefore, an increasing interest to use silver birch (*Betula pendula* Roth.) as an alternative to other tree species for afforestation, in particular on post-arable soils, can be observed in recent years.

Even though certain data about the impact of birch on the soil environment in Central Europe are available, the understanding of belowground biodiversity and interactions between above- and belowground systems is still largely unexplored. Considering the ecological and utilitarian importance of this issue, we undertook a study on key soil biota – earthworms, which constitute most of macrofauna biomass and contribute to a number of ecosystem services.

The study covered five sites on sandy soils and five on loamy soils. The stands were of different ages (21-80). Each site included both afforested and arable plots located on the same soil type. Earthworms were sampled from three soil blocks (25 × 25 cm and 30 cm depth) on each plot. Four sampling campaigns were carried out, in spring and autumn 2020 and 2021. Upon assignment of earthworms to species and ecological groups (epigeic, endogeic and anecic), their biomass was also determined.

We identified 10 earthworm species across all plots: four endogeic, five epigeic, and one anecic. More biomass was recorded in afforested plots than on arable fields, both on loamy and sandy soils. We demonstrated that afforestation had a significant positive effect on biomass of epigeic species only, and that forest age was an important predictor of total earthworm biomass on sandy soils.

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Effects of tree diversity on topsoil carbon and fungal diversity in European planted mixed forests are modulated by biotic and abiotic factors

T3.11 Forest resilience: the vision from belowground

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Abstract: Mixed-species forestry has emerged as a promising approach for sustainable forest management to mitigate climate change impacts through enhanced carbon (C) sequestration while maintaining productivity, biodiversity and other ecosystem services. However, we still have a poor understanding of the mechanisms driving soil C sequestration in tree mixtures, especially in the way it is driven by plant-soil-microbe interactions and biotic and abiotic factors.Using physiochemical soil analyses across nine European sites within the global network of tree diversity experiments, TreeDivNet, along with amplicon sequencing of soil fungal communities, we quantified the influence of mixed forest plantations on topsoil C stocks, fungal community composition and diversity, and their interactions. We further investigated the influence of biotic (tree growth, fungal diversity), edaphic (soil fertility and texture, nutrient status), and climatic (temperature and precipitation) factors on the relationship between tree diversity and C stocks in the topsoil. We hypothesised that increased tree diversity leads to increased topsoil C stocks and soil fungal diversity, and that this effect is modulated by the site-specific interaction of biotic and abiotic

factors.We found topsoil C stocks in high diversity stands to be greater than in monocultures across study sites. Increased soil fertility, mean annual temperature, as well as inter-annual temperature variability, were found to negatively affect tree diversity soil C relations. While tree diversity was not found to directly influence fungal diversity, topsoil C stocks were positively correlated to fungal species richness. In addition, the net diversity effect of tree mixtures on topsoil C stocks was positively correlated with fungal species richness, suggesting indirect linkages between tree and fungal diversity.Our study shows direct and indirect linkages between tree diversity, fungal diversity and topsoil C stocks, and highlights that these interactions are mediated by local abiotic context. Our findings underscore the need for site-specific optimization of C sequestration under consideration of tree diversity.

Elucidating soil biodiversity, crucial for climate change mitigation in forest soils?

T3.11 Forest resilience: the vision from belowground

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Abstract: The role of forests in climate change mitigation is widely recognized as forests can store vast amounts of carbon both above- and belowground. However, many forest ecosystems are affected by environmental pressures, and are at risk of becoming sources of CO2. This emphasizes the need to focus on boosting carbon persistence in addition to increasing carbon stocks. There is a growing body of literature that pinpoints soil biota as the missing link between forest management and carbon stabilization. Microbial communities are expected to increase in abundance and catabolic activity, which could lead to more CO_2 emissions from soils. Additionally, soil fauna are involved in almost any aspect of organic matter turnover: from regulating the activity and functional composition of microbiota to increasing the physical accessibility for the soil biome to soil organic matter and by transferring SOC throughout the soil via bioturbation. Yet at the moment, we lack the understanding of how belowground community composition relates to net carbon persistence through time. This study uses an observatory set of paired forest stands located on degraded sandy soils with a large carbon-saturation deficit to detect changes in carbon dynamics. A full array of chemical, carbon and biological analyses have been executed, allowing to investigate the mechanisms affecting C stability and how soil biota are involved. I hypothesize that the changes in carbon stability found in our study area can be linked to the composition of the soil community. Specifically, I hypothesize that belowground community composition and abundance, resulting in a certain combination of traits (a so-called trait space), represents a certain belowground functioning (emerging mechanisms), which translates into carbon stability via stabilization mechanisms. A better understanding of the mechanisms that involve soil communities and the link to carbon stabilization, is needed to optimize forest management to boost carbon persistence in soils.

Exploration of base cation transporter genes in Suillus genus in relation to mineral weathering capability

T3.11 Forest resilience: the vision from belowground

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Abstract: The role of ectomycorrhizal (ECM) fungi in biological weathering is increasingly recognised, although the quantitative significance of microbially mediated mineral dissolution for plant growth is debated. ECM fungi can weather minerals and mobilise essential nutrients such as base cations by physical force, extrusion of low molecular weight organic acids, free radicals and chelators. *Suillus* species in particular, are found to preferentially inhabit mineral soils and are frequently reported to possess weathering capabilities. Though studies growing ECM fungi with minerals have shown heightened nutrient content in mycelia compared to growth without minerals, the mechanistic understanding of nutrient mobilisation associated with weathering remains largely unknown.

Here we focus on characterising the diversity and phylogenomic distribution of base cation transporters in ECM genomes. We hypothesise that species with extensive mineral weathering capabilities will have higher copy-numbers of transporter genes associated with the transport of base cations to enable rapid uptake and transfer of recently mobilised nutrients. We examined transporter family gene copy-numbers of 110 Agaricomycetes species, and analysed evolutionary expansions and contractions of transporter gene families across the phylogeny.

Preliminary results show large variations in copy-numbers in all transporter gene families across all species and there are rapid expansions of cation transporters at the *Suillus* node. Genome analyses will be complemented by pure culture studies comparing base cation mobilisation and uptake by *Suillus spp.* to that by other species with varying copy-numbers and ecology. Fungal cultures will be grown with and without mineral additions (granite and gabbro) and mycelial base cation uptake and biomass will be quantified. Additionally, a transcriptomic study of *Suillus* spp. when in synthesis with *Pinus sylvestris* seedlings will be conducted taking guidance from the genomic study results.

Exploring the diversity and resilience of the mycobiome in Norway spruce in response to abiotic stress and pathogenic fungi

T3.11 Forest resilience: the vision from belowground

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Abstract: The mycobiome, or the community of fungi living in and on plants, may play a vital role in the health and survival of trees in the face of environmental stressors such as climate change and pathogenic fungi. As we move towards more sustainable forest management practices, understanding the complex relationships between trees and their microbial communities will be crucial in developing effective strategies to promote the resilience and well-being of forest ecosystems. The host plant genotype has been noted to be also one factor defining fungal composition. In that sense, the mycobiome is an integral part of a tree's general biology and can be seen as an extension of its genotype. As part of a continued effort to understand the effects of host genetics and environmental factors on fungal composition, we monitored the mycobiome associated with phloem and roots of rooted cuttings of Norway spruce under different watering conditions. To test the "mycobiome-associated-fitness" hypothesis, we compared the artificially inoculated *Heterobasidion parviporum* and mycobiome interaction on necrosis development. We aimed to 1) identify the specific mycobiome and certain species within Norway spruce genotype/family level and their interactions with *H. parviporum* and 2) identify mycobiome stability under abiotic disturbance (lower water availability). The mycobiome was identified by sequencing the ITS2 region. Our findings indicate notable variations in the diversity and abundance of the phloem mycobiome among the Norway spruce genotypes. These highlight the substantial influence of genetic variation within spruce genotypes on the composition and diversity of the phloem mycobiome. Variations in particular mycobiome genera in Norway spruce genotypes in response to water availability in the phloem suggest that the abundance of certain fungal genera in the phloem of Norway spruce trees is also influenced by environmental conditions. In the root mycobiome, key fungi such as *Phialocephala fortinii* and *Paraphaeosphaeria neglecta* were identified to confer inhibitory benefits in Norway spruce against *Heterobasidion parviporum* growth. Particular endophytes were also more stable under low water conditions in roots than ectomycorrhizal fungi. Ultimately, this knowledge could contribute to developing sustainable forest management practices that promote the well-being of trees and their ecosystems, enhancing forest resilience.

Greedy trees: Increased N-status Norway spruce trees enhanced Carbon allocation for the roots but not to its fungal symbionts nor surrounding trees.

T3.11 Forest resilience: the vision from belowground

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Abstract: Nitrogen (N) is one of the main factors limiting tree growth in the boreal forest, and trees growing in these soils rely on ectomycorrhizal fungi symbionts that provide nutrients in exchange for carbon (C). We provided supplemental N, equivalent to 25% of the estimated N present in the needles, to Norway spruce trees either through the transpiration stream or directly to the soil. We included 1% ^{15}N to track the distribution of the added N. After eight weeks, the trees were labeled with ^{13}C via photosynthesis to evaluate the effect of the increased N-status on the allocation of assimilated ^{13}C belowground. To evaluate the effects on root and the root-associated fungal transcriptomic activity, RNA was sampled after one and four growing seasons, and the community composition of the root-associated fungi was assessed using DNA amplicon sequencing.

Needle %N increased by 29% in trees treated via the transpiration stream, and by 58% in the soil treated trees. This increase in %N was mirrored by the distribution of ^{15}N throughout the canopy. Root %N increased 13% in both treatments. We found no evidence of ^{15}N transfer from the roots of trees treated via the transpiration stream to the root-associated fungi nor to surrounding trees. Both treatments significantly increased ^{13}C allocation belowground, assessed by ^{13}C efflux soil, with transpiration stream treated trees having higher soil ^{13}C efflux than the soil treated. Amplicon data showed significant changes in fungal community composition after four growing seasons, which were associated with changes in prevalence of seven dominant genera: *Cenococcum*, *Cortinarius*, *Hyaloscypha*, *Lactarius, Piloderma*, *Russula*, and *Suillus*. Fungal metatranscriptomic analyses showed that N-enrichment induced treatment specific C-starvation responses. With the transpiration stream treatment, processes including autophagy, glycolysis/gluconeogenesis and amino acid metabolism were induced, whereas ground N-enrichment induced biosynthesis of secondary metabolites, glycolysis/gluconeogenesis and glycerolipids metabolism. Altogether, our results show that increasing the tree's N-status initially enhances C-allocation belowground but the prevalent C-starvation responses shown by the linked fungal community suggests that the increase in allocated C is metabolized in the roots rather than transferred to the fungi.

Impacts of elevated CO2 on interactions with root microbes for enhanced oak growth and defence against pathogens

T3.11 Forest resilience: the vision from belowground

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Abstract: Trees are adapted to survive and face multiple (a)biotic stresses through millions of years of evolution. However, Climate change (CC) is increasing the number and rapidity of these stressors, endangering treescapes and the surrounding ecosystem. A crucial factor is the increasing atmospheric CO_2, the basis of the plant life, together with water. Even when it could be considered as a plant growth stimulant (e.g. increased growth), elevated CO_2 (eCO_2) has been demonstrated to trigger a plant stress response. In addition, many studies have highlighted the impacts of CC factors (warming temperatures, rising CO_2 and/or drought) on plant physiology, communities, and interactions with mycorrhizal fungi. Symbiosis between plants and beneficial soil microorganisms like mycorrhizae are known to promote plant growth and defence against (a)biotic stresses in plants. Therefore, understanding the role of mycorrhizal in plant responses facing environmental changes is critical. However, mycorrhizae role is largely underappreciated, and field experiment research is scarce. This project will test the mycorrhizae effects on oak, the eCO_2 impact on mycorrhizal colonization and their role in mediating growth-defence trade-offs. For this, microscopy and untargeted metabolomic analyses were performed in oak seedlings grown under ambient CO_2 (aCO_2) and eCO_2 and then infected with powdery mildew at the Free Air CO_2 Enrichment (FACE) facilities of the Birmingham Institute of Forest Research (BIFoR). Powdery mildew infection was monitored from May to July. At the end of the experiment, plants were removed and root traits were measured. Mycorrhizae staining was performed by ink-acid method in 20 seedlings/CO_2 levels to visualise endophytes. Root-extracted metabolites were subjected to LC-MS/MS analysis. Spectra were filtered by using XCMS R scripts. Statistical analysis, using METABOANALYST, showed statistical differences among treatments. Identification and functional pathway analysis was performed using MARVIS to select putative biomarkers. Additionally, elemental analysis was performed to quantify C/N ratios. Correlation analyses were performed to reveal the mycorrhizae relevance in powdery mildew resistance and its interaction with eCO_2. Data showed a protective role of mycorrhizae that can be limited by future CO_2 atmospheric levels, endangering forest health under climate change conditions.

Isolation, characterization and application of microorganisms to improve drought-stress tolerance in trees for restoration projects

T3.11 Forest resilience: the vision from belowground

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Abstract: Forests play a key role in mitigating the effects of climate change. However, due to increasingly frequent periods of severe drought, more and more forests are damaged. Especially tree seedlings show a high mortality under drought. Thus, improving drought tolerance of tree seedlings is of central importance for forest restoration. Many microorganisms are known to positively influence plant growth, for example by reducing several abiotic plant stresses. In the present study, soil microorganisms isolated at different forest sites were analyzed regarding their ability to reduce drought stress or to promote plant growth. The goal is to apply the newly isolated plant growth-promoting bacteria and fungi (PGPB/PGPF) during reforestation projects.

In 2021, we isolated 1,500 bacteria and fungi from two different temperate mixed Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*) forests in southern Germany after longer periods of drought. So far, around 400 isolates were identified on genus level. The most abundant bacteria were *Paraburkholderia* (121) and *Bacillus* (43) while *Penicillium* (8) and *Umbelopsis* (7) were the most frequently isolated fungi. Biochemical characterization revealed one *Streptomyces* strain and one *Paraburkholderia* strain showing a high salt, pH and osmotic stress tolerance as well as the ability to produce siderophores, solubilize phosphate and utilize 1-aminocyclopropane-1-carboxylic acid, the precursor of ethylene, as a nitrogen source. For application to the tree seedlings in monoxenic *P. abies* cultivations, three different systems were used: two petri-dish systems based on either agar or white/black peat and perlite and a newly developed 24-deep-well system. In these, two bacterial stains and one fungal strain leading to higher seedling weight and length were identified. In subsequent pot experiments, the effects of the identified PGP strains are now verified under more realistic conditions. Moreover, the genomes of the most promising isolates will be further analyzed for a deeper understanding of the mechanisms underlying these positive interactions. Additionally, metagenomes of the soil samples taken in 2021 are analyzed to identify microorganisms that are generally associated to drought. Taken together, these data could contribute to finding nature-based solutions to alleviate the negative effects of climate change on tree seedlings during restoration projects.

Mycorrhizal Inoculation: Promoting Tree Health and Survival in a Changing Climate

T3.11 Forest resilience: the vision from belowground

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Abstract: Planting and maintaining a healthy tree canopy is one of the most effective ways to combat the negative impacts of climate change. Due to the more frequent and intense droughts caused by climate change, improving drought resilience of newly established trees is of high priority. The combined impacts of abiotic and biotic stress agents make drought resilience a critical concern for tree planting efforts. Mycorrhizal fungi form intricate networks of fine hyphae that explore a greater soil volume, thus increasing tree resilience to drought stress. Using chestnuts (*Castanea*) as a study system, we explored the combined impact of drought and chestnut blight caused by the fungal pathogen *Cryphonectria parasitica* on tree growth, biomass, leaf fluorescence, stomatal conductance, and cell death response in greenhouse conditions. We exposed one-year-old chestnut seedlings inoculated with mycorrhizal fungi to drought and chestnut blight infection. Drought had a significant impact on all growth and physiological parameters when compared to normally watered plants. Mycorrhizal infection supported tree growth under drought stress. We will discuss the interaction of pathogen and mycorrhizal infection, and the applications of mycorrhizal inoculation in improving tree health. The results serve as a base line for studying the mechanisms involved in the interaction of mutualistic and pathogenic fungal infections in chestnuts, and for investigating the mechanisms by which mycorrhizal associations enhance tree resilience.

NatureCarbonQuality - Effects of agroecosystem naturalization on carbon in different pools with varying stability and their modelling

T3.11 Forest resilience: the vision from belowground

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Abstract: NatureCarbonQuality - Effects of agroecosystem naturalization on carbon in different pools with varying stability and their modelling

Agroecosystems naturalization gained increasing interest for mitigating climate change: a 0.4% increase in soil carbon stock would reduce CO2 in the atmosphere and enhance resilience. However, long-term carbon sequestration depends on microbial resistance of carbon in different pools associated with physical fractions of soil: low resistance carbon (labile) called "particulate organic matter" (POM) and high resistance (stable) called "mineral-associated organic matter" (MAOM). The effect of agroecological system naturalization on carbon quality is understudied.

Four ex-agricultural plots with varying naturalization degrees in northern Italy were identified, each with a different practice and different implementation times: mulching (1 year), cover crops (6 years), reforestation for truffle cultivation (>20 years), riparian natural reforestation (>20 years). Three replicated plots were compared with adjacent conventional agricultural systems at 0-5cm and 5-20cm depths. Samples were analysed for carbon in POM and MAOM pools. The ARMOSA process-based model, developed to simulate cropping systems, was modified to quantify the effect of reforestation on carbon pools evolution on a long-term prospective.

Results shows significant effect of naturalization on carbon storage with cover crops, riparian natural reforestation, and truffle reforestation; but not with mulching, indicating the need for sufficient time after practice implementation. POM augmented at 0-5cm but not at 5-20cm depth, while MAOM significantly increased in both depths. This effect could be explained by i) importance of exudation and carbon leaching from upper soil layers for MAOM increase, and ii) effect of surface litter on POM. The study shows a prominent role of stable deep carbon that needs to be protected and further studied to comprehend mechanisms regulating its increase and stability. Long-term modelling shows the suitability of ARMOSA to include reforestation as a modelling scenario. Results confirms that reforestation is the most suitable practice not only to increase the total soil organic carbon but also the stable MAOM pool. The results in the three sites >1yo are well above the +0.4% threshold, with an average of +145% carbon in reforested areas and +28% with sustainable agricultural practices (mulching and cover crops).

Nitrogen Addition Exacerbates the Negative Effect of Throughfall Reduction on Soil Respiration in a Bamboo Forest

T3.11 Forest resilience: the vision from belowground

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Abstract: Impacts of drought events and nitrogen (N) deposition on forests are increasingly concerning in the context of global climate change, but their effects, in particular, their interactive effects on soil respiration and its components remain unclear. A two-factor random block field experiment was conducted at a subtropical Moso bamboo forest in Southwest China to explore the response of soil respiration (R_s), autotrophic respiration (R_a), and heterotrophic respiration (R_h) to throughfall re-duction and N addition. Our results showed that throughfall reduction significantly decreased R_s, which is mainly attributed to the decrease in R_a as a result of the decline in fine roots biomass. The N addition led to microbial carbon limitation hence significantly decreased R_h, and thus R_s. We also observed the negative effect of throughfall reduction on R_s was exacerbated by N addition, which is attributed to the significant reduction in R_a under the interaction between throughfall reduction N addition. Our findings suggest that R_a tended to respond more sensitively to potential drought, while R_h responds more sensitively to N deposition, and consequently, increased soil N availability caused by N deposition might aggravate the negative effect of expected drought on soil carbon cycling.

Olive trees (Olea europaea L.) shape and influence the soil bacterial community of a wheat-barley Agroforestry system under different soil managements

T3.11 Forest resilience: the vision from belowground

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Abstract: Agroforestry is an agriculture system that integrates woody perennials with arable crops, livestock, or fodder in the same place of land. Agroforestry systems are characterized by high species diversity providing more ecosystem services (i.e., soil fertility maintenance, carbon sequestration, climate change mitigation, and biodiversity conservation) than agricultural monocultures. Agroforestry is the most promising system in terms of adaptation to ongoing climate change. Tree rows in agroforestry systems enhance soil quality and microbial soil-related biodiversity by shaping and altering its composition and structure. The advancement of biotechnology and next-generation sequencing (NGS) have facilitated the comprehension of the mechanisms at the base of the interaction between trees and their related microbiome. Despite these progresses, there is still a knowledge gap about this topic. The aim of this work was to investigate the influence of *Olea europaea* L. in shaping and influencing the bacterial soil community of a wheat-barley agroforestry system by comparing different soil managements, namely conventional tillage versus minimum tillage, and with or without cover-cropping. The microbial community characterization was performed by sequencing the V5-V6 region of the bacterial 16S rRNA gene with the Ion Torrent Platform. NGS preliminary analyses indicate the presence of 4,760 amplicon sequence variants (ASV) belonging for the 99.8% to bacteria and the rest to archaea domain. Among the genera present, the *Bacillus* spp. is the most abundant respect to bacteria involved in nitrogen cycles (for example: *Bradyrhizobium*, *Rhizobiaceae*, *Nitrosomonadaceae*), but additional analyses are in course to better evaluate the effect of olive trees and the presence or absence of cover crops.The obtained results could raise awareness and understanding of the complex interaction between olive trees and soil microorganisms, and how the different soil management could influence this interaction in the field.

On the role of earthworms for the recovery of soil structure in skid trails

T3.11 Forest resilience: the vision from belowground

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Abstract: With Central European winters getting warmer, timber harvesting operations often happen under suboptimal conditions on wet, non-frozen soils. This increases the susceptibility of soils for compaction. Fine textured soils in skid trails often stay compacted for decades. In a controlled experiment in the Vienna woods, we assessed the effects of different harvesting technologies on the degree of soil compaction and the impairment of soil functions. To measure the recovery potential of soils in skid trails after ground-based logging, we compared trails compacted 1 and 18 years ago. The soil structures under and next to the skid trails were evaluated with CT-scans of undisturbed soil cores collected at two depth levels (2.5-7.5 and 12.5-17.5 cm). We measured soil hydraulic properties at the same cores. This information was linked to earthworm data collected in a similar plot design. Earthworms were sampled with a combination of mustard extraction and hand-sorting and identified to species level. We detected five different species at the site (*Aporrectodea rosea, Dendrobaena platyura, Lumbricus rubellus, Octolasion lacteum*). Preliminary results suggest a recovery of the earthworm population in skid trails within 18 years, following a stark decline or near eradication post harvesting. It is expected that earthworms help improving the macropore structure of compacted soil. However, we assume that the upper biologically more active soil layer recovers quicker than the deeper soil, where compaction is more persistent.

Partitioning Soil Respiration in Differing Irish Forests Types for Better Climate Models

T3.11 Forest resilience: the vision from belowground

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Abstract: Forest ecosystems play a significant role in global carbon cycling, harboring a substantial portion of aboveground and belowground terrestrial carbon. Accurately understanding the balance between photosynthetic activity and ecosystem respiration is crucial for determining whether forests act as carbon sources or sinks. In this context, measuring soil respiration and partitioning autotrophic and heterotrophic components are essential to comprehend carbon and nutrient cycling in forest ecosystems. This study investigates resilience factors in Irish forests by evaluating soil carbon (C) flux dynamics in three distinct forest types: typical commercial coniferous forest on mineral soil, broadleaf-dominated native woodland on mineral soil, and a mixed species forest on peat soil. The study sites, characterized by variations in age, soil type, management practices, and species composition, provide valuable insights into respiration rates and their implications for climate change mitigation.

Since November 2022, data collection has revealed that the native woodland on mineral soil exhibited the lowest average soil respiration rates (0.23 g (CO2) m^{-2} $hour^{-1}$). The lowest value (0.15 g (CO2) m^{-2} $hour^{-1}$) was recorded in February 2023, while the highest value (0.65 g (CO2) m^{-2} $hour^{-1}$) was observed in November 2022. Conversely, the mixed forest on peat soil showed the highest average total ecosystem respiration rate (0.30 g (CO2) m^{-2} $hour^{-1}$), with the lowest value (0.16 g (CO2) m^{-2} $hour^{-1}$) in March 2023 and the highest value (0.58 g (CO2) m^{-2} $hour^{-1}$) in May 2023. Consistent with previous studies, heterotrophic flux contributed more to total ecosystem respiration than autotrophic flux across all study sites and seasons.

To enhance the understanding of soil respiration and carbon dynamics in different forest types, this project collects additional data on litterfall, coarse woody debris, fine root turnover and distribution, carbon stock estimation, moss-derived carbon, and organic matter physical fractionation. These supplementary datasets support the development of accurate models for carbon and nutrient cycling in forests, enabling better predictions of the impacts of environmental change on these vital ecosystem processes. Ultimately, the findings from this study will contribute to improved climate models, helping policymakers and land managers make informed decisions for sustainable forest management and climate change mitigation.

Persistency of Ectomycorrhizal Dipterocarp, Tomentella sp. in tin tailings reforestation

T3.11 Forest resilience: the vision from belowground

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Abstract: Planting of forestry species as one means of rehabilitating the ex-mining land areas in Malaysia and has started since 1980's. Indeed, the necessity to repurpose mined land has been recognized since the early twentieth century. The majority of these initiatives have been on finding ways to improve the physical and chemical conditions of the sites. Forest Research Institute Malaysia (FRIM) is one of the organizations that devoted to such operations and achieved success. In Bidor, Perak, Malaysia, a trial plot was established on ex-tin tailings soil, with aim of utilising ectomycorrhizal fungi (EMF) in rehabilitation of heavily degraded sites. The study begins with planting of *Acacia mangium* and is followed two years later by two dipterocarp species (*Hopea odorata* and *Shorea leprosula*). Before out-planting, these tree species were pre-inoculated with an indigenous ectomycorrhiza, *Tomentella* sp. During the early establishment, the inoculated plants outperformed non-inoculated plants. From the morphotyping, supported with PCR and ITS study confirmed the persistency of the inoculated EMF strain even after 18 years. It was discovered that treatments with inoculation had higher mycorrhizal abundance than treatments without inoculation. The performance of *A. mangium* and dipterocarp plants after years of out-planting, as well as their response to ectomycorrhizal inoculation and diverse EMF that remain during succession, will all be covered in this study.

Regeneration failure after forest disturbance alters soil microbial communities with consequences for carbon storage

T3.11 Forest resilience: the vision from belowground

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Abstract: Increasing forest disturbance is among the most profound impacts of climate change on terrestrial ecosystems. Insect outbreaks, storms, or wildfires can destroy the whole tree layer, with serious consequences for biogeochemical cycles until succession returns the ecosystem back to a forested state. However, tree regeneration is often inhibited by ungulate herbivory and herbaceous competition, and disturbed ecosystems remain in non-forested states for decades. The impact of such tree regeneration failures on soil carbon (C) and nitrogen (N) cycles is highly unknown, because a multitude of plant-soil feedbacks are involved, and underlying processes have hardly been investigated. Here, we studied soil microbial community structure, gene abundance of bacteria, fungi, and N cycling microorganisms, soil enzymes, and C-N dynamics across a disturbed forest landscape in Central Europe, covering a range of successional stages after storm damage and bark-beetle attacks. We used a chronosequence-approach including disturbed sites regrown with *Picea abies* stands, and disturbed sites dominated by herbaceous pioneer plants, particularly *Calamagrostis* grasses. Soil C and N stocks increased under a prolonged herbaceous cover. Three decades after disturbance the stocks were ca. 45% higher than those of regrown forest stands. We link this increase to changes in the structure and functioning of the microbial community, which reduces the decomposition of organic matter. With a prolonged herbaceous cover, decreasing fungal abundances coincided with declining activities of phenol oxidase and of hydrolytic enzymes used to acquire nutrients. Since ectomycorrhizal fungi were almost absent compared to regrowing forest stands, this may be linked to reduced ectomycorrhizal mining for organic N. Moreover, ammonia-oxidising (*amoA*) gene abundances increased along with ammonium and nitrate concentrations, pointing towards an accelerated inorganic N cycle under a prolonged herbaceous cover. A surplus of inorganic N and grass-rhizodeposits renders it also likely that saprotrophs are less dependent on organic matter-bound C and N. Taken together, we found strong evidence for a linkage between above- and belowground communities following forest disturbance. We suggest a prolonged cover of herbaceous pioneer plants opens the nitrogen cycle through microbial communities which reduces mining for organic N and thus, increases soil C storage.

SERVICE CROP AS A SOIL QUALITY IMPROVER IN PLOTS DESTINED FOR FOREST LANDSCAPE RESTORATION

T3.11 Forest resilience: the vision from belowground

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Abstract: The use of service crops is an important tool in soil conservation management, being fundamental in the collection of data to describe early or undesired changes in soil conditions resulting from managed forests, being the study of the biological properties of soils the most sensitive to these variations or disturbances becoming excellent indicators of soil quality for the management of resources in restoration, however, research on this subject is still scarce in Paraguay. The objective of the experiment was to evaluate the biological activity of soils managed with and without the use of service crops in plots intended for forest landscape restoration. It was carried out during 2 years with four soil samplings in the Hernandarias, district near the Tati Yupí Natural Reserve, Paraguay, in four treatments with strips of native species; T1 for timber purposes; T2 for timber purposes + service crop; T3 for energy purposes; and T4 for energy purposes + service crop, where each experimental unit had conservation and harvesting strips. The service crop used was *Cajanus cajan* L. Millsp. Soil samples were extracted from each experimental unit at a depth of 0-20 cm, maintained at a temperature of 4 °C. For the measurement of microbial activity, through respiration, the soil samples were incubated for 7 days at 25 °C, in closed flasks with a NaOH solution for subsequent titration with sulfuric acid. Significant differences were found in the values of respiratory activity in the treatments where the service culture was included, $p>0.05$ by Tukey's test whose values were 0.68 and 0.73 µg $C\text{-}CO_2$/g ss h^{-1} for species with timber and energy purposes, respectively. This shows that the use of service crops contributes positively to the restoration of soil quality.

Soil microbial communities in pure and mixed forests of Oaks and Pines: linking soil microbial data to forest management in the Mediterranean region

T3.11 Forest resilience: the vision from belowground

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Abstract: Cork and pine nuts are two of the most valuable non wood forest products of Portugal. The forest tree species that yield these products - cork oak (*Quercus suber*) and stone pine (*Pinus pinea*) - represent approximately one third of mainland Portugal. These species share similar ecological ranges, thus being able to coexist in mixtures. Climate change will likely increase soil degradation by reducing the input of organic matter, overall diversity and exacerbating the already existing desertification processes in the Mediterranean region.
This study intends to understand how forest composition affects soil fungal and bacterial communities and how this knowledge can be used to support forest management decisions under a climate change scenario. For this, we collected soil samples in a north-south ecological gradient including differences in both soil and climatic variables, in Portugal mainland. The plots were organized in triplets (with pure and mixed stands of each species) which were completely characterized in terms of species density, structure, richness and biomass and also tree vitality and health. Soil samples were collected for chemical and physical properties as well as for fungal and bacterial community's characterization using a targeted metagenomics approach based on rDNA amplicon sequencing.
Such an interdisciplinary study will provide valuable information regarding beneficial and antagonistic microorganisms present in the soil, help to explain possible ecological interactions between species in pure and mixed stands with their changing environments and, ultimately, provide guidance for management practices able to preserve soil health status and a sustainable forest production.

The impact of restoration on the activity of microorganisms in European forests

T3.11 Forest resilience: the vision from belowground

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Abstract: Forests are under pressure due to climate change and poor management practices. They are experiencing disturbances, loss of biodiversity and soil degradation. However, soil is an important but fragile and nonrenewable component of a forest ecosystem. It encompasses one of the largest carbon reservoirs, containing a significantly greater amount of carbon compared to the aboveground biomass. Therefore, forest restoration is necessary to halt the decline of forests and to reverse soil degradation.

In this study soil carbon and soil biota are being analyzed in 12 European forest areas, selected for restoration in the context of the EU Horizon 2O2O Superb project. These areas reflect the different stress factors faced by forests in Europe, and further include the different biogeographical regions and management practices.

Soil samples were taken to compare soil biota between reference-, degraded-, and restored stands. This was done by taking samples to a depth of 15 cm with fixed depth classes in order to analyze microbial biomass and functional catabolic diversity. The data obtained from the analyses, will enable us to assess the situation of the restoration measures.

We expect that undisturbed forests or forests in a high restoration stage contain a higher activity of microorganisms. Some preliminary results for Romania, where sampling took place in primary, close to nature and highly managed forests, are that primary forests do have more diversity of microorganisms in the 0-5 cm and 5-15 cm soil layer compared to close to nature and highly managed forests. Microbial activity and diversity is higher in forests with predominantly deciduous trees.

Based on the results best practice guidelines for effective implementation and monitoring of forest restoration can be provided.

Tree species effects on stocks and stability of soil carbon: Links to mycorrhizal association and soil biota composition and functioning

T3.11 Forest resilience: the vision from belowground

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Abstract: Tree species with leaf litter traits driving slow rates of leaf litter decomposition have traditionally been associated with accumulation of higher soil organic carbon (SOC) stocks than tree species with fast litter decomposition rates. This hypothesis has mainly been based on observations of thick C-rich forest floors under tree species associated with ectomycorrhizae (ECM). However, a recent hypothesis suggested that tree species with foliar litter traits conducive to fast decomposition will lead to more pronounced microbial transformation and stabilization of litter C. The latter tree species are often associated with arbuscular mycorrhizae (AM) and may enhance deeper incorporation of C by more active soil fauna communities and by higher belowground rates of litter input. The Danish common garden tree species experiment include ECM and AM tree species that differ widely in traits such as foliar litter chemistry. The experiment has been studied over the last 15 years to document and explain soil C stocks supported by emerging studies of soil biota community composition and functioning.

The six common European tree species formed distinct groups in soil carbon characteristics as well as in soil biota community composition and functioning that partly reflected their mycorrhizal association. Forest floor C stocks were consistent with the traditional perception of slowly decomposing leaf litter in ECM species being conducive to high C stocks. However, an intriguing pattern of higher C stocks in the mineral soil in AM tree species with high litter quality and characteristic soil biota functioning supported the recent microbial stabilization hypothesis and suggested deeper incorporation of C in more stable forms.

Based on new results on microbial, macro- and mesofauna communities and their functioning, and on repeated soil sampling, this talk will revisit the common garden experiments for a synthesis of processes and patterns in organic matter formation that may explain observed patterns in quantity and quality of SOC.

What if we managed forests to sustain soil life?

T3.11 Forest resilience: the vision from belowground

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Abstract: The last two decades have brought remarkable insights into the exceptional diversity of belowground life in forests, its dependence on inputs from living trees, and its critical importance in generating the many ecosystem services that forests provide. In contrast, forestry policies and practices still reflect an outdated image of forest soils as inert substrates. What if we purposefully managed forests to improve the health and fertility of soil, rather than just mitigate damage? How would we manage forests if our primary objective was to sustain belowground life and the critical ecosystem processes that these organisms mediate? In contrast to the prevailing view of soil organisms depending on dead organic matter generated by trees, recent evidence indicates that metabolites secreted by living tree roots and associated mycorrhizal fungi are essential for sustaining belowground foodwebs. Our view of forest ecosystems needs to recognize the importance of these belowground fluxes from trees, and forestry practices such as clearcut-harvesting, monoculture plantations, and fertilization need to be re-examined through this lens.

T3.12 Forest Restoration Success and How to Achieve it

A Novel Approach for Prioritizing Stepping Stones in Forests to Enhance Connectivity

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Climate change exacerbates challenges, affecting the range, genetic diversity, behavior, and survival of species. To address these issues, conservation, restoration, and enhancement of ecologically valuable forest areas and their connectivity must be prioritized. Maintaining functional connections between protected areas is essential for promoting gene flow, migration, and recolonization in the face of climate change.

In aiming to implement a conservation program focused on improving forest connectivity, two crucial steps are required. First, suitable areas within forests need to be identified and prioritized. Second, these areas must be selected and established, considering forest ownership and incentive transfer to ensure program success.

In our study, we present a novel approach to identifying and prioritizing stepping stones for preserving connectivity in Austrian forest ecosystems. We combined national and regional biodiversity data to develop a framework that considers structural and functional connectivity metrics. The framework includes four compounded indicator values: Protect Value, Connect Value, Species Value, and Habitat Value. These indicators incorporate information on protected areas, habitat corridors, connectivity areas, species richness, and ecological value. We identified areas with high prioritization values in 25% of the assessed forest area (8,336 km²). The framework provides decision support for managers and conservationists in prioritizing areas for forest habitat connectivity conservation. Accompanying field assessments is essential and should complement the framework's results.

Analysis of canopy cover and grass cover relationship in a Forest Landscape Restoration Plot, Hernandarias, Paraguay.

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: The presence of grasses in Forest Landscape Restoration projects has an impact on the growth and survival of the species of interest, and their control represents a high cost. The objective of the study was to analyze the relationship between canopy cover and grass cover. The experimental plot was set up in the district of Hernandarias, located in the department of Alto Paraná, Paraguay. It covers 5.9 ha and is made up of 5 blocks with 8 treatments, each experimental unit covers 1080 m^2 and has conservation and utilizations strips. Measurements of grass cover (%) were made 18 months after planting, where each unit were sub-divided in 16 units, disregarding the edge. The crown canopy cover (CCC) was estimated considering the measurements made on the x and y axes. Grass and other invasive species control were made in every unit with a canopy cover ≥ 40% and with a height ≥ 30 cm. The results show that treatments 2 and 1 have the lowest grass cover and the highest tree canopy cover; both treatments have Eucalyptus as the tree component. It was observed that the higher the tree canopy cover, the lower the percentage of grasses occurrence, so it is considered that the species with a wide canopy development favours grass control, avoiding the setback of the restoration process and reducing the costs of chemical management.

Analysis of external factors influencing restoration schemes

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Ecosystem restoration has been implemented globally, with billions of dollars spent annually for the establishment, associated knowledge, and capacity building. These restorations are expected to address several environmental, social, and economic issues. However, despite the expectations, restoration schemes have failed in several parts of Africa to deliver sustainable outcomes. Studies have tried to assess the factors behind the lack of success and identified technical, ecological, and governance issues. In addition, some of these studies identified spatially and temporally specific mechanisms to improve these internal factors, thereby contributing to the success of restoration schemes. However, restoration schemes still struggle to deliver the expected outcomes despite these efforts. Therefore it is imperative to identify the reason behind restoration schemes' lack of sustainable performance. This identification requires a broad and practical view to provide sustainable solutions to the current inadequacies.

Moreover, identifying spatially and temporally broad and relevant factors will help evolve and function as a sustainable governance mechanism for restoration schemes. In this regard, we identified external environmental factors such as political, economic, social, technological, ecological, legal, and institutional influencing restoration schemes more than the internal technical, ecological, and governance issues. We evaluated the influence of these external environmental factors using the PESTEL analysis tool or framework, taking the case of four African countries (Algeria, Cameroon, Ethiopia, and South Africa). These significant external environmental factors are out of the control and influence of the restoration schemes and hence primarily hinder them in achieving their intended target. Therefore, analysing these factors provides a means to include sustainability in strategic analyses of the restoration schemes because it incorporates the main dimensions of sustainable development: environment, society, and economy. This means restoration scheme stakeholders can analyse these and devise mechanisms to avoid the influence of these factors in their governance practices.

Assessing the recovery in species, size and location diversities of a lowland tropical rainforest by multiple indices at stand and neighborhood scales

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Tropical forests are rapidly being converted for agricultural use, but abandoned agricultural lands can recover naturally through secondary succession. However, comprehensive knowledges of how species composition, size structure and spatial patterning (represented by species, size and location diversities) change during recovery at multiple scales are still lacking. Our aim was to explore these change patterns to understand the underlying mechanisms of forest recovery and propose corresponding solutions for restoring regrowing secondary forests. Here, twelve 1ha forest dynamics plots (4 plots each in young-secondary forests (YS), old-secondary forests (OS) and old-growth forests (OG) from a chronosequence of tropical lowland rainforest after shifting cultivation) were used to assessed the recovery in species, size and location diversity of trees at stand (plot) and neighborhood (focal tree and its neighbors) scale by using 8 indices. The relative recoveries of YS and OS were quantified by dividing each of the indices in YS and OS to those in OG. Results showed that species and size diversity increased while location diversity decreased with the recovery process. The relative recovery of location diversity was higher than those of species and size diversity in both YS and OS, while species diversity was only higher than size diversity in YS. The relative recovery of species diversity at neighborhood scale was higher than that at stand scale in OS, while there were no differences between scales in size and location diversity. Additionally, using only the Shannon index and Gini coefficient at two scales can provide consistent insights into the recovery patterns of diversity as indicated by the 8 indices. Our study demonstrated that recovery rates of secondary forests relative to old-growth counterparts could be comprehensively quantified using multiple diversity indices in three types at two scales. This quantitative assessment on the relative recovery of disturbed forests could be helpful in applying appropriate management activities and selecting rational approaches to speed up restoration process of degraded forest ecosystems.

Keywords: Secondary forest restoration, Location diversity, Size diversity, Species diversity, Stand scale, Neighborhood scale

Attractiveness of area Exclosures as a Carbon Sinks in Ethiopia

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Area exclosure in the Ethiopian context can be defined as the degraded land that has been excluded from human and livestock interference for rehabilitation. The primary objective of the research was evaluation of carbon sequestration and economic valuations in particular with the establishment of exclosures. Exclosures of 10, 15, and 20 years old were selected and each exclosure was paired with an adjacent free grazing land. A total of 120 quadrants were sampled using a stratified preferential sampling design technique with flexible systematic model and 180 household respondents were surveyed with multi-stage stratified random sampling procedure incorporating household's survey questionnaires, FGD, and KI discussions. All exclosures displayed higher ECS, and plant species richness, diversity and aboveground standing biomass than the free grazing lands. Differences in ECS between exclosures and free grazing lands varied between 32.96 and 61.0 $tha^{-1}$and increased with exclosure age. Over a period of 20 years, the carbon dioxide sequestered in the investigated exclosures was 223.88 tha^{-1}, total soil nitrogen increased by 2.93 tha^{-1} and additionally available phosphorus stocks amounted to 40 Kg ha^{-1}. Furthermore, the majority of the respondents had positive views on the effectiveness of exclosures. The empirical results from binary logistic regression model showed age, tenure, farm size, off-farm activities and credit access were positive and significant predictors and livestock number is negatively affected the sustainability of exclosure. Our study showed that the establishment of exclosures on degraded free grazing lands in the northern highlands is a viable option to restore vegetation composition, richness, diversity and aboveground biomass. However, economic and social impacts of exclosures should be included in feasibility studies before establishing exclosures. Although our study showed that exclosures are effective to restore ECS, expansion of exclosures would increase grazing pressure on the remaining area. Therefore, the decision to establish additional exclosures should include an economical analysis and evaluation of the social consequences of such a decision. The positive views on exclosures imply that there is a substantial opportunity to mobilize the local communities in the efforts to manage the existing exclosures in a sustainable manner and to establish exclosures in the future.

Biodiversity Islands as a Strategy for Forest Conservation and Restoration

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: To achieve success in forest restoration it is crucial to restore forest biodiversity. Forest biodiversity restoration can be accomplished by restoring or providing additional habitat, creating buffer areas, and establishing corridors that connect forest fragments. As a strategy to contribute to achieving these goals, we propose the implementation of Biodiversity Islands (BI): areas of land with greater diversity than the surrounding areas, where plant and animal species can thrive without interference from human activity. BI constitute genetic, cultural, carbon and nutrient "banks" in the fragmented forest landscape, hosting plants, animals, microorganisms, ecosystems, landscapes and water resources according to their scale. BI are refuges for flora and fauna, serving as sources of propagules and protecting resources from fires, pests and other stresses, providing ecological, economic, and social benefits at the ecosystem, landscape, and global levels. Designs depend on purpose, spatial distribution of reserves throughout the landscape, landscape degradation, species present, and location. BI can exist in a range of human dominated landscapes (natural, rural, urban) and can range from square meters to many square kilometers in size. We provide examples from throughout the world, including case studies for both conservation and production purposes such as tree and vegetation islands, riparian forests and agroforestry systems (AFS). As components of BI, more complex systems, such as multistrata AFS can constitute BI in themselves, while less complex AFS can form part of a buffer area. In all cases, the inclusion of diverse systems within a BI provides greater biodiversity than conventional agriculture or degraded areas. Other BI are relicts from previous land uses and/or are kept by human populations for other purposes while serving a BI objective as well (e.g. sacred forests). In promoting BI, we encourage the application of integrated landscape management and inclusive community led action. BI can be a valuable framing tool for practitioners and policy makers. Possibly the BI principles could be applied more broadly to protect live systems worldwide.

Carbon and conservation trade-offs for restoration in the Brazilian Savannah

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: The Cerrado biome in Brazil is one of the most biodiverse savannahs in the world, but it is also one of the most threatened biomes due to deforestation and land use change. Given limited resources, it is urgent to understand the trade-offs between ecological and economic outcomes to design prioritization frameworks that can bring economic and socio-ecological objectives together. This study aims to analyze the trade-offs between ecological and economic management objectives to restore habitats and reduce deforestation susceptibility in the Cerrado. Production possibility frontiers and attainment levels were derived for various restoration scenarios and prioritization objectives, including potential profit that could be generated with carbon credits from forest biomass. Modeling was conducted by combining metrics for Fire Risk, Vulnerability of Fauna, Deforestation Susceptibility and Above and Below Ground Carbon into a single shapefile. Priority areas for each objective were identified within the portion of the Central Plateau Ecoregion that occurs in the States of Goiás, Minas Gerais, and the Federal District of Brazil. Results show that few areas have a high potential for maximizing two objectives together. In general, ecological and economic variables have sharp trade-offs, meaning that improving revenue from carbon will reduce the attainment of the ecological variables. We suggest that at a landscape level, ecological priorities could be targeted, while specific sites with high economic potential can be selected for local projects. Regarding the potential of selling carbon credits to fund restoration activities, we discovered that among the restoration methods analyzed, only Natural Regeneration returns a profit, but it is also the method that requires a longer time. Assisted Natural Regeneration and Total Planting are faster methods, but they require additional investments, since relying on carbon credits is not enough to return profits that could fund restoration activities. We suggest that projects should target actions that would increase economic benefits to help fund the restoration together with the carbon revenue. This points to the fact that restoration projects need to consider not only the feasibility of methods but also stakeholders' objectives and demands.

Challenges and opportunities for degraded land rehabilitation in Eastern Amhara; Ethiopia

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Land degradation is a global issue, with particular severity in developing countries. Despite all rehabilitation efforts, land degradation is continuing with high aggregate rates in Ethiopia. Therefore, this study aimed at assessing challenges and opportunities to rehabilitate a degraded land in south Wollo Zone. A multistage sampling method was used. The descriptive statistics was used to analysis a data. The perception of a problem with land degradation in the research area is held by 97.5% of respondents. Furthermore, even if it takes time, 77.9% of respondents believe that land degradation may be remedied. Soil erosion, deforestation, overgrazing, and decreased land productivity were cited reported as the main types of land degradation in their area, respectively, by about 65.5%, 19.5%, 6.5%, and 4.5 of the respondents. Likewise, 68.5% of respondents stated that rehabilitation practices previously carried out in the study area were not successful. Challenges that contribute to the failure of rehabilitation practice in the study area were lack of follow-up, watering, caring, and protection of the rehabilitated site from free grazing. Besides, low sense of ownership on rehabilitated sites, poor seedling survival, land tenure & institutional problems, socio-economic problems and availability of limited livelihood options and higher degradation level of the site to be rehabilitated were reported as challenges that affect success of rehabilitation measures. Opportunities for the rehabilitation of degraded land, however, include willing of communities to participate, government attention, the involvement of various stockholders, the presence of diversified types of agro-ecologies, multipurpose plants, and sizable degraded areas that can be restored. It is concluded that rehabilitation efforts could not be successful unless those challenges are addressed. Therefore, it is strongly suggested that frequent follow-up, tending operations, control of free grazing, the planting of edible plants for livelihood benefits, and building a sense of ownership will improve the success of rehabilitation practices.

Challenges and Opportunities in Rehabilitation of an Ex-Tin Mine

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Tin mining was a lucrative industry in Malaysia since the late 1800s up to early 1900s due to high demand for tin. Mining of tin ores had promoted rapid economic development but drastically transformed the landscapes of mining areas. These areas were stripped off vegetation and topsoil removed, detention ponds were created and sand barns were heaped. When mining activity ceased with the plunge of tin prices worldwide, ex-tin mines became abandoned and impoverished areas. With no topsoil and organic matter, regeneration becomes impossible especially when there is no seed source in adjacent areas or surrounded by oil palm plantations. Therefore, human intervention is needed to induce or provide a suitable environment to encourage the growth of tropical multipurpose trees especially climax species on tin tailings with cost-effective techniques. Forest Research Institute Malaysia (FRIM) has embarked on the greening of an ex-tin mine in Bidor, Perak since 1996. After 20 years of rehabilitation, the research station was recognised by the Malaysia Book of Records in 2016 as the 'Largest Man-made Forest Established on Ex-Tin Mine'. With suitable techniques in soil amelioration and introduction of fast-growing species as nurse trees, over 60 indigenous tree species including endangered and endemic species can now be found in the research station. In addition, more than 100 bird species had been recorded besides various other animals and fungi. This paper aims to share on the experiences in rehabilitation of an ex-tin mine and outcomes from greening this once barren land.

Choose the trees! Uncovering Farmers' Preferences for Forest Restoration in China through a Choice Experiment

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Grain for Green Program (GFGP) is the largest payment for ecosystem services(PES) program in Chinese history, which is aimed at converting marginal croplands on steep slopes into grasslands and forests by afforestation/reforestation activities. The program started in 1999 and it has been running till now. The GFGP covers more than 1500 counties and affects 32 million households. However, it has been criticized for oversimplified design, not engaging local communities in the decision-making, and not customized to local conditions. For example, GFGP only takes tree planting as a project activity and disregard other restoration activities (i.e., tree species diversification, underplanting). To address these concerns, we present a case study to explore more options for PES schemes and farmers' preferences to different forest restoration activities. The study area is in Western China and consists of three villages, which have participated in GFGP before. Respondents are selected using random sampling method. Choice experiment (CE) is applied to understand farmers' willingness to accept PES contracts characterized by different attributes, such as payment levels, length of contract, payment modes, proportion of land involved in the program, and restoration activities. Previous studies have already applied CE to investigate farmers' preferences for PES contracts, but most of them only focus on contracts for tree planting. We aim to fill in the knowledge gap by examining farmers' preferences for other restoration activities. Also, this study adds to the literature about farmers' preferences for environmental programs in a developing country setting, particularly within the current Chinese PES framework. Along with the CE, household survey data are collected, including household demographics, capital assets, and experiences with PES programs. In the experiment, respondents are presented with six choice sets, and each choice set has three alternatives, from which they are asked to choose their preferred one. The working hypothesis is that farmers are more willing to accept short contract length, low proportion of land involved in the program, high payment levels, individual compensation, and different restoration activities. As such, this study can contribute to the PES design, improve the effectiveness of PES programs, and take farmers' preferences into account.

Cloud forest tree regeneration diversity and composition under different restoration approaches: protecting natural regeneration versus tree planting

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Forest restoration is a key nature-based solution to addressing biodiversity loss and climate change. However, little is known about the effectiveness of different restoration approaches in the recovery of the diversity and composition of old-growth forests. We evaluated the recovery of tree regeneration (seedlings and juvenile) in former cattle pastures after 21 years of natural regeneration (after cattle exclusion) and planting tree native species in comparison to an old-growth tropical montane cloud forest in Veracruz, Mexico. We randomly establish ~ 30 plots per condition. We found a total of 78 species of trees in the regeneration strata. There were no differences in seedling and juvenile´s diversity (Shannon index exponential) between the conditions. The composition of species differed between the two conditions (PERMANOVA). Tree planting presented more similarity (Bray-Curtis) in species composition with the old-growth forest than the natural regeneration (48% and 43% of similitude, respectively). Regarding the dominance and equity of the seedling and juvenile community, most of the species contributed less than 5% to the total abundance in all conditions. In the restoration planting, the late-successional species *Quercus sapotifolia* and *Ocotea psychotrioides* represented 16 % and 8% of the abundance of seedlings. Our results show that while both restoration approaches have favored the recovery of diversity, planting with native species has favored greater recovery of the species composition of the old-growth forest, compared to the natural regeneration. Overall, the results support the potential of different restoration approaches to recover the tropical montane cloud forest landscape.

Combating the Invasion: Native Species Triumph Over Lantana camara

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Invasive species have taken a huge toll on our biodiversity, and one such invasive, *Lantana camara* is listed as one of the world's top ten invasive species. Effective management strategies are crucial in controlling this persistent species, which requires continuous vigilance and planned phenological monitoring. We conducted field experiments in Doon Valley to screen potential native species competing with Lantana at different locations. Using the standard BBCH scale, we observed the Phenological Growth Stages of five native species, marking the first time a detailed phenological study using the BBCH scale of these species. Importance Value Index (IVI) and other diversity indexes were calculated for selecting the competitive native species.

Furthermore, we conducted pot and field experiments with these native plants comparing Lantana to study intraspecific and interspecific competition using Relative Interaction Index (RII). They presented a robust competition to Lantana, with *Broussonetia papyrifera, Pterospermum acerifolium, Urtica dioica, Pongamia pinnata*, and *Bauhinia variegata* leading the charge. In addition to the native plants, we also introduced native grass species to the field experiments. Using the seed ball method, we observed the competition from native grass species such as *Penissetum pedicellatum* and *Sachharum spontaneum,* which proved to be strong competitors against Lantana. These findings hold significant implications for policymakers, researchers, and land planners. They offer a roadmap for adopting competitive native species to combat the invasive Lantana, particularly in the Indian Himalayan Region.

Cross-boundary Prioritization and Monitoring of Forest Restoration: Lessons from Longleaf Pine in the Southeastern USA

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Beginning in 2015, researchers at the U.S. Forest Service and its university and NGO partners began an ambitious collaboration to inventory, map, analyze and monitor critical longleaf pine (Pinus palustris) habitat to prioritize conservation and restoration activities. In large part, this effort was driven by the need to identify the desired restoration endpoints and goals in this important but severely degraded subtropical habitat, and monitor progress toward achieving those goals over time at fine spatial resolution. The team worked to develop and deploy novel remote sensing and statistical techniques and tools to map the extent and condition of longleaf pine ecosystems across the southeastern U.S. states of Alabama, Georgia and Florida. High-resolution geospatial data products were developed using machine learning techniques, including artificial neural networks and decision trees, to model the relationships between forest characteristics measured in field plots and a wide range of spectral metrics derived from a variety of remotely sensed imagery, including aerial photographic imagery and Landsat. Regionally specific models were then used to map forest characteristics at high resolution across large areas. For example, in one study, field plot data was related to normalized Landsat 8 imagery using general linear regression and machine learning models. Multiple raster surfaces of forest metrics, including basal area, stand density, forest type and presence of longleaf pine were created across a 28.8 million acre study area in these three states. The overall accuracy of the eight softmax neural network forest type models ranged between 0.78 and 0.87, averaging 0.83, and 35 moderate resolution (30m) spatially explicit raster surfaces of estimated forest characteristics were integrated with existing vector, tabular and raster datasets to inform and prioritize longleaf forest conservation and restoration efforts. This presentation provides an overview of the effort, which includes multiple interconnected projects and published research studies conducted over more than a decade, and presents lessons learned and recommendations for using remote sensing and advanced inventory techniques to prioritize forest conservation and restoration activities and improve monitoring and verification at various scales.

Effects of a Trench as a Moisture Harvesting Structure to Restore Degraded Land in Southern Ethiopia

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Knowledge about the biomass productivity of trees planted in a rainwater harvesting structure, i.e., a trench (T), relative to a normal pit (P) on degraded land is scarce. The objective of this study was to compare the effect of T with P on the growth and biomass production of the *Acacia saligna* and *Casuarina equisetifolia* which were planted on degraded land. All the individual stems of both species in the T and P, their diameters at breast height (DBH) and heights in 2016 and 2020 were measured. Species-specific allometric equations were used to quantify the biomass production of the studied species. The t-tests were used for data analysis; both *A. saligna* and *C. equisetifolia* individuals planted in the T had higher DBH and height increments as compared with *A. saligna* and *C. equisetifolia* that were planted and grown in a P. The results revealed significant differences in the mean DBH and height of *A. saligna* and *C. equisetifolia* planted in a T and P ($p < 0.05$). Between 2016 and 2020, the total biomass (TB) of *A. saligna* planted in a T and in a P increased significantly ($p < 0.05$) on average by 25.5 kg/tree and 7.7 kg/tree, respectively ($p < 0.05$). Similarly, the mean TB values of the *C. equisetifolia* planted in a T and a P between 2016 and 2020 increased significantly ($p < 0.05$) by 28.9 kg/tree and 13.1 kg/tree, respectively. Finally, establishing trenches to restore degraded lands was shown to facilitate the growth and biomass production of planted species on degraded land.

Effects of understory invasive plants and native plants on community stability in Benggang ecological restoration of different artificial forests

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: To explore the community construction scheme of Benggang ecological restoration based on nature, four stands (*Pinus elliottii*, *Eucalyptus urophylla*, *Acacia auriculaeformis*, and *Cinnamomum camphora*） were studied for early restoration in Benggang area of Guangdong Sanlinshan National Forest Park, located in the southernmost tip of mainland China. In terms of understory invasive and native species, we conducted the quadrat survey, analyze the community stability of different stands through species diversity, niche width, niche overlap, ecological response and species association index, and optimize understory plant allocation. The results were showed as follow: (1) Among the four stands, the number of species, diversity index and niche width of understory invasive in *Eucalyptus urophylla* stand was the lowest, and the niche overlap between understory invasive plants and native plants was also the lowest. (2) The future development trend of the understory plant community was the best in *Pinus elliottii* stand, followed by *Eucalyptus urophylla* stand. The average rate of the positive development of *Pinus elliottii*, *Eucalyptus urophylla*, and *Cinnamomum camphora*, the three stands was higher than the negative development, except for *Acacia auriculaeformis* stand. (3) The interspecific associations of the understory plants of the four stands were small (OI≤0.5), and most of them were negative associations, and the communities were in an unstable stage. (4) The pattern of community allocation can be optimized as: *Eucalyptus urophylla*-*Dicranopteris Dichotoma*-*Rottboellia Linn*-*Miscanthus Sinensis*, *Pinus elliottii*- *Miscanthus Sinensis*-*Imperata Cylindrica*-*Blechnum Orientale*, *Acacia auriculaeformis*-*Miscanthus Sinensis*-*Blechnum Orientale*-*Rhodomyrtus Tomentosa*, *Cinnamomum camphora*-*Rhodomyrtus Tomentosa*-*Rottboellia Linn*-*Mallotus Paniculatus*. Therefore, when planting fast-growing trees to rapidly afforest for early restoration in Benggang area, we can give priority to stands with abundant understory native plants and few understory invasive plants (such as *Eucalyptus urophylla* stand). Positive associated understory native plants can be select for understory plant community allocation, so as to effectively resist understory invasive plants and form stable progressive understory plant community.

Enabling conditions for Forest Landscape Restoration in Mozonte, Nicaragua-A community forestry perspective on FLR

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Mozonte, in northern Nicaragua is a landscape with important presence of indigenous community as owners of around 23 thousand hectares of land and with a recognized governance structure. This thesis explores enabling social, policy and environmental conditions for FLR in the community of Mozonte via in-depth interviews with stakeholders, participatory P/RRA workshops and secondary data. Given the importance of the community and the overlapping set of conditions that favors FLR and community forestry (CF), a CF perspective is emphasized. The results showed that the community have motivations for FLR, relating restoration as solutions to many of their socio-environmental issues and expecting economic, environmental and social benefits as: water security, improved local climate, diversified income, and the enhancement of cultural and timber values. Proposed restoration interventions were agroforestry systems, reforestation of riparian zones and critical areas for watersheds, coffee zones, and the formalization of a community reserve.

Major challenges found were a complex land tenure context and a set of favorable policies that however, lack an effective implementation and enforcement. Coffee farms in the north, as land-use change driver, their associated bad practices and impacts on water were a high concern expressed by people. Forest fires are another important threat to FLR in Mozonte, but they offer the opportunity to expand and strengthen effective institutional coordination, an enabling condition for both FLR and CF. Potential synergies among FLR and CF such as linking FLR with food security and formalizing management of a community reserve in Cerro Guásara have a positive perspective. Despite limitations, these results can be a tool for the community and potential partners to advance FLR strategies and community forestry in Mozonte.

Explore Before You Restore: Incorporating Complex Systems thinking in Ecosystem Restoration

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: The global movement for ecosystem restoration has gained momentum in response to the Bonn Challenge (2010) and the UN Decade on Ecosystem Restoration (UNDER, 2021-2030). While several science-based guidelines exist to aid in achieving successful restoration outcomes, significant variation remains in the outcomes of restoration projects. Some of this disparity can be attributed to unexpected responses of ecosystem components to planned interventions. Given the complex nature of ecosystems, we propose that concepts from *Complex Systems Science* (CSS) such as regime shifts, ecological resilience, and ecological feedbacks, should be employed to help explain this variation in restoration outcomes. Our framework, Explore Before You Restore, illustrates how these concepts impact restoration outcomes by influencing degradation and restoration trajectories.

Additionally, we propose incorporating CSS concepts into the typical restoration project cycle, and suggest that they are explicitly included in the guidelines to improve restoration outcomes.

Exploring the Path to Forest Restoration through International Forest Aid in Asia

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: As a response to the extensive forest degradation across Asia, forest restoration has been actively integrated into Official Development Assistance (ODA) projects. This study aims to understand the evolving trends and priorities in Asian forest restoration-related ODA projects. By synergizing the systematic review and topic modeling techniques, we offer an in-depth examination of the status, predominant themes, and trajectories of forest ODA and the global community's response to forest restoration in Asia. This study includes statistical data from the OECD Development Assistance Committee (DAC) from 1998 to 2021. Our analysis reveals that an upward trend in multi-country projects in Asia since 2010 is identified. Although a substantial percentage of the Asian forest ODA funds are directed towards China and India, the initiatives show a wide geographical distribution across numerous countries. Our text mining approach revealed four dominant themes in Asian forest ODA: "Reforestation and Disaster Management," "Social Forestry," "Landscape Management," and "Production and Industry." Frequency and time-series analysis indicates a gradual shift from the "Social Forestry" theme to "Landscape Management" and "Production and Industry" themes. This shift reflects a more holistic and integrative approach to forest ODA in Asia, accommodating various socio-economic and ecological considerations. Our findings have significant implications for designing future projects, including topic selection and regional prioritization. The insights could prove instrumental in integrating forest restoration strategies in forest ODA, paving the way for a more efficient approach to global forest restoration, addressing multifaceted goals from social, economic, and ecological perspectives, and further contributing to improved local livelihoods, better governance, and sustainable development.

Floristic Composition ,Structural Diversity under Passive and Active Restoration of Biodiversity Hotspots in Kakamega-Nandi Forest Ecosystem, Kenya

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Restoration of degraded landscapes is emerging as a global conservation priority. Opinion is divided, however, whether active restoration is a better approach than passive interventions in regard to ecological outcome. We assessed the variation in woody species composition and stand structure in a degraded forest site in western Kenya where both tree planting and natural regeneration had been applied for four years. The site was protected from repeat incidences of disturbance using enclosures. Natural regeneration registered a significantly higher woody species richness (36.75±6.97) than active restoration (12.75±1.75) four years later. Similarly, natural regeneration had a higher Shannon-Wiener diversity index (3.05±0.72) than active restoration (2.32±1.26). Woody stem density was significantly higher under natural regeneration (21,789±7,087 stems ha^{-1}) than active restoration (13,118±1,857 stems ha^{-1}) even though up to 10,000 seedlings per ha were planted at the beginning of the study in active restoration plots. Mean sapling height was higher under natural regeneration (2.60±0.31 m) than active restoration (1.38±0.30 m). The diameter size-class distribution for saplings ranged between 2.1cm and 15.0 cm in natural regeneration plots, and below DBH level and 10.0 cm in the planted plots. The results suggest that natural regeneration may be superior to active restoration in rehabilitating degraded landscapes in the humid tropics where repeat incidences of disturbance are under control. The long-held view that active restoration leads to greater woody species diversity and stand structure may have been spurred by the fact that ecological restoration interventions are often carried out in open sites that are exposed to continual incidences of disturbance, which tends to hamper the recruitment and survival of natural regrowth.

Functional traits to predict financial value of enrichment planting in degraded tropical forests

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: A global push to increase reliance on sustainable renewable materials is expected to increase the demand for tropical timber. However, sustainable production of tropical timber, especially high-value tropical hardwoods, remains a challenge for the global wood product supply chain. Restoration of degraded lands through enrichment planting of native tree species could provide a solution, but the financial viability of thousands of native tropical tree species remains largely unknown. Therefore, we evaluated how the financial viability of 22 tree hardwood species native to northern Borneo in enrichment plantings of a degraded forest in Sabah, Malaysia, varied based on their plant functional trait composition. Partial least square models showed high internal rate of return (IRR) values to be correlated with low leaf calcium, magnesium and nitrogen content, and leaf pH and specific leaf area. All considered conservative trait values. Therefore, our results did not support our hypothesis regarding the trait-IRR relationship, based on the plant economic spectrum, i.e., high financial value was not predicted by acquisitive traits. Additionally, we found that high IRR was achieved by species that could concurrently maintain a high growth and survival rate. Our results show that enrichment planting for high value hardwood production in degraded forests can be financially viable, to different degrees depending on the species, and that conservative traits are linked to high financial value.

Integrated approaches for restoring degraded landscapes and enhancing the resilience of inhabitants

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Abstract Landscape restoration interventions have been priorities to combat land degradation in Ethiopia. This paper presents important learned lessons from the integrated landscape interventions implemented at Gergera watershed in Tigray, Ethiopia to restore degraded landscapes and enhancing the resilience of inhabitants.

We will present principles and steps to be followed in the process of implementing a successful landscape restoration intervention. Community led restoration with shared goals and vision and intervention priorities was the main landscape restoration approach introduced to the experimental watershed.

This approach with multiple interventions provide a multitude of benefits in a short to longer time scale, such as improved household food security, diversifying income sources, rehabilitating abandoned lands, improving feed, fodder availability, improving environmental quality. Degraded hillsides and gullies and farmland expected to be abandoned in 2-3 years due to gully formation were saved and restored through planting economically and ecologically important plants supported with physical structures. A gully as wide as 120 meters and 6-25 meters in depth converted from threats to opportunities and become sources of income for women and youths. Water availability was improved due to reduced runoff and increased irrigation, drinking water for livestock and humans. Restoration impacts have brought a mindset-shift that degraded lands can be restored and used to improve the livelihood of the community. Quality planting materials availability, integrating landscape restoration with livelihoods improvement and incentives to grow trees in farms and landscapes are key success factors for an effective, inclusive, and sustainable landscape restoration and in creating functional agroforestry practice.

We, therefore, recommend integrated watershed and/or landscape restoration practices should be guided through developing a community led vision and intervention priorities with appropriate socioeconomic and restoration packages and incentives in Ethiopia and beyond.

Key words: Land degradation, climate change, restoration, community, livelihood, green jobs

Learning from 25 years of operational restoration and research in the INIKEA – Sow-a-Seed rainforest restoration project

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: The INIKEA Sow-a-Seed project in Sabah, Borneo, was launched in 1998 to rehabilitate 18,500 hectares of tropical rainforest degraded by logging and later by fire. Sabah Foundation, The Swedish University of Agricultural Sciences, and IKEA built the project from the ground, including basic infrastructure, roads, nurseries, and housing for employees and families, and last but not least, developing knowledge. We used a range of restoration techniques depending on the level of degradation; In the moderately to highly disturbed areas, climber cutting, weeding, and selective girdling of pioneer Macaranga trees was repeated several times during ten years, while in the least disturbed areas, we made a one-time treatment consisting of climber cutting. Enrichment planting was also done in the moderately disturbed areas when few non-pioneer species were present. In total, we planted 5 million trees from 90 species. Here we summarize five key lessons learned after 25 years. 1) The restoration project created a valuable natural resource. 2); The selection of tree species can now be adjusted to the aim of the restoration; 3) Planted trees contribute to stand development in highly disturbed areas, but if resources are limited, ANR alone can often be sufficient to boost recovery; 4) Tree diversity matters for broader biodiversity; 5) Genetic variation of native trees is a neglected potential for native reforestation.

Mobile and web applications to involve the public in scouting and monitoring for forest health

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Engaging the public in research has benefits to forest research projects, including increased geographical scope, more frequent data points, and earlier detection of forest health problems. Building a research program with non-professional scientists requires an easy-to-use platform to guide new participants to successfully contribute useful information. We have designed a series of mobile and web applications to facilitate public science and will focus on two case studies. TreeSnap is a mobile phone application that engages the public in scouting for trees affected by insects and diseases, including North American ash, chestnut, hemlock, and elm. Volunteers can use the free app on Android or Apple phones to provide GPS locations, images, and characteristics to tree research programs. In contrast to other reporting apps, we increase the utility of the collected data by asking a set of customized questions for each species, such as a list of signs of emerald ash borer for ash trees and presence of cones for hemlocks. Scientists can use the TreeSnap website to sort and filter trees, download user observations, and contact individual users. With over 2000 active users and over 16000 tagged trees, TreeSnap is an important resource for scientists to find lingering trees that may harbor genetic resistance. We are actively seeking new partners to expand TreeSnap. A second new software system is in development to support plot monitoring. Research for forest health often needs data taken over years to record tree survival, changes in species composition, growth rates, and more. Our app will enable participants to work within a custom plot monitoring system set up by a partner scientist, with the ability to define plots then take regular data measurements. The first plot monitoring protocol is for hemlock species threatened by hemlock woolly adelgid. Users will report on infestation levels, canopy health, and tree survival. We welcome the opportunity to provide this software to other groups who have plot monitoring needs. Our 6 years of experience building apps that connect forest research programs to the public has proven that excellent, easy-to-use software paves the way for useful data and participant satisfaction.

Non-timber forest products management as a forest restoration strategy, based on a successful case of community forest management in Petén, Guatemala

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Non-timber forest products are an important part of many cultures and societies, providing food, medicines, fodder, aromatic products, bushmeat and honey. The Maya Biosphere Reserve (MBR) is one of the most successful cases of Community Forest Management, thanks to the forest concessions given to communities at the end of the 1990s, after the peace process in Guatemala. In the 1960s, the extraction of xate (Chamaedorea spp.) began with a largely artisanal process, but today it employs thousands of people and brings in thousands of dollars annually. On the other hand, ramón (Brosimum alicastrum Sw.) is one of the multi-purpose tropical species. It is currently in increasing demand as it is on the list of "superfoods" and is sought after for the development of food supplements. The main objective of this research was to systematise experiences on the use of xate leaves and ramón seeds in the communities of Uaxactún and Carmelita, in order to obtain lessons learned. The research approach was qualitative, with deliberate sampling and snowballing, seeking theoretical saturation of information. The methodological tools were literature analysis, interviews, ethnographic methods and focus groups. This work provides knowledge on the management, conservation and restoration practices developed in the concession areas of the villages of Uaxactún and Carmelita in the MBR; thanks in large part to the commercialisation of these two products. Eighteen technical and socio-economic bases were identified that have favoured the results of the concession process, after more than 20 years of accumulated experience. These bases are expected to become principles for similar initiatives and projects in tropical America.

Piloting Aerial Seeding in Restoration of Degraded Landscapes: Preliminary Results from Maasai Mau Forest in Kenya

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Aerial seeding technology has big potential for restoring large areas of degraded landscapes including forestlands as it is fast and cost-effective and has the capacity to cover inaccessible and rugged terrains. The technology was piloted on the abandoned and degraded area of Maasai Mau Forest in Kenya covering 3,600 ha using three thousand six hundred (3,600 kg) seed of fifteen indigenous tree species suitable for the area in November 2019. The objectives were to evaluate the success rate of the technology by assessing; density of tree seedlings emergence and establishment, relative success of individual tree species used in the restoration effort and factors for success. The results would inform the recommendation of the technology for widespread use in restoring millions of hectares of degraded lands to achieve the country's commitment to restore 5.1 million hectares of degraded lands by 2030. Assessments are conducted annually for all parameters. Data was collected using circular plots of 0.03 ha which were randomly distributed across very steep, steep and flat sites within selected blocks in the aerial seeded areas. Germination was recorded on nine tree species after nine months but at significant densities and establishment levels between species and across topographical zones. An average of 570 ± 313 seedlings per hectare was recorded accounting for 6.8% of the seeding rate of 8,409 seeds per hectare. The study identified *Dombeya torrida* and *Croton macrostachyus* exhibiting high seedling frequency and abundance among the fifteen species seeded. However, with time, the thickness of undergrowth vegetation and human activities seemed to reduce species performance. Performance of *Dombeya torrida* and *Croton macrostachyus* indicate that they are fast growers and may be good colonizers of degraded forestlands. We conclude that aerial seeding has fairly good success rates and may be used to restore degraded landscapes in Kenya.

Post-fire restoration: Can we learn from restorations already carried out in the past?

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Forests acting as carbon sinks play a key role in mitigating climate change due to the storage of carbon in their biomass and soils. Nevertheless, this natural process can be reversed due to disturbances such as wildfires, droughts, pests and diseases. Emissions from organic matter burning in vegetation, litter, or even in the mineral soil can be significant depending on the conditions of the fire severity. In addition, in the context of climate change we are currently suffering, the size of fires, the length of the burn season and the emissions can be increasing every year. As a consequence, restoration projects in the affected areas are the key to reverse the ecosystem degradation and avoid the carbon losses.

Post-fire restoration efforts typically involve a collaborative effort between government agencies, conservation organizations, and local communities. There are different types of post-fire restoration actions, such as reforestations, soil stabilization, fuel reduction, habitat restoration or water quality improvement. These processes can take many years and require many resources. However, on one hand, there is a lack of knowledge in the indicators of success or failure of these restoration actions; and, on the other, it takes many years to know if the restoration action has been a success or not.

With this situation as a starting point, in the context of the SUPERB Project we have collected the existing information of post-fire restoration projects that have been carried out in the past or were currently being carried out. We worked in two ways: from an online questionnaire and an exhaustive bibliographical review. This information allowed us to create a database with work done, success/failure indicators, actions to avoid, etc. We are presenting a first approach of the success vs failures indicators observed, that would very useful when carrying out of projects and future post-fires restoration actions.

Relationship between specific leaf area and survival of forest species in a landscape restoration experiment trial in Hernandarias, Paraguay

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: The correct selection of species in an active restoration process is a determining factor for the future success of the project. In order to optimize the selection of these species, different criteria are used, one of which is the adaptability of the species to the conditions prior to intervention. According to this, the objective of the study was to evaluate the relationship between specific leaf area (SLA) and the survival of the species used under the conditions of this trial. The methodology consisted of evaluating the survival of 30 forest species at 18 months after planting, without considering their replacement, in the Atlantic Forest ecoregion of Alto Paraná (Dinerstein et al., 1995), in the experimental plot of Itaipu Binacional in Hernandarias, Paraguay, which had 8 treatments and 5 blocks, distributed in a randomized block design . Additionally, 5 leaves from 5 individuals per species were collected, processed using ImageJ software, and then placed in an oven for 72 hours at a temperature of 60°C to obtain dry weight. The samples were weighed on a precision balance of 0.0001g to determine the dry weight. Using these data, SLA was estimated using the variables of dry weight and leaf area for each species, and their relationship with survival was evaluated through a simple linear regression analysis. The statistical analysis confirmed a relationship between SLA and survival with an R2 value of 0.42, and species with lower SLA indicated a higher percentage of survival. Therefore, they could serve as a parameter for selecting more efficient species in terms of their survival for any restoration project in the Atlantic Forest ecoregion of Alto Paraná, always considering the necessary functional diversity.

Restoration from even-aged conifer plantation toward mixed forest by planting broad-leaved tree at line cutting sites in Mt. Fuji, central Japan

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Transforming from pure and even-aged forests toward mix and uneven-aged forests is a central topic of forest management science. In Japan, most of coniferous plantations is pure and even-aged. The silvicultural technique to ecological restore such plantations is still under developing. I studied the growth and mortality of planted broad-leaved tree at line cutting sites in an even-aged conifer plantation. I would like to answer the following question: what factors affecting the growth and mortality of the planted seedlings at line cutting sites? The study site is located at 1600m in elevation at the west slope of Mt. Fuji and a 44 years old plantation (*Abies veitchii*) subject to line cutting (10-m width) in 2005. In 2007, broad-leaved saplings (*Acer palmatum*, *Alnus hirsute*, *Fagus crenata*, *Prunus jamasakura* and *Quercus crispula*) were randomly planted at line cutting sites and a permanent plot (1.06ha) was established. Every planted broad-leaved tree was protected by plastic tube from serious browsing by sika deer (*Cervus nippon*). Height and mortality census for planted broad-leaved trees was carried out in 2010, 2016 and 2023. After 2007, *Larix kaempferi* was naturally and successfully regenerated. I applied regression tree analysis to clarify the effects of distances from the nearest planted and naturally regenerated conifer (*L. kaempferi*), size of planted broad-leaved saplings and the nearest trees on growth and mortality of planted bread-leaved trees. For growth, *A. palmatum*, *A. hirsute*, and *P. jamasakura*, which were better growth species, was affected by distance from planted conifers, while *F. crenata* and *Q. crispula,* which were less growth species, was affected by distance from naturally regenerated conifers. Thus, to accomplish making mixed and diverse forests, careful management which considered species growth traits should be necessary.

RESTORATION POTENTIAL OF DEGRADED FOREST USING NATIVE SPECIES IN THE SOUTHERN REGION OF PENINSULAR MALAYSIA

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: The federal government funded the restoration, reclamation, and rehabilitation of degraded areas (3RSM) programme managed by the Forestry Department Peninsular Malaysia (JPSM). The programme aimed to restore the forested land using native species. The establishment of a native species required a suitable silviculture regime. This study aims to assess the survival and growth performance of *Shorea roxburghii* planted on degraded forest land in the 3 sites with 4 spacing types of Southern region of Peninsular Malaysia. *S. roxburghii* was chosen as a pilot plant due to the availability of seeds yearly. Based on growth performance analysis, the average height of the seedlings increased gradually, averaging about 1.5 to 3 meters annually, with a better survival rate (>80%). The *S.roxburghii* was well adapted and performed well in its growth. Based on the results of this study, *S.roxburghii* is a promising native species and has the potential to be planted as potential species to help rehabilitate the degraded forest.

Keywords: *Shorea roxburghii*, native tree species, degraded forest, growth performance

Scarabaeidae family as an indicator for the early evaluation of restoration success with nucleation techniques

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: The beetles of the family Scarabaeidae, a group of insects widely studied as ecological indicators of anthropogenic disturbances, because many of these species depend on native forests, are highly sensitive to disturbance processes such as fragmentation and forest transformation (Gardner et al. 2008). Using these aspects, the general objective of the research was to characterize the contribution of the Scarabaeidae family to the early evaluation of riparian forest restoration processes. The study area is located in the district of Minga Guazu, department of Alto Parana, Paraguay, in an area of forest production with *Eucalyptus* sp. for firewood. It consists of an area of nine hectares, subjected to active restoration with nucleation techniques, which in turn is divided into four subplots with the same treatment, of which three are being monitored. These three subplots have cores composed of 10-20 individuals of native forest species (fourteen in total). For the collection of Scarabaeidae a pitfall trap type was applied, based on Aguilar (2010) and López (2010), where the baits were (a) bovine intestine and (b) pig feces; the traps were placed in ten cores, distributed in the three subplots and monitored every 24 hours, during 3 days, after their installation. Identification was carried out at the National Museum of Natural History of Paraguay. Eleven individuals of 6 different species were collected, all copro-necrophages, among which *Coprophanaeus cyanescens* and *Dichotomius nisus* stand out, indicating the improvement of soil fertilization and aeration, as well as the presence of large mammals, since they depend on them as their main source of food (Nichols et al. 2009).

Simple innovations to scale assisted forest restoration: the promise of improving outcomes with cost-efficient low-tech approaches

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: To rapidly regenerate the world's forests it is imperative that we test and evaluate as many promising restoration approaches as possible. To pinpoint cost effective approaches that may facilitate scaling global forest restoration efforts, we systematically reviewed and quantified the ecological outcomes of a suite of emerging low-tech restoration techniques (hereafter 'simple innovations') with potential for landscape-scale implementation in areas that are slow to recover naturally. We reviewed approaches that have facilitated forest, woodland, and/or mangrove recovery while also decreasing implementation costs, offsetting costs of interventions, leveraging underutilized resources, and/or efficiently restoring natural processes. The simple innovations reviewed were: alternative propagation (e.g., direct seeding), applying biowaste, applying biochar, mixing native and exotic/economic species, mixed plantings, soil microbiome amendment, and spatially patterned planting. For these topics, our initial searches identified 6,456 studies from which fully reviewed all that met our inclusion criteria (field studies conducted in biomes dominated by woody vegetation that included empirical recovery data or data on implementation costs; N = 342). We extracted ecosystem recovery data for all studies that compared a given simple innovation to business-as-usual approaches (N = 143) and implementation costs from all studies that included them (N = 17). The simple innovations evaluated generally had either higher (48.5%) or the same (37.7%) mean ecological recovery values, and rarely had lower recovery values (13.8%; Fig. 1a), when compared to business-as usual controls; emphasizing that these simple innovations may have tremendous capacity to improve restoration outcomes, especially with respect to aboveground biomass/carbon accumulation (N = 63) and plant growth (N = 61). While these innovations have high potential to improve restoration outcomes, we found that they are rarely evaluated at scale and have mostly been tested in the tropics. Thus, we outline strategies to rapidly assess their efficacy, while championing the importance of capacity-building and knowledge-sharing networks in facilitating broader discussions of restoration best practices. Meeting ambitious global terrestrial restoration targets will be incredibly challenging, we argue that we already have many of the tools and the groundswell of support that we need to drive this movement forward.

Structured monitoring is needed to quantify success in forest restoration and deliver global climate and biodiversity goals

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Ambitious international policy targets have reinvigorated the global ecosystem restoration agenda, to reduce biodiversity loss and restore ecosystems. Yet, the consistent failure to deliver previous goals should serve as a warning. Targets need to be underpinned by a consistent system for monitoring, reporting and verification (MRV) of restoration gains.

Here, we describe an MRV system to consistently define the biodiversity and ecosystem services (BES) gained within a landscape through restoration actions. This MRV-BES system forms the basis of our outcome-based accountability framework that can enable high performing restoration projects to be financially rewarded for their bundled BES gains, and for the confidence with which gains meet expectations. The performance of any restoration project would be evaluated by the similarity of their BES measurements against reference trajectories that approximate the spectrum of development and target state of sites in that landscape. At the same time, project should achieve additionally evaluated by their dissimilarity to counterfactual models approximating the ecosystem development spectrum had no restoration occurred.

We exemplify the MRV-BES framework, with the pioneer work carried out within SUPERB (Systemic solutions for upscaling of urgent ecosystem restoration for forest related biodiversity and ecosystem services), a H2020 ecosystem restoration project part of the EU Green Deal. We monitored several restoration projects across Europe to establish the sequence of ecological changes we would expect restoration sites to follow toward reference ecosystems (reference trajectory). We have combined high-throughput taxa identification (automated acoustic recording, eDNA data) with remotely sensed data (airborne LiDAR, multispectral imaging) to link changes in BES to characteristics of forest ecosystem structure. The reference trajectories can then be used to evaluate the performance of restoration projects in the same landscapes.

We show our framework has the potential to incentivize investments in restoration projects using cost-effective monitoring methods. Ultimately, this work can help reverse the loss of biodiversity by informing the decisions of forest managers.

The nurse shrubs' Role in the Soil Enhancing in reclaimed opencast coal-mines: interactions with Grazing

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Native shrubs play a vital role in facilitating the establishment of oak seedlings in opencast coal mines, with greater relevance in Mediterranean areas. Thus, we hypothesize that nurse shrubs in mining areas can enhance edaphic properties by mitigating the negative impacts of trampling and grazing by the ungulates. For that, we evaluate the combined effects of nurse shrubs (plots with and without shrubs) and grazing (plots with and without fences to prevent browsing and trampling) on soil properties in a reclaimed coal mine in Northern Spain.

Regarding chemical soil properties, higher values of electrical conductivity, K^+, cation exchange capacity, and C/N ratio beneath the shrubs were described. Similarly, total organic matter, total N, total organic C, total P, available P, and Mg^{2+} levels were higher under shrubs, but only with grazing. On the other hand, pH and Ca^{+2} levels were higher outside the shrubs, but Ca^{+2} only without grazing. In grazed areas, Na^+ levels decreased under shrubs.

Among physical properties, bulk density increased, and porosity decreased exclusively in grazed plots. In contrast, sand content increased under shrubs within the grazed plots, while clay content decreased in those areas. In addition, ungrazed areas showed the highest water holding capacity and available water.

Overall, our findings indicate that shrubs have a direct positive impact on soil fertility, particularly in grazed areas, as nurse shrubs and grazing exhibit synergistic effects. Furthermore, they indirectly contribute to the improvement of physical properties by mitigating the adverse effects of grazing, specifically soil compaction, through the reduction of trampling by livestock and wild ungulates. Hence, these results highlight the significant role of nurse shrubs in soil amelioration, facilitating the establishment of plants in reclaimed mines, thereby offering substantial implications for the restoration of pastures and forests.

Trends, challenges, and drivers of land cover change in community-based mangrove restoration (CBMR): A case study from Sucre, Colombia.

T3.12 Forest Restoration Success and How to Achieve it

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Abstract: Mangrove forests offer an array of ecosystem services to coastal communities. Mangrove restoration can be a crucial strategy to contribute to the recovery of mangrove ecosystem functionality and services in sites where they have been degraded. One of the approaches for restoration is community-based mangrove restoration (CBMR). In this study, we combine two methods to investigate CBMR in Sucre Province (Colombia), where promising restoration sites for annexation to the Blue Carbon National Program exist. First, we will use Q-methodology to map the main mangrove management stakeholders' discourses. Second, we will map Sucre's mangrove forest extent from 1984 to 2022 using remote sensing techniques. The Q-methodology results will identify mangrove management stakeholders' perceptions of trends and challenges in mangrove restoration management in Sucre. The remotely-sensed verification will complement these perceptions by examining the context of restoration sites through a temporal analysis of mangrove cover supported by existing literature. Finally, this study aims to contribute to understanding whether and how CBMR enables socio-ecological transformations and to inform complex decision-making and policy-making processes for mangrove conservation and livelihood improvement.

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

Agroforestry-based Forest Landscape Restoration in Timor-Leste: Challenges and Opportunities

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: Timor-Leste is the newest country and one of the least developing countries in the Southeast Asia region. The country has been facing multidimensional challenges in land governance leading to deforestation, land degradation, and poverty. Further, Timor-Leste is also prone to climate change effects including unpredictable rain, storm wind, flooding, and drought. Agroforestry is a viable option to balance poverty alleviation and ecological functions of the forest and lands in Timor-Leste. The study presents the challenges and opportunities of agroforestry-based reforestation to improve ecosystem services of degraded landscapes and alleviate poverty in Timor Leste. The study reveals agroforestry has been traditionally practiced in different forms including alley cropping, tree border, alternate row, and irregular patterns. Further, agroforestry initiatives have been conducted with support from different international donors in almost whole municipalities. Agroforestry practice has the potential to increase the diversity of trees on farms which potentially improves ecosystem services and soil health. It also potentially generates income through the production of food crops and employment opportunities for the young generation of the local population. As the main livelihood sources for the rural population rely on land-based resources, therefore the improved income and livelihoods from their lands potentially will encourage forest to expand agricultural land. However, the lack of capacity and knowledge on improved agroforestry systems for both farmers and extension workers is one of the constraints in promoting agroforestry for the restoration of degraded landscapes in the country. Lack of financial access is also another challenge to sustain agroforestry. Economic return from planting trees is long-term while landowners demand fast cash flow to fulfill daily needs. Land tenure insecurity has discouraged private sectors from investing in large-scale agroforestry. The study suggests that a direct incentive is necessary to promote agroforestry for landscape restoration, in addition to land tenure security. Capacity building to extension workers and intensive assistance to farmers, as well as market accessibility are required to foster agroforestry in Timor-Leste. Further, establishing a community-based monitoring system is necessary to generate information on the progress of agroforestry such as potential carbon sequestration and food crop productivity needed by market or investors.

Assessing subtropical forest ecosystems' response to climate extremes by using dynamic process network and eddy covariance observations

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: The recent IPCC AR6 synthesis report confirms the significant impact of human activities on global warming, leading to an increase in the frequency and severity of extreme climate events. Subtropical ecosystems in East and Southeast Asia monsoon region, which contribute approximately 8% to the world's forest net ecosystem productivity, are also under significant pressure due to these climate extremes. This study seeks to assess the responses of subtropical forest ecosystems to three primary types of climate extremes, i.e., droughts, heatwaves, and extreme rainfalls.

We propose to utilize eddy covariance observations and high-resolution satellite data collected from three representative subtropical ecosystems in the region, i.e., a Moso bamboo forest, a Lei bamboo forest, and an evergreen broadleaf forest. The Dynamic Process Network approach, based on information theory, has been demonstrated as a robust method for investigating and assessing ecosystem functionality using high-frequency observations. Additionally, the Cumulative Power Law Model will be employed to evaluate these ecosystems' sensitivity to climate extremes in the region. This proposed research is expected to enhance our understanding of the complex responses of subtropical ecosystems to climate change.

Climate change on subtropical cloud forest and restoration strategies: a case study on the endangered beech forest in Taiwan

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: The directional range shift, including the poleward and upward migration of tree species under global warming, is an issue of growing concern for natural resource management. Mountain regions have a dramatic climatic gradient, so species can approach a temperature-suitable habitat in a very short distance. However, the accompanying interspecific competition, substitution, and progressive replacement of forest communities may also occur. Cloud forests on tropical and subtropical islands have been proven to be one of the most vulnerable ecosystems to climate change. The montane cloud beech forest in Taiwan, which is predominantly dominated by the glacier-relict species of *Fagus hayatae*, was projected to suffer severe impacts with a 92.90% habitat loss under a medium stabilization scenario (RCP 4.5) or 99.23% under a high emission scenario (RCP 8.5) based on an intact historical and future climate database developed by The Taiwan Climate Change Projection Information and Adaptation Knowledge Platform (TCCIP).

In Taiwan, *Fagus hayatae* is mainly distributed in the northeast mountains and exposed to the winter monsoon to meet its cool-temperate ecological requirements. All populations currently inhabit isolated mountain tops and ridges from 1,000 to 2,000m asl. Our model simulations revealed that the fragmented and ridge-top habitats impose strong limitations on their migration and lead to a high extinction risk. Long-term field surveys from a series of permanent forest plots from 1,000 to 1,800m elevation also support the model projection. The low-elevation populations exhibited an unstable size-class distribution compared to high elevations, and a cascade-like population decline was triggered by extreme climatic events such as typhoons.

To mitigate the impact of climate change on the endangered *Fagus* forest, several conservation strategies have been implemented, including (1) Annual monitoring by drone to detect the mortality of adult trees; (2) The establishment and identification of genetic variation for each relic population; (3) Assisted propagation from seed collection and preservation, as well as air layering for adult trees in the wild; and (4) Assisted migration by using *Fagus* saplings to accelerate the regeneration of thinned-out plantations along projected migration corridors.

Determinants of Public Participation in Watershed Management: An Application of the Institutional Analysis and Development Framework

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: Increasingly, adaptive processes and decentralization are vital aspects of watershed governance. A significant gap exists in our understanding of the factors that facilitate public participation in China. In this study, we combine the Institutional Analysis and Development framework with multiple models and ordered probit regression to investigate empirically the determinants of willingness to participate (WTP) and actual participation of the public in integrated watershed management (IWM) planning and implementation activities. Data derived from questionnaires are used to define stakeholders' perceptions of IWM. The sustainability of the regional conservation plan is primarily based on the satisfaction of citizens with management performance. Considering the importance of the terrestrial-aquatic interface for watershed integrity, we also investigated the effectiveness and appropriateness of riparian forest management. We find that individual environmental intention and behavior are influenced by biophysical conditions, rules-in-use, socioeconomic characteristics, and interactional capacity, to varying extents. The results of this work reinforce the necessity for an integrated and holistic approach to regional watershed resource management. The results also show that information-sharing significantly improves the WTP and actual public participation in IWM. Interpersonal communication and cross-reach support in an interactional capacity are also significantly correlated with WTP, while the overall performance of governance and inappropriate forest practices influence intention and behavior. Participants were more inclined to engage in river basin activities if they had previously observed poor forest management behavior (e.g., burning slash and shrub, clear-cutting, logging within a riparian zone, herbicide and pesticide use). The biophysical conditions and socioeconomic characteristics of the watershed do not markedly affect WTP but shape actual participation behavior. These findings provide workable insights into the social and institutional factors that shape the participation by individuals in watershed governance as it moves towards a decentralized and sustainable future.

Developing tools for evaluating forest degradation under climate change: case studies from East and South-East Asian evergreen broad-leaved forest

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: The degradation of tropical forests contributes to global greenhouse gas emissions including loss of biodiversity, ecosystem services and consequently negative impact on wellbeings and livelihoods. Thus, monitoring forest degradation is the key for developing forest restoration plans, policies, and actions. However, monitoring forest degradation is understudied and poorly understood, mainly because most of the programs focused on deforestation, which is easier to monitor. Few monitoring tools that existed mostly focused on larger spatial scale, in contrast, most of the forest restoration programs took place at smaller scale. In addition to this, the existing monitoring tools almost disregard the climate change complexity that will eventually impact success of forest restoration tropical forest. To address these issues, we develop forest degradation monitoring tools as measured by criteria and indicators related to biophysical attributes of forests that consider local climate change. In this presentation, we will introduce the tools and discuss the application of tools under climate change including associated challenges and opportunities with case studies from evergreen broad-leaved forest across East Asia and Southeast Asia. We hope these tools will help practitioners to evaluate forest degradation at a local scale and develop effective restoration plans and actions for recovery of degraded forest.

Development of standard nursery growth media for enhanced domestication of East African sandalwood in Kenya

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: Tree nurseries play a vital role in afforestation and reforestation programmes across the globe. The quality of planting stock leads to successful field establishment and growth performance thus leading to high yield. The need to domesticate *Osyris lanceolata* (East African Sandalwood), which is a threatened species, has increased the demand for quality Sandalwood seedlings in Kenya. The population of this species had dwindled over the years due to over-exploitation from the natural ecosystem due to its commercial potential. Wild-harvested Sandalwood from Kenya is illegally poached and smuggled mostly to India as a substitute to the Asian Sandalwoods as an ingredient in the multimillion dollar cosmetic, perfumery and flavour industries. For successful domestication of the species, there is need to develop appropriate nursery growth media for production of quality seedlings. Currently, there is no standard nursery growth media for propagation of the species. As such, a nursery experiment was established to evaluate sandalwood growth performance under different ratios (v/v) of forest soil, manure and sand. The study was set using randomized complete block design with 5 treatments, each replicated thrice. The ratios used were: 5:1:1+NH (control), 5:1:1+H, 4:1:1+H, 3:1:1+H and 2:1:1+H with "NH" representing non-hosted seedlings while "H" represented hosted seedlings. The seedlings were hosted with *Acacia polyacantha* except the control. The results show 5:1:1+H had the best seedling growth in terms of height and collar diameter at the end of the experiment (19.23cm and 2.74mm, respectively); 123.3% and 87.7% higher than the control, respectively. In terms of shoot and root biomass, 5:1:1+H had the highest biomass (1.80g and 0.44g per seedling, respectively); this was >150% higher than the control. The highest sturdiness quotient (SQ) was observed in 5:1:1+H (8.53) while the lowest SQ was recorded in 2:1:1+H (5.92). There were no significant differences in root/shoot ratio of sandalwood seedlings raised from different soil mixtures ($p<0.23$). The highest seedling survival rate of 88.9% was recorded in 5:1:1+H while the lowest was recorded in 5:1:1+NH (62.2%). The treatment of 5:1:1+H is the most appropriate for production of quality sandalwood seedlings to enhance domestication of the species.

Diverse approaches to forest landscape restoration in mainland Southeast Asia.

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: Forest landscape restoration (FLR) represents a cost-effective, long-term, and sustainable nature-based solution to address adverse impacts of degradation. It aligns with national and international priorities, including climate change mitigation, livelihood improvement, and biodiversity conservation. Economic analyses confirm that long-term benefits of FLR outweigh initial investments. However, countries in the Greater Mekong Subregion (GMS) exhibit divergent priorities and approaches, impeding the required scale of FLR implementation to reverse historical and ongoing degradation.

WWF actively engages in diverse FLR approaches within the GMS tailored to contextual factors and aligned with the UN Decade on Ecosystem Restoration. Their aim is to generate benefits for both nature and people within local and global landscapes. I propose to present the comprehensive range of activities undertaken by WWF, demonstrating clear objectives and effective monitoring mechanisms.

In Myanmar, WWF supports Assisted Natural Regeneration and firebreaks to restore local territories of the Karen in the Tanintharyi region. These efforts integrate indigenous peoples and local community knowledge and practices to restore ecosystem services. Food production within restored forests encourages wider adoption of FLR.

FLR349 in Thailand employs an agroecology lens to address the expansion of monoculture maize agriculture, which has led to extensive deforestation and degradation, particularly in the Northern watershed areas. This model promotes sustainable agriculture based on the agroecological concepts of "Three Forests, Four Benefits" under the "Sufficiency Economy Philosophy" of His Majesty King Bhumibol Adulyadej, Rama IX of Thailand.

The Community-based Forest Restoration and Management for Livelihoods program in Lao PDR targets villages with degraded forests in and around the Xe Sap National Protected Areas. This inclusive approach embraces natural forest restoration and management and supports climate-resilient livelihoods. WWF Laos is piloting a wildlife recovery assessment tool with Mekong Timber Plantations to explore how private concession-based timber plantation companies can contribute to FLR.

WWF supports the Vietnamese Government through various approaches including restoring natural forests to enhance climate resilience and diversifying commercial plantations through extended rotations. Additionally, each location is analyzed to highlight successful strategies and challenges overcome to derive lessons for scaling up these approaches and implementing FLR initiatives in similar situations to amplify impact.

Ecological restoration and environmental impacts caused by construction activities

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: This paper presents the natural hazards caused by human activities i.e. surface mining and highway construction in Beijing mountainous area. The exploitation of large open pit mines and the construction of highways have caused severe disturbance to land and vegetation. This kind of disturbance causes a series of problems, for example, serious loss of water and soil, geologic hazards like landslides and collapses, which affect the ecological and living environment. The reconstruction of the vegetation ecosystem is the key to improve soil condition. Therefore, soil and water conservation measures should be designed reasonably according to the features and physical truths of a project or an engineering. And engineering measures and vegetation measures should be combined for protection. In order to improve the fraction of slope surfaces' coverage and plant roots' ability to reinforce soil, deep-rooted and local plants should be widely used and shrub proportion should be increased appropriately. Among the ecological measures for greening in rock slopes in mountainous areas, the use of geogrids with embedded ecological bags results in the minimum runoff volume, while the use of geogrid chambers leads to the minimum sediment yield. Among the ecological protection measures for slopes in mountainous areas, the runoff volume and sediment yield are the lowest when geogrid chambers are used. In plain areas, the runoff volume and sediment yield of trapezoidal hollow hexagonal brick greening measures are both lower than those of hollow hexagonal brick greening measures. Based on the effectiveness of different ecological protection measures in reducing runoff and sediment, the optimal ecological protection measures should be selected for vegetation restoration on various typical slopes to ensure the best control of soil erosion. The ecological restoration and afforesting goal whose premise is to achieve slope stability will be finally achieved and plant community which is in harmony with the surrounding environment will be formed so that the aim to prevent soil and water loss will be reached.

Effect of Prolonging Nursery Lifespan on Survival Rate of out planted Tree Seedlings

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: Effect of Prolonging Nursery Lifespan on Survival Rate of out planted Tree Seedlings

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ABSTRACT

The most challenging issue for rehabilitation of degraded lands in Tigray mostly is attributed to poor survival rate of planted seedlings. Therefore, the objective of this research was to evaluate the survival rate of planted seedlings through prolonging the nursery lifespan of seedlings which ensures the vigorosity of the seedlings to withstand the moisture stress of the areas. The treatments were seedlings of three, five, seven and nine month's nursery lifespans. The tree species considered for this study were *Moringa stenoptella; Jatropha curcas, Leucaena leucocephala and Ziziphus spina Christ* that poorly survives in the area were selected and subjected to the different treatments (nursery lifespan). The spacing between blocks, plots and plants were four, three, and two meters respectively with RCBD design. Plantation pits were prepared two weeks ahead of plantation for moisture retention. The required post and pre plantation management activities were equally applied to all treatments and species. Data such as plant height and survival rate have been collected for a year at different months. Analysis of variance (ANOVA) was employed to see if there was a mean difference between the treatments. LSD mean separation was employed to compute for multiple comparisons or post hoc tests. Prolonging the nursery lifespan of the seedlings has brought a significant effect on both survival rate and plant height. However, the tree species didn't consistently respond to the treatments (lifespan). Some tree species increase their survival rate with increasing nursery lifespan while, others, not. The best survival rate of tree species was identified at five months nursery lifespan except for Jatropha which consistently increases its survival rate with increasing nursery lifespan. In general, prolonging only the seedlings nursery lifespan may not be enough for improving the survival rate, but also needs to add fertilizer at the expense of prolonging the seedlings nursery life span.

Key words: *Nursery lifespan, survival rate and prolonging*

Forest landscape restoration measures as a cost effective solution for climate change mitigation and adaptation in India

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: Global deforestation and forest degradation have led to massive loss of biodiversity. Hence, it is important not only to protect but also restore the forest ecosystems. Forest biodiversity protection, biomass production and climate change mitigation and adaptation are some of the important key motivations for forest restoration.

Tree-based landscape restoration is a widely accepted cost-effective measure to combat climate change. India's commitment of Nationally Determined Contribution to the Paris Agreement is to sequester additional 2.5 to 3 billion tons CO_2 equivalent by 2030 through increased forest and tree cover and this ties in with the Bonn Challenge commitment to restore 21 mha of deforested and degraded lands by 2030 (now increased to 26 mha during UNCCD COP 14 meeting held in Sept. 2019) as well as the SDGs. This commitment can only be met if existing forests are protected and improved and tree cover is extended by 25 to 30 mha.

The main objectives of the Forest Landscape Restoration (FLR) in India is to reverse the process of degradation of forests & improve its productive potential, improve the regeneration of native flora & enrich the biodiversity, and enhance biomass production, carbon stocks & incomes of the rural households.

For a successful FLR works in India, focus needs to be on proactive involvement of communities and local people, better coordination among the various government agencies and departments for effective implementation of project activities, robust Institutional mechanism, and continuous fund flow and support to sustain the activities and keep the restored areas intact.

Here, we present how India can achieve the NDC and Bonn Challenge through forest landscape restoration. Potential to increase forest and tree cover and the carbon sequestration that can be achieved has been discussed. This will support planning for landscape restoration through the past and on-going initiatives which identifies different types of interventions implemented.

Forest Restoration under Climate Change in Southeast Asia: Innovative Tools, Models, and Approaches

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: Forest restoration is gaining increasing attention at international and national levels. However, identifying forest degradation, particularly at smaller scales, remains a challenge due to diverse drivers and site-specific factors. Existing frameworks for identifying forest degradation are useful on a larger scale, but a framework that incorporates local knowledge is needed for smaller-scale assessments. In this research, we propose a new mechanism called the Degradation and Restoration Assessment Mechanism (DReAM) that facilitates the identification of forest degradation and opportunities for restoration in landscapes. The DReAM framework is based on an iterative process that incorporates input from local knowledge-holders and established regional expertise. It provides a comprehensive approach to understanding forest degradation and monitoring restoration progress. We tested the utility of the DReAM mechanism in multiple sites across the Lancang-Mekong Region, including Cambodia, Laos, Myanmar, Thailand, and Vietnam. Through the application of the DReAM mechanism, we derived a set of appropriate criteria and indicators for identifying degraded forests. These criteria and indicators can serve as guidelines for developing effective rehabilitation approaches. Importantly, the DReAM mechanism is designed to be accessible and applicable to any individual or group interested in identifying forest degradation or assessing rehabilitation efforts.

Integrating technology and community management for forest and water resource management for climate adaptation: Lessons and approaches

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: Context:

Climate change poses significant challenges for forest and water resource management, necessitating the integration of technology and community management approaches. This abstract presents key lessons and approaches from the Water Security and Climate Adaptation in Rural India (WASCA) project, which aims to enhance climate adaptation in forest and water resource management.

Topic of Study:

This study focuses on the integration of technology and community management for climate adaptation in India's forest and water resource management, drawing lessons from the WASCA project.

Methods:

The WASCA project utilised advanced technology and community-based management strategies to address climate-related challenges. Remote sensing, geographic information systems (GIS), and hydrological modelling were employed to assess the impacts of climate change on forests and water resources. Community engagement and participatory approaches were adopted to foster local ownership, knowledge sharing, and resource mobilisation. Adaptation strategies were implemented in collaboration with local communities, including afforestation, reforestation, sustainable water management practices, and capacity-building programs.

Main Results:

Technology integration provided valuable data and insights, enabling evidence-based decision-making and planning. It facilitated accurate monitoring of changes in vegetation cover, hydrological patterns, and water availability, helping identify vulnerable areas, prioritising adaptation measures and water budgeting. Community management played a pivotal role in ensuring the effectiveness and sustainability of interventions. This collaborative approach fosters social cohesion, empowering communities to take ownership of climate adaptation efforts. Despite its many successes, there are challenges in integrating forest management at the institutional level.

Conclusions:

The findings from the WASCA project demonstrate that integrating technology and community

management is a promising approach for climate adaptation in forest and water resource management in India. The combination of advanced technology and community engagement enhances the accuracy and relevance of adaptation measures. Moreover, it strengthens social resilience and supports sustainable livelihoods. Policymakers and practitioners should consider these lessons to develop context-specific adaptation strategies, recognising the importance of community participation and traditional knowledge in climate adaptation efforts. By integrating technology and community management, India can effectively respond to the challenges of climate change and ensure the resilience of its forest and water resources to benefit local communities and the environment.

Physiological and ecological responses of moso bamboo of different ages to summer drought stress

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: Bamboo is known for its fast growth rate and carbon sequestration capabilities, making it an important part of the forestry carbon sequestration. However, due to the climate change, extreme high temperatures and droughts are becoming more frequent, posing a threat to the health of the forests and the carbon sinks they carry. This study aims to investigate drought resilience of Moso bamboo by simulating drought conditions in Lin'an, Zhejiang, and monitoring the physiological response of new and old Moso bamboo culms to the drought. We found that moso bamboo shows different drought resistance strategies at different ages: (1) Under summer drought stress, soil microbial diversity and root infection rate of arbuscular mycorrhizal fungi decreased significantly in moso bamboo forest, especially in new bamboo. Adult bamboo transferred more nutrients to fungi to maintain water uptake ability by reducing root fungal infection rate decline. (2) Stem hydraulic structure and sap flow monitoring revealed age-related differences in water use of moso bamboo. New bamboo had higher transpiration, photosynthetic capacity and xylem water transport capacity than old bamboo. Under drought stress, water consumption of both decreased significantly, but new bamboo still maintained higher transpiration. Continuous heat and drought damaged photosynthetic capacity and hydraulic structure of new bamboo due to insufficient water support. However, old bamboo started water-saving mode in the early stage of drought and performed better than new bamboo in terms of stomatal control of transpiration and nocturnal water recharge capacity. (3) Drought reduced leaf photosynthesis, but increased isoprene release. Moso bamboo increased carbon investment in drought defense. This study revealed the different drought resistance strategies of moso bamboo at different ages. Adult bamboo relied more on symbiotic fungi to maintain water uptake ability, while new bamboo maintained higher transpiration and photosynthetic capacity but suffered more damage under heat and drought stress. Old bamboo adopted a water-saving mode and performed better than new bamboo in terms of stomatal control and nocturnal water recharge. Our findings provide new insights into the physiological and ecological responses of moso bamboo to drought stress and have implications for its sustainable management and conservation.

Study of Genetic Diversity in An Effort to Save The Genus of Dacrydium (Lamb.) in Kalimantan Indonesia

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: The tropical coniferous genus *Dacrydium* is widespread in Kalimantan, Indonesia. Four species can still be found in Borneo. Locally known as *Alau*, this genus thrives in a range of habitats from heath to deep-peat forests, especially in Central Kalimantan. This genus is threatened by logging, fires, and forest conversion for other uses. The objectives of this study were to investigate the genetic diversity of *Dacrydium* in the study area which is a large unified diverse landscape.. Our research was conducted in a heath forest located within PT Taiyoung Engreen logging company in Gunung Mas District, PT Dasa Intiga in Kapuas District, and a deep-peat swamp forest located in Sebangau National Park in Palangkaraya District. The four species that are suspected to exist in Kalimantan, namely *Dacrydium beccarii* Parl.; *Dacrydium pectinatum* de Laub., *Dacrydium elatum* (Roxb.)Wall. ex Hook. and *Dacrydium xanthandrum* Pilg. were met in various abundances. Isoenzyme markers were applied to analyze the genetic diversity of *D. beccarii* and *D. pectinatum* using 20 samples per species from each site.

The results showed that *D. beccarii* and *D. pectinatum* have a large number of missing alleles, rare alleles, and individual alleles, which are found in different species in the three research sites; all show their owngenetic peculiarities. That makes it necessary to develop a strategy to protect the alau quite locally , Especially *D. pectinatum* is of high concern as it is quite threatened. *D. beccarii* and *D. pectinatum* have similar total heterozygosity (H_T) namely 0,686 and 0,700. Most the genetic diversity of both species 71,1% and 0,65% present within the population, and the fixation index (FIS) values close to zero -0,021 and 0,187, which means both species has a tendency to random mating. It is necessary to implement a strategy for saving Dacrydium. This can be implemented from our research site. Actions will include the translocating of individual seedlings between research sites where each has a private allele with different advantages to be planted in all original habitat to increase genetic variation, and establish demonstration plots to safeguard genetic variation (diversity), and additionally carry-out genetic enrichment planting, especially for *D pectinatum*.

Sustainable Forest Ecological Restoration in the Context of Corporate Social Responsibility

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: In 2013, an eco-centric Corporate Social Responsibility (CSR) initiative called the Khao Huai Mahat Forest Restoration project was launched through the collaboration of four organizations: GC, Kasetsart University, The Air and Coastal Defense Command, and The Konrakpa Club under Charklookya-Huai Mahat community. With a ten-year timeframe, the primary objectives of the project included restoring the degraded forest, improving the economic and social well-being of the surrounding communities, raising awareness about environmental protection and forest conservation, and safeguarding the only forest area within the Map Ta Phut Industrial Estate in Thailand.

Khao Huai Mahat was once a thriving forest ecosystem that provided essential ecological services, including high-quality water, NTFPs and a rich source of medicinal plants for the community's livelihood. However, due to decades of forest exploitation for agricultural practices and frequent fires, the forest area has deteriorated. To address this issue, a project master plan was formulated with three main activities: restoration, construction of weirs, and fire protection measures. These initiatives aim to enhance water absorption, increase biodiversity, and contribute to mitigating climate change. The local community has shown strong support for these activities and recognizes the significance of the project.

To facilitate monitoring and decision-making, a digital platform has been established, capturing baseline information and documenting implemented activities. Biodiversity monitoring was the key indicator, while the growth of planted trees and the functionality of weirs are monitored annually. The project has received certification from the Thailand Greenhouse Gas Management Organization as a Low Emission Support Scheme, highlighting the project's contribution to greenhouse gas storage and sustainability.

Despite the potential for projects to exceed initial timelines, the 400-hectare ecosystem of Khao Huai Mahat serves as a testament to the transformative power and impact of community-driven initiatives. The project exemplifies best practices and a robust corporate social responsibility (CSR) model, emphasizing the crucial role of community involvement in restoring forest ecosystems.

The Untapped Potential of Bamboo Forests for Carbon Offset in Mitigating Climate Change: A Comparative Study with Tree Forests

T3.13 Forest restoration under climate change in Southeast Asia: innovative tools, model, and approaches

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Abstract: In light of the increasing deforestation rates and climate change challenges in Southeast Asia, this study examines innovative strategies for forest restoration, focusing on the carbon sequestration potential of bamboo and tree forest Afforestation/Reforestation (AR) projects. Employing a global empirical analysis, we compare the carbon sequestration capacity of these two types of forests in diverse climatic and geographical conditions. This investigation uses Landsat remote sensing data to analyze five tree- and five bamboo-AR projects, certified by the Verified Carbon Standard (VCS), Chinese Certified Emission Reduction (CCER), and the Fujian Forestry Certified Emission Reduction (FFCER), providing a comprehensive perspective on these forests' potential in carbon offset schemes. Additionally, a detailed case study conducted in Tongshan County, China, further illuminates our understanding by utilizing LiDAR data to compare the carbon sequestration performance of a bamboo afforestation project with a tree afforestation project. This ground-level analysis offers insight into the adaptability and sustainability of these forest types within a rapidly changing climate. This research scrutinizes the advantages and limitations of remote sensing technologies like Landsat and LiDAR in accurately assessing and monitoring AR projects, potentially guiding the development of more advanced and effective tools for forest plantation projects. Through this analysis, we present evidence-based recommendations to enhance the design, implementation, and monitoring of forest carbon offset projects. These findings are essential to contribute significantly to the ongoing discourse on sustainable forest management, particularly in regions experiencing ecological degradation under climate change. By spotlighting the untapped potential of bamboo forests, this research proposes a broader, more innovative approach to forest restoration in Southeast Asia, thereby setting a precedent for similar endeavors worldwide.

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

Agility in changing environments: how genomic and enviromic technologies transformed a Eucalyptus globulus tree improvement program

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Physical and economic environments are changing rapidly and with increasing uncertainty. Agility is now a fundamental requirement of tree improvement programs globally, demonstrated through sensitivity, flexibility, and responsiveness to sudden changes in breeding or deployment objectives. Thankfully, advances in genomics, enviromics, and phenomics have provided tools to help meet this challenge.

Australian Bluegum Plantations (ABP) conducts an advanced-generation *Eucalyptus globulus* breeding program, which we present as an example of how adoption of genomic and enviromic technologies can deliver greater agility in response to changing climatic and market demands. Application of genomic tools has been foundational to the transformation of ABP's program, to correct identity errors in the pedigree and orchards and increase breeding value accuracy through single-step genomic BLUP (ssGBLUP). Races and landraces are accommodated in ssGBLUP as 'metafounders' and the optimisation of this process has helped classify pedigree founders from unknown origins into genetically similar groups. ssGBLUP facilitated the joint analysis breeding populations from ABP and a collaborator. This has crucially increased our flexibility via improved genetic diversity. The power of ssGBLUP was leveraged with factor analytic analysis to calculate genotype-environment interaction. Enviromic characterisation of 33 trial sites using 145 environmental variables then enabled identification of five deployment zones based on envirotypes. Mapping of these new deployment zones using predicted climates has revealed the dominant envirotypes expected in future decades. Selection and breeding for survival and growth in these environments is now underway.

Agility in the ABP program is also achieved through sublining and integration of breeding and deployment activities. Breeding and deployment populations are divided into non-exclusive sublines based on suitability to envirotype, wood properties, and disease resistance. This approach provides a framework for flexibility and responsiveness to changing market or environmental demands which can be applied to new objectives that emerge from the bioeconomy sector. By deployment of control-pollinated families, parents from particular sublines can be paired to produce seedlots for different combinations of traits and environments. Selection for reproductive attributes is practiced with each new introduction of seed orchard clones. Active program developments include genomic and marker-assisted selection and rapid phenotyping methods.

Assessing adaptability and resilience of pure species and clones of Eucalyptus grandis and Eucalyptus camandulensis in planted forests

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Assessment of resilience and adaptability of clones of the marketable tree species- *Eucalyptus grandis* on high potential highland areas and *Eucalyptus camandulensis* for low potential areas is key towards addressing climate change adaptation and mitigation. This study explores the need to sustain quality timber supply towards bio-circular economy and use of clones plantations. The research focused on three main objectives of; One, to assess survival of pure species and clone hybrids. Two, assessing the recovery and resilience pure species and clone hybrids within blocks in Turbo. Three, to model the potential of clones from low and high potential zones as future resilient crosses. The research data was collected within Turbo through total enumeration. There were six (6) blocks of thirty four (34) treatments of fifteen clones of *Eucalyptus camandulensis and Eucalyptus grandis* of GC03, GC785, GC514, GC167, GU7, GC796, GC642, GU8, GC522, GC10, GC12,GC584, GC14, GC15, GC581,18 pure and one local *Eucalyptus grandis*. Inventory of the stands was by the tree height and diameter at breast height(DBH). Annual rainfall and temperature ranges were acquired and minimal and optimal weather conditions were calculated. Data analysis included; survival and abundance of pure species and clones within the years, comparison of annual volume of the stands within years of optimal and minimal rainfall and temprature, modelling on future performance of pure species and clones. Tentative results show high survival of pure species of *Eucalyptus grandis* at the first five years with an average of >50% trees present in the blocks compared to clones on this site similarly to abundance of pure species to stand density. Recovery of the clones after minimal weather conditions was low compared to pure species. Response in terms of volume accumulation of clones; GC514, GC581 and GC796 was significant than the other clones likewise to significant performance of EG6, EG10 and EG3. The results suggest adaptive climate-smart breeding methods and growing of resilient clones and species within planted forests towards climate change mitigation and livelihood improvement. The study was limited to research conducted within a high potential forestry area, replicates of the clones for wider sites should be considered.

Assessment of bud flush and damage in young Norway Spruce trees through airborne high-resolution multispectral images

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Scandinavia is facing climate changes with a predicted increase of mean temperature between 2-4° C, which is expected to result in longer vegetation periods and consequently increased tree growth. This might lead to an increased risk of frost damage to newly sprouted buds as the timing of bud flush will change and temperature might backlash during spring.

Studies of one-year-old Norway spruce (*Picea abies*) seedlings suggest a strong correlation between early bud flush and frost damage. Bud flush and hardiness have been assessed for adult Norway spruce plantations. However, the effects on planted and established young spruces is yet to be described. The classical way to gather data on bud flush is manual assessment. As an alternative, Remote Sensing technology has been proven feasible to score bud flush in conifers with the advantage of scoring more trees in shorter time with lesser resources.

This study aims to provide data for the bud flush of young spruces derived from multispectral high-resolution drone images. The genotype of the spruces is known at individual tree level. The data was collected during spring 2023 and data collection will be repeated in the following years. Bud flush is estimated from the spectral values of the tree crowns using manual assessment of the bud flush in a subset of the trees as training data. To ensure capturing a high level of variation in bud flush phases, images were taken before the vegetation period and up to twice a week during the period with most rapid bud flush. In a second step, multispectral high-resolution images will be used to assess the damage on the new shoots later in the vegetation period. During the session, the results from the first sampling season will be shown and discussed in relation to the genetic variation and the risk of damage.

Breeding Against Spring Frost? - Heritability of Spring Frost Tolerance in Norway Spruce (Picea abies)

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Climate change is challenging the traditional breeding objectives, since future tree species will face more diverse abiotic and biotic pressures that require higher plasticity and adaptive potential. The boreal forest biome is predicted to shift towards an earlier start of the thermal growth season by the end of this century. Rising temperature is advancing the bud break and dormancy release in coniferous species, thereby increasing the risk of frost damage in newly developed buds due to early frost backlashes. Norway spruce, a dominant boreal conifer species, has high ecological and economical importance in Nordic countries, but is also vulnerable for early frost events.

The aim of our study was to investigate the heritability of spring frost tolerance in Norway spruce and whether the variation of frost tolerance in the Swedish Norway spruce breeding population could be used for genomic selection. To that end, the correlation between frost tolerance and vitality, height and timing of budburst were analysed.The spring frost tolerance was assessed in 3 consecutive springs in young Norway spruce stance in Northern Sweden. Freezing tolerance was measured by an electrolyte leakage assay of newly emerged buds from 38 Norway spruce families. Spring frost tolerance, bud burst timing, height and vitality were used as traits in the narrow-sense heritability and genetic correlation analyses. Finally, breeding values of the field population are predicted with a genomic selection model.

Our narrow-sense heritability estimations indicate variation of spring frost tolerance (0.35) in the Swedish Norway spruce population. Frost tolerance also showed moderately negative correlation (-0.568) to budburst timing and low negative correlation (-0.262) to vitality. Our study suggests that the Swedish Norway spruce breeding population accommodate variation of spring frost tolerance in newly developed buds. We believe that frost tolerance trait could be incorporated in the Norway spruce breeding programs to improve frost tolerance of the Norway spruce seedlings especially in the frost prone areas.

Development of a genomic selection method for silver birch - a commercially important boreal forest tree species

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract:
Due to changing climate and rapidly northward moving ecological zones, broadleaved hardwood species are becoming ever more economically and ecologically important for boreal forests. To facilitate the adaptation of forests to climate change, we will need detailed knowledge about the mechanisms controlling carbon sequestration in hardwood biomass.

For an enhanced carbon sink effect, we are developing a genomic selection method for silver birch (Betula pendula) breeding. Birch is among the most fast-growing, widely distributed and economically important boreal hardwood trees. Additionally, under greenhouse conditions, flowering can be induced in trees as young as two years of age. The shortened generation time raises the possibility of speed breeding: growing several early flowering generations in succession with genomic selection, allowing faster genetic and phenotypic change. Our program will speed up breeding by selecting the best trees for breeding crosses through early phenotyping of trees and apply the long-term (10–20 years of growth) field testing on the trees only a only after several successive generational crosses.

Many quantitative traits are expected to be under stabilizing selection: phenotypes differing too much from the optimal range are selected against. Therefore, we expect effect alleles of the same sign to be negatively correlated. Such prior assumption influences the genetic relationship matrix used in genomic prediction - typically such a matrix implicitly assumes the random effect sizes are independent of the linkage structure. The tendency of linked alleles having the opposite signs can be included as a new parameter and estimated along with the variance components.
We compare a number of genomic methods on their ability to predict tree growth from the sequence data, as measured by the predictive ability. To supplement the classic BLUP, we introduce a matrix parameter describing the tendency of alleles with opposite signs to be linked.

Development of Drought Tolerant Indigenous Trees for Enhances Productivity and Adaption to Climate Change in Kenya

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Drylands of the world-over are more affected by impacts of climate change. In Kenya, arid and semi-arid lands (ASALs) occupy over 80% of the land area and are increasingly being recognized as the new frontier for afforestation programs. National Forestry Program (NFP) and Kenya's Strategy for Achievement of 30% tree cover by 2032 have recognized drylands as key targets area for afforestation using tree species such as *Acacia tortilis* and *Melia volkensii*. Acacia is widespread in ASALs of Africa and the Middle East and has been overexploited for charcoal production. Similarly, Melia, an important endemic and high valued tree species growing in the ASALs of eastern Africa has been over-harvested for timber. The two species have been are targeted for breeding. Projects on 'Development of Drought tolerant Trees for Adaption to Climate Change in Drylands of Kenya' and 'Capacity Development Project for Sustainable Forest Management in Kenya' are a pioneer multidisciplinary initiatives implemented from 2012 to 2021whose overall goals were to promote quality plantations of indigenous species in the ASALs through: breeding drought tolerant trees for increased productivity and adaptation to climate change; development of quality seed/seedlings supply system; and creating awareness of drylands forestry using improved drought tolerant germplasm. The project's had four main synergetic discipline-oriented components: (a) Molecular component to determine inter and intra population genetic variation; (b) Tree breeding component to select Candidate Plus Trees (CPTs), establishing seed orchards; seed stands and progeny trials for continuous improvement and phenology studies (c) Drought tolerance component to develop drought tolerance indices and (d) Extension component through farmer forestry field schools to upscale adoption of improved germplasm in target Counties and establishment of improved seed/seedlings supply system. 100 CPTs each of Melia and Acacia were selected from various populations by considering qualitative and quantitative traits. To harness the outputs from the work, breeding toward second generation improvement have continued through a Project on 'Strengthening Community Resilience to Climate Change through Landscape Restoration and Sustainable Forest Management in Kenya' since 2022. The findings that has been obtained over the years are useful for guiding tree breeding and forest restoration programs.

Development of genomic selection model in Norway spruce based on genomic and epigenomic markers associated with wood quality and disease resistance

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: The genetic and epigenetic basis of wood development and disease resistance to the pathogenic fungus *Heterobasidium parviporum* have been studied in Norway spruce (*Picea abies* L. Karst.) using 620 trees, including 218 half-siblings from 17 families (currently used in breeding programs) and 402 seedlings presumably representing unrelated trees from natural stands in Finland. They were genotyped via exome-capture sequencing using both untreated and treated with bisulfite. After filtering based on sequencing depth, quality, and missing data, 79,293 high quality single nucleotide polymorphisms (SNPs) were identified and used for genome-wide association studies (GWAS) that included phenotypic traits related to growth and disease resistance, taking also into account the confounding effects of genetic structure and kinship in the mixed linear model (MLM). In total, 472 SNPs were associated with height, while 2,225 and 2,146 SNPs were associated with the length/width ratio of necrosis in phloem and xylem measured after infection with *H. parviporum*, respectively. The same individuals were also sequenced and epigenotyped after treating the targeted exome with bisulfite (so-called targeted-bisulfite sequencing). In total, 21,161 single methylation variants (SMVs) were identified after filtering based on depth and quality. These epigenomic markers were used for epigenome-wide association studies (EWAS) with the same phenotypic traits and resulted in 70 SMVs associated with height, and 172 and 158 SMVs associated with phloem and xylem necrosis, respectively. Both genomic and epigenomic data obtained have been used then for development of a new genomic selection (GS) model following regression model approach to predict breeding values of each individual from the 17 half-sibling families. The model has been then tested and validated by using the 402 individuals from natural populations. The identification of epimarkers emphasizes the role of epigenetic regulation in the expression of the phenotype in Norway spruce, and the importance of the use of both genomic and epigenomic factors for improving our overall understanding of the mechanisms controlling crucial adaptive processes. In addition, this allows the development of more effective strategies for both conservation and breeding programs in tree species.

Does conifers genomic selection need a whole-genome level imputation step? A case study in Norway spruce.

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: In conifer breeding, so far as we know, we usually use a few thousand to a hundred thousand SNPs based on exome capture, genotyping by sequencing (GBS), and SNP array genotyping platforms to study the efficiency of genomic selection. In our study, we want to validate whether imputing the current relatively sparse SNPs to a whole genome-level, based on a species range-wide genome imputation panel, will improve genomic selection. In our current Swedish Norway spruce breeding program, we have re-sequenced more than 1000 range-wide samples and genotyped ca. 600 individuals for each of 20 populations using a 50k SNP array across Sweden. We are planning to build a whole-genome level imputation panel and validate if we could use the imputation panel to improve the efficiency of our genomic selection.

Effect of population structure in genetic evaluation of growth and wood properties in Norway spruce and its implications in breeding programs

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: It is well known that the geographic ranges of tree species have expanded and contracted several times during glacial and interglacial periods. Norway spruce (*Picea abies*) is a dominant conifer species of major economic importance in northern Europe. The recent analysis of genome-wide data revealed demographic movements, followed by secondary contacts, resulted in division of Norway spruce into seven genetic clusters.

A large-scale Norway spruce breeding program initiated in Sweden during the last century. The current breeding populations of Norway spruce in southern Sweden has a heterogenous background, composed of both local and the recently introduced materials from the seven P. *abies* genetic clusters (population structure).

The main objective of this study was to assess effect of population structure as a fixed effect in quantitative genetic evaluation of growth and wood properties, using about 6000 increment-cores collected in two open-pollinated progeny trials of Norway spruce in southern Sweden.

Genetic parameters for growth, Solid- and fibrewood, chemical and resin characteristics as well as genetic correlations among these traits were estimated in five different model scenarios, including:

1. No population
2. All populations
3. Most northern populations
4. Central populations
5. Most southern populations

Narrow-sense heritability (h^2) estimates and genetic gains were highest based on model one, while such estimates decreased significantly in model two, particularly for growth and density related traits. This implies that when the effect of population structure is ignored, the estimated genetic parameters for such traits can be biased, and therefore, the obtained genetic gains are inflated. Similarly, we have observed that additive genetic correlations among traits vary in five tested scenarios. For instance, the unfavourable genetic correlation between density and growth-related traits were higher in northern populations, compared to the southern and central ones.

Overall, findings of our study suggests that population structure and genetic background of breeding materials may have major influence for genetic improvement and delineation of Norway spruce breeding populations as well as selection of trees for industrial purposes.

Genetic background of early flowering in Betula pendula for the successful development of efficient and rapid breeding.

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Information on flowering genetics and flowering variability is important for the development of breeding programs. The importance of these will increase when breeding by means of genomic selection method will be implemented into operational breeding. This study aimed to evaluate the genetic background of early flowering in Betula pendula.

The project aimed to quantify the genetic parameters of early flowering in two genetic progeny trials located in southern Sweden. Both trials were planted in 2014 and consisted of offsprings from 19 full-sib families. The parents of the families came from the elite silver birch population in southern Sweden. There were around 20 - 70 plants per crossing in both trials. During three observation seasons, the occurrence of male and female flowers was registered. The number of flowers was quantified subjectively using a simple four-stage scale from 0 (no flowers) to 3 (many flowers). Height, diameter, and quality traits were also collected.

Nine years after planting, there were on average around 20% of trees having male flowers. In one family, flowering frequency exceeded 50%. The female flowering was much less frequent with an average of less than 10%. Out of the 19 families, only 10 families had an individual with female flower. Flowering frequency was slightly higher in the northernmost experiment and there was a positive correlation of transfer distance (distance between experiment location and parental origin) and male flowers production.

The male flowers started to be produced earlier than females' flowers. There was also a great genetic variation in the ability to produce male and female flowers in early years after planting. Nine-years results also indicate a positive effect of northward transfer on the frequency of trees producing male flowers. There is no such indication for female flower production. These results indicate that flowering ability must be considered in selection to facilitate the performance of crosses in new generations and for the deployment of the results through seed orchards. The indication of positive effect of transfer might be considered when new seed orchards are planned for establishment.

Integrating environmental gradients into forest tree breeding: genomic norms of reaction in maritime pine

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Global warming threatens the productivity of forest plantations. Traits targeted by forest breeding programs are mostly final growth traits of the trees (height, circumference). However, such phenotypes are very integrative: the final growth traits are the results of multiple years of growth in interaction with an evolving environment. To tackle these interactions and to propose new breeding strategies ensuring resilience of forest trees in the coming years, individual genomic reaction norms were modelled. Random regression models were used to fit wood ring series, reflecting the longitudinal phenotypic plasticity of tree growth, according to various environmental gradients. The predictive performance of the models was considered to select the most relevant environmental gradient, namely a gradient derived from an ecophysiological model and combining trunk water potential and temperature. Even if the genotype ranking was preserved over most of the environmental gradient, strong genotype x environment interactions were detected in the extreme unfavorable part of the gradient, which includes environmental conditions that are very likely to increase in the future. Combining genomic information and longitudinal data allowed to predict growth in unobserved environments: considering an equivalent phenotyping effort, the cross-validation scenarios led to predictive performances ranging from 0.25 to 0.59 highlighting the importance of phenotypic data allocation. Genomic reaction norms are useful for the characterization and prediction of the function of genetic parameters and facilitate breeding in a climate change context.

Is gridling a method to increase seed production in silver birch seed orchards? - Effect of girdling on male and female flower formation.

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Silver birch is considered a species that might mitigate problems that have occurred in the silviculture of coniferous species in Sweden. Thanks to the breeding program initiated in the late 1980's current birches are producing from 15% to 20% more volume and are of significantly better quality. Currently, the main obstacle to using more birch in operation forestry is the access to well-performing seedlings due to the low production of seeds.

Last years, a decrease in volume of seed production has been observed in Swedish birch seed orchards. In greenhouse seed orchards, the production of seeds and their quality dropped abruptly. In addition, great clonal variability in the setting of flowers and consequently seeds production has been observed. Thus, the higher demand for plants on the market cannot be covered.

The girdling treatment, also called partial ring-barking, is the complete removal of the bark and a portion of the cambium layer from around the circumference of either a branch or trunk. It has been found for other species that girdling can increase the abundance of flowers.

The aim of this project was to evaluate the effect of girdling on flowering abundance in silver birch. The hypothesis in the study was that applying girdling treatments would increase the abundance of flowering on girdled branches.

The experiment has been started in a clonal archive in southern Sweden. Seventeen genotypes with three ramets each were subjected to three girdling treatments removing 25%, 50% and 75% of tree branch circumference. Treatments were applied to branches of similar size. Two branches have been treated on two-time occasions (in mid-May and mid-June). Two branches were considered untreated control. The number of buds, male and female flowers was counted, and branches length and diameter were measured before and after treatments in two following growing seasons to quantify the most optimal girdling regime to increase seeds production of silver birch. Here we present the results after the first observation year.

Landscape breeding: A new paradigm in forest tree management

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: In conventional forest tree breeding, tree selection follows a recurrent scheme with repeated rounds of crossing, testing and selection, the so-called breeding cycle. This is a long process sustained by costly logistical and organizational commitments and constrained by factors such as the experimental size of the test trials, the accuracy of the measurements, and the ability to model individual genetic effects across sufficient environments. The genomic revolution opened the possibility to develop molecular tools to infer accurately the realized proportion of the genome shared among individuals - the pedigree. In conifer trees, this is the bases of an alternative approach to crossing-based conventional breeding, the so-called Breeding without Breeding. Originally, this approach was proposed to circumvent artificial mating, but it remained constrained by the need for establishing structured open-pollinated (OP) trials at a limited number of environments. Recent developments in remote sensing technology offer high-throughput, accurate, and spatially explicit means for tree phenotyping that can operate at large landscape scales and thus account for climatic variables, water, and soil data, among other variables to model ecological or environmental zones. Furthermore, remote sensing phenotyping also allows assessing a myriad of tree properties otherwise difficult or impossible.

We havee developed a digitized tree breeding strategy that overcomes the limitations of conventional breeding. Landscape Breeding aims to accelerate forest tree improvement by operating directly on commercial forests and accounting for climatic and environmental variables. Norway spruce, the most economically important species in Sweden and model system in conifer genomics, is our study case.

New method to study drought stress in Norway spruce seedlings using high-throughput plant phenotyping integrated with metabolomics and transcriptomics

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Drought stress is a major constraint limiting the distribution of Norway spruce (*Picea abies* (L.) H. Karst.). Provenance trials, a common approach to assess adaptive variation among populations, are limited due to the finite number of sites and seed sources involved, as well as their labour-intensive nature. Here, we present a novel multi-sensor high-throughput plant phenotyping (HTPP) approach and protocol to assess the drought stress adaptation potential of Norway spruce provenances at the most critical life stage of the tree, the seedling stage. Two climatically contrasting Norway spruce provenances were studied by HTPP while exposed to 21 days of drought stress under controlled conditions. Multivariate analyses of data derived from the HTPP platform show that the HTPP approach allows the estimation of more than 50 phenotypic traits (chlorophyll fluorescence, RGB and hyperspectral related traits) to differentiate early and late drought stress responses between populations. We further linked the phenotypic data to needle metabolomics, transcriptomics and stem anatomy. Consistent with the phenotypic results, we observed significant metabolic changes towards the later stages of drought stress (e.g. increase in zeaxanthin associated with photoprotection via non-photochemical quenching), with each provenance exhibiting a distinct metabolic signature under both well-watered and drought-stressed conditions. Analysis of the mRNA-Seq data revealed over 4000 differentially expressed genes, the majority of which were shared between the two populations. A small proportion of genes were provenance-specific, consistent with the differences observed between the two provenances in the phenomics and metabolomics datasets. Finally, stem anatomical differences were identified between drought-stressed seedlings and control plants, and the proportion of specific stem tissues such as xylem was differentially affected on the studied provenances, which may have implications for future wood production. In conclusion, our study highlights the relevance of the HTPP approach and introduces a standardised HTPP protocol for evaluating drought stress adaptation in Norway spruce seedlings, which can potentially be extended to other tree species. By integrating different -omics approaches, we have gained a deeper insight into the mechanistic basis driving phenotypic responses to drought stress, providing a basis for further research and potential strategies to mitigate the adverse effects of drought.

Norway spruce somatic embryogenesis in Finland to enhance bioeconomy using genetically wide material

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Somatic embryogenesis (SE) has been recognized to have vast potential to produce improved reforestation material. Yet only a few commercial applications have been reported in conifers. Recent developments in Norway spruce (*Picea abies* (L.) H. Karst.) SE in Finland e.g. high initiations rates, high recovery from cryopreservation, short in vitro germination have developed into a SE pipeline, which can be applied to genetically wide materials. This development has led to construction of SE technology platform and research greenhouse spaces located in Savonlinna.

Current cryostorage at Luke exceeds 5000 Norway spruce genotypes from elite crossings of tree breeding program. Luke registered the first SE derived Norway spruce basic material for forestry in 2017. The basic material (named as Laukansaari) includes 12 full-sib families of progeny tested plus trees. Propagation pilots have been carried out since 2018 (over 170 000 germinants sold). In a Public Private Partnership (2021-2023) project realized with commercial partners, two more basic materials are registered, SE knowhow is transferred to partners, and selection based on root rot resistance marker PaLAR3 is applied in SE. No trade-off between resistance locus PaLAR3B and somatic embryo production ability has been observed.

Field tests of SE material have been established and they are maturing, and the first preliminary results are available after growing season 2023. To decrease production cost of somatic plants, we have developed a robot prototype (patent pending) for in vitro germination in collaboration with South-Eastern Finland University of Applied Sciences. Robot selects, classifies, orients and plates good embryos to germination, stacks, and changes full plates to empty ones.

Population Structure and Genetic Diversity in Eucalyptus pellita Based on SNP Markers

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Context:
At present, there is little research on molecular breeding of E. pellita. With the development of technology, whole genome resequencing based on single nucleotide polymorphism (SNP) markers to improve related traits of E. pellita is an important direction of selective breeding.
Aims:
The aim of this study was to develop SNP markers for E. pellita genome, and to identify its population structure, genetic diversity and population differentiation.
Methods:
In this study, the genetic diversity of 1st generation 196 E. pellita families from 23 geographically defined was assessed using 1,677,732 SNP markers identified by whole genome resequencing.
Results:
SNP annotation showed that the ratio of non-synonymous to synonymous coding mutations was 0.83. Principal component analysis (PCA), phylogenetic tree and population structure analysis permitted the families to be categorized into three groups. Genetic relationship analysis showed that IDN was closely related to PNG. Genetic diversity analysis showed that the mean values of He, PIC, I and H were 0.2502, 0.2027, 0.3815 and 0.2680, respectively. The results of genetic differentiation (Fst) showed that PNG region was divided into two groups (PNG1 and PNG2), the Fst (0.172) between QLD and PNG2 region was higher than QLD and PNG1, and the Fst (0.024) between IDN and PNG1 is smaller than IDN and PNG2.
Conclusion：
This study has a certain reference value for genetic identification, population origin, germplasm preservation and breeding of E. pellita, and also provides a basis for subsequent association analysis to explore excellent alleles and introduction.

Progress of genomic selection in Swedish Norway spruce and Scots pine national breeding program

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Since the first publication of genomic selection concept in trees in 2010/11, genomic selection using cross-validation were studied in a dozen of commercially important conifer species. SNPs from low density array, exome sequencing, GBS and more recently from medium-density SNP-array were used for genomic selection. Also genomic selection from cross-validation were effective, with an average efficiency about 90%, relative to phenotype selection. The genomic selection across breeding populations and across generations are much lower based on simulation and real data. By developing two 50K SNP-arrays using whole genome re-sequencing in Norway spruce and Scots pine, we studied genomic selection (1) across generations using models based on parental population (F1) only for selection at F2 and F3 populations, (2) across breeding populations with or without genetic connections between them and (3) using GWAS to enhance genomic selection efficiency. Possible causes of low cross-population and cross-generation genomic selection efficiency are studied and the proposed mitigation strategies including re-sequencing of parental population are presented. Several case studies of genomic selection in Norway spruce and Scots pine are presented.

Spatial transcriptomics reveals developmental patterns in the tissues of vegetative and reproductive buds of Norway spruce.

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: Vegetative and reproductive development in Norway spruce (*Picea abies*) is difficult to study. Trees are tall, have long juvenile periods, and infrequently produce female cones. Additionally, there is a lack of genetic studies and a massive, 20Gbp, and not thoroughly annotated genome. To best manage our forestry resources and seed orchards, a systematic understanding of development is key to ensure productivity, biodiversity, and climate change preparedness. We performed a spatial transcriptomic experiment on early developing buds (representing female cones, vegetative growth, and a naturally occurring, early female cone producing mutant) at 3 time points in the fall to investigate bud development. The buds ranged in size from meristems to fully formed buds with recognizable tissues and organs.

With spatial transcriptomics, thin tissue sections are taken from each bud and are placed on a specially designed microscope slide to collect and record the location of each mRNA molecule within a section. When the transcriptome from the sections is clustered, the visually identifiable tissue patterns also appear in the clusters. We grouped the clusters into 4 tissue domains: pith, vascular, lateral organ primordia, and lateral organ differentiated. The top genes in each tissue domain are characteristic of the tissue. For example, upregulated genes in vascular tissues are involved in the transport of sugars, hormones, and water. Examination of genes expressed in female organs revealed many genes related to female development, like the recently published *PaSPL1* transcription factor (TF). This TF helps regulate the reproductive shift and cone-setting in Norway spruce and is only expressed in female buds and female parts of mutant buds. Some genes have a temporal pattern, like those linked to cold acclimation being mainly expressed late in the fall. Others have a strong spatial pattern, like the YABBY TFs, that are expressed in lateral organ tissue domains and regulate abaxial-adaxial development. In order to easily visualize these expression patterns, a shiny app was developed that shows exactly where and when in each bud section a specific gene is expressed.

Speed-breeding – Accelerated breeding for improved hardwood growth and quality

T3.14 Forest Tree Breeding in the Context of Climate Change and Bioeconomy Development

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Abstract: It is difficult to exaggerate the role of trees and forests in the mitigation of climate change:
trees are elementary both as essential long-term carbon sink and as raw material for the bioeconomy. By accelerating tree breeding, the aim of our project is to both mitigate the effects of climate change and facilitate the adaptation to them.
By developing an accelerated breeding program for silver birch (Betula pendula), one of the most fast-growing, widely distributed, and economically important boreal broadleaved tree species, we will facilitate the production of improved hardwood genotypes for silviculture purposes. Based on the fact that silver birch flowering can be accelerated under greenhouse conditions, and already 2-year-old seedlings can be induced to flower, our program will speed up breeding by selecting the best trees for breeding crosses through early phenotyping of 1-year-old trees and apply the long-term (10-20 years of growth) field testing on the trees only a only after several successive generational crosses. ‘
Since we are working on Finland’s current silver birch breeding population, our results can be directly implemented in breeding and silviculture of silver birch. The best speed-bred genotypes can be directly incorporated into an ongoing traditional birch breeding program. Furthermore, they can also be clonally micropropagated for silviculture purposes. Our speed-breeding project is complementary to an ongoing project exploring the genetic basis of carbon sequestration in silver birch, with the aim to develop a genomic prediction method for genome-assisted tree breeding.

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

Assessing the Land Cover from the Canadian Wetland Inventory Map (CWIM) Using Field Data from Eastern and Central Canada

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Mapping the land cover, including forests and wetlands, for a vast country like Canada is a big challenge. One option is using satellite images. A wetland map was produced by applying the Random Forest classifier to Sentinel-1 and-2 imagery in Google Earth Engine. The resulting map is known as the 10 m Canadian wetland inventory map (CWIM). This paper aims to assess the accuracy of the map by comparing the map with ground-truth data collected from ground-truth sites of four study areas in Canada. These areas include 951 sites in New Brunswick, 309 sites in Nova Scotia, 1088 sites in northern Québec and 848 sites in northern Ontario. For each study area, the map accuracy was computed regarding validation accuracies. The overall validation accuracy of the CWIM was between 41% to 55%. We also compared the area of each class to those extracted from previous regional maps. In all four regions, the area of bogs was underestimated, but the area of fens was overestimated. The area of swamps was underestimated in the New Brunswick and Québec areas but overestimated in the two other regions. The marsh areas were underestimated in the Nova Scotia area but overestimated elsewhere. The area of the Water class was underestimated in the Northern Ontario and Northern Québec areas but overestimated in the two other regions. We suggest that the misclassifications occurring with the CWIM could be reduced by: 1. increasing the amount of geographically-representative ground-truth data; 2. defining more wetland classes based on spectral characteristics; 3. including digital elevation models and associated metrics to the classification; 4. including satellite imagery acquired at different water levels and/or different seasons, and; 5. using imagery-derived vegetation indices that do not have spectral saturation such as NDVI. Given the limitations of the CWIM, caution should be used when applying this map to regional applications that require high accuracy

Choice of CO2 equivalent metrics influences risk of CH4 emissions associated with wetland restoration

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Several international climate agreements emphasize the potential of natural ecosystems - including wetlands - to remove CO_2 from the atmosphere. However, wetlands play a dual role in the radiative forcing of climate, affecting the atmospheric burden of both CO_2 and CH_4. The cooling effect of wetland CO_2 sequestration can be offset by wetland CH_4 emissions. To assess the climate footprint of wetlands on a comparable basis, the wetland GHG fluxes need to be normalized to CO_2 equivalent (eq) value using CO_2-eq metrics. The reporting of CO_2-eq GHG fluxes has been standardized using the Global Warming Potential (GWP) in the policy world and the sustained global warming potential (SGWP) within the wetland community. However, CO_2-eq metrics that equate GHG fluxes using a single factor can be misleading as the climate impact mechanisms of CO_2 and CH_4 differ markedly. An alternative is the dynamic GWP* that captures the effects of changes in CH_4 fluxes instead of the magnitude of CH_4. We used the GHG perturbation model to simulate wetland radiative forcing and temperature change associated with wetland state conversion over 100 and 500 years based on a synthesis of published carbon fluxes values. We then calculated GWP, SGWP, and GWP* CO_2-eq GHG fluxes. The dynamic GWP* captured initial cooling and warming period associated with drainage and restoration, respectively, while the static S/GWP did not. Intact wetlands with low methane fluxes continue to serve as carbon sinks and deliver cooling effect on the climate. Draining wetlands with low methane flux will shift wetland systems to carbon sources, resulting in consistent warming impact. Conversely, draining wetlands with medium or high methane fluxes had an initial cooling effect given reduced CH_4 emissions, followed by a sustained warming effect. The climate benefits of restored wetlands depended on their ambient CH_4 emissions, with the climate benefit lag period longer with higher CH_4 emissions. Based on our radiative forcing model and GWP*, we argue that protecting and restoring wetlands are important nature-based climate solutions (NbCS), and that warnings to not restore wetlands due to the risk of greater CH_4 emissions are unjustified in the context of their role as NbCS.

Climate benefits of rewetting forest wetlands recovers slowly over decades and is lowered by groundwater fluctuations

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Rewetting of drained forest plantations on organic soils is crucial for restoring biodiversity in forests worldwide and is also seen as an effective climate mitigation strategy. However, there is a lack of comparative analyses on post-rewetting greenhouse gas emissions and field measurements of the actual effects of rewetting on gas exchange. Additionally, the assumption that rewetting will immediately restore the pre-drainage functionality of organic soil is questionable, given the significant alterations in soil hydrology, biogeochemistry, and microbial dynamics caused by drainage.

Here, we present a quantitative analysis of literature data on methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2) net fluxes from rewetted fen soils in temperate forest wetlands in Europe and North America. Secondly, we provide field measurements of greenhouse gas fluxes and hydrology from a rewetted site in Gribskov, Denmark's third-largest forest.

The literature data analysis reviews current knowledge in the field and establishes relationships between soil hydrology metrics and emissions of CO_2, CH_4, and N_2O from drained and rewetted forest peat soils. The analysis reveals that rewetting reduces overall emissions, with CO_2 being the primary driver of soil greenhouse gas budget before and after rewetting, followed by CH_4. The literature data also suggest that emission reductions occur gradually over decades, indicating that beneficial climate effects cannot be expected immediately after rewetting.

Our field measurements investigate the relationship between short-term (<1 year) hydrological and climate variability after rewetting and soil fluxes of CO_2, CH_4, and N_2O. Using a novel automated system called SkyLine, we collected over 22,000 flux measurements for each gas over a three-year period, coupled with groundwater levels and climate variables. The data clearly demonstrates that hydrological and climatic variability plays a crucial role in determining emissions of all gases post-rewetting. Thus, different relations between CO_2/CH_4 and groundwater levels for cold and warm periods and under specific hydrological conditions, N_2O emissions may also become significant in rewetted peat soils.

In summary, our data emphasize the importance of considering different temporal scales of greenhouse gas fluxes in rewetted organic forest soils when assessing the climate mitigation potential of rewetting and to derive reliable emission factors.

Designing nature-based solutions for ecosystem services: a decision support system for forests and wetlands in the Brenta river area (Italy)

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: The assessment of environmental and resource costs (ERC) associated with integrated water management systems is mandated by the European Union (EU) Water Framework Directive, with the aim of identifying effective measures to reduce, mitigate, and compensate for these costs. Nature-based solutions (NBS), including forests and wetlands, are increasingly recognized as cost-effective approaches to achieving water-related targets while providing additional benefits such as biodiversity enhancement, carbon sequestration, and recreation opportunities.

This paper, developed within Life Brenta 2030 project, focuses on the case study of the Brenta river area (Northern Italy), supplying approximately 35.5 million m^3/year of drinking water, primarily from underground water. The middle course of the river falls within the EU Natura 2000 Network of protection areas and faces challenges arising from intensive farming practices (irrigated crops and livestock) and other economic activities, as well as recreational practices, resulting in trade-offs between water and nature resource management, and socioeconomic needs.

To address ERC associated with water management, a set of NBS has been preliminarily identified through collaboration with local experts and stakeholders. The identified NBS - namely wetlands, forest infiltration areas, and transitioning to organic and conservation farming practices - aim to improve water table recharge and water quality while providing additional ecosystem services such as carbon sequestration and biodiversity conservation.

To assess the suitability, effectiveness, and efficiency of the proposed NBS, an integrated approach is adopted. A decision-support system is developed, considering the targeted challenges, expected outcomes, and budget constraints to identify the optimal combination of solutions. The approach combines an extensive literature review of the targeted NBS, the development of suitability maps based on a spatial analysis of biophysical and socioeconomic features within the case study area, and a cost-benefit analysis applied to various scenarios characterized by different levels of NBS blending.

Our research aims to contribute to the advancement of knowledge in the field of NBS for integrated water management, providing policymakers, scientists, and practitioners with practical approaches and tools to support the selection of NBS. Furthermore, it contributes to global and regional targets outlined in the UN Agenda 2030 and the EU Nature Restoration Law.

Evaluating the GHG balances of drained and restored peatland forests in boreal Sweden

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Rewetting of drained peatland forests potentially reduces carbon dioxide (CO_2) emissions but also re-establishes the emission of methane (CH_4), thus the impact of rewetting on the net greenhouse gas and carbon balance remains uncertain. In this study, we compared fluxes of CO_2 and CH_4 based on eddy covariance measurements for a drained nutrient-poor peatland forest and a nearby rewetted peatland in boreal Sweden for two years after rewetting. The rewetted site was a net carbon source to the atmosphere (86 ± 5 g m^{-2} yr^{-1}) for both years, relative to the drained forest which was a net carbon sink (-98 ± 20 g m^{-2} yr^{-1}). The carbon budget was dominated by CO_2 flux in both rewetted (NEE = 71 ± 4 g m^{-2} yr^{-1}) and drained forest (NEE = -167 ± 30 g m^{-2} yr^{-1}) areas. The CO_2 component fluxes of ecosystem respiration and vegetation uptake (GPP) was 65% and 79% lower at the rewetted site than in the drained forest. In the second year after rewetting, the GPP increases by 26% in response to vegetation recovery, resulting in a 47% smaller net source of CO_2 from the site. While CH_4 emission remained small (< 0.80 g m^{-2} yr^{-1}) at the drained forest for both years, it increased substantially in the rewetted site from the first (2.8 ± 0.1 g m^{-2} yr^{-1}) to the second year (4.3 ± 0.2 g m^{-2} yr^{-1}) after rewetting.. Overall, our study highlights that rewetting of drained nutrient-poor peatland forests may considerably increase GHG and C emissions during the initial years. However, long-term observations under various site conditions are warranted to better understand such effects on the GHG balance.

Guiding restoration of drained peat soils aiming for minimum GHG-emissions

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate
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Abstract: Wet ecosystems have over millennia accumulated carbon as peat due to anaerobic conditions. In the recent past (c. 150 years), Swedish mires and swamp forest ecosystems have been drained for agriculture and forestry reasons. After drainage soil decomposition increases releasing CO_2 as well as N_2O, where these soils contribute 1/5 of the Swedish greenhouse gas emissions (GHG). Emissions can be avoided by rewetting, and the soil may again become a carbon sink. However, there is a risk of large CH_4 emissions from rewetted peat soils which may have negative climatic effects in the short term. We have compiled measurement data into emission factors in a guidebook, written in Swedish, to guide management and restoration into different low GHG options. We have also identified the land categories where rewetting is critical for climate mitigation purposes. These are:

- Agricultural organic soils
- Forest on drained peat in temperate climate

Aiming for minimum GHG emissions the soil water level should preferably be aimed at a water level between 5 to 30 cm below the soil surface, avoiding visible water due to a risk of CH_4. It may be challenging to reach a steady high water level through rewetting, especially if the land is forested. Besides ditch blocking, thinning or removal of all trees is often needed to be able to reach a preferred water level. Swamp forests are however possible if enough water is added laterally. Depending on the site conditions, different land use and ecosystems may follow upon restoration, like;

- Grassland
- Wet meadow
- Fen
- Swamp forest

In an expected drier climate, farmers could be persuaded to rewet soils if able to continue grass production, with the added benefit of reducing drought stress in the landscape. Rewetting is also on the political agenda, why we in the guidebook show how decisions to rewet certain land categories may impact the radiative forcing from managed peatlands over the next 100 years.

Impact of rewetting on the carbon balance of a drained nutrient-poor peatland forest in Northern Sweden

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Natural peatlands represent a small but important long-term carbon sink. For forest management approximately 1.5 to 2.0 million hectares in Sweden were drained over the past century. The Nordic countries have therefore identified peatland restoration as part of its strategy to reduce greenhouse gas (GHG) emissions in the land use sector. However, while peatland restoration may lead to reductions in CO_2 emissions from drained peatlands, rewetted peatlands show initially higher CH_4 emissions. Most empirical evidence in the boreal zone was obtained from sites in Finland, while data is lacking in Sweden. In our study, we investigate the spatial variability of GHG exchange before and after peatland rewetting, determine the biogeochemical factors that govern these variations and examine the overall impact of rewetting on the GHG balance of a drained peatland forest in boreal Sweden. We use the manual closed-chamber method to measure the soil-atmosphere fluxes of CO_2 and CH_4 along six transects at the Trollberget rewetted peatland forest near Vindeln, Sweden. The rewetting actions at the site were carried out in November 2020 and a drained section has been kept as control near the outlet of the mire. We observe higher CH_4 emissions and lower CO_2 emissions compared to drained conditions, however, no significant change in the net soil-atmosphere C exchange within the initial years following rewetting.

Inland Freshwater Wetlands as a Nature-based Solutions (NbS) to Mitigate Global Climate Change: Opportunities, Challenges and Way Forward

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Reducing or eliminating human-caused emissions of carbon dioxide is fundamentally required. This will help mitigate climate-related risks and keep the increase in global mean surface temperature to less than 2 degrees Celsius. The sequestration of carbon by natural ecosystems is an emerging and cost-effective Nature-based Solutions (NbS) that can help accomplish the goal of carbon neutrality and minimize the annual additions of atmospheric carbon. Over the course of the past two decades, a wide range of colour-based descriptors has emerged as a means of characterizing the one-of-a-kind qualities, specialized roles, and distribution of organic carbon. The inland freshwater wetlands hold a large amount of stored carbon that is very significant to address the global phenomena of climate change. Here, we performed a systematic review-based analysis of inland freshwater wetlands in order to highlight the status of stored carbon and its potential role in mitigating global climate change. We estimated that the global carbon storage from major inland freshwater wetland ecosystems is approximately 519 Pg C. Significant amounts of carbon stored in peatlands, wetlands, and natural freshwater marshes are 465.1, 40.8, and 13.1 Pg, respectively. At the same time, these ecosystems are one of the major sources of natural greenhouse gas (GHG) emissions like methane, carbon dioxide and nitrous oxide if not properly managed. Along with it, the loss of areal extent at an alarming rate is also a thrust issue that needs to be addressed by restoring and developing inland wetland ecosystems. Therefore, these natural ecosystems have a huge potential to be NbS under the proper management conditions.

Moist humus forms and the soil water balance of forest ecosystems in Northwestern Germany

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: The indicator function of humus forms can make an important contribution to the further development of monitoring methods for the evaluation of soil ecological properties in moist forest stands. In the BioFeuchtHumus project, the moist humus forms (aerohydromorphic humus forms) are considered in particular. These occur in mixed oak forests with the soil type Stagnosol in the lowlands of Northwestern Germany. Moist humus forms are particularly sensitive to climate change due to their dependence on precipitation and evapotranspiration. In the BioFeuchtHumus project, measurements of soil water tension and temperature are carried out directly at the boundary of mineral soil and organic horizons in the selected forest areas in the lowlands in order to record the influence of water in the organic horizons. For this purpose, 56 study sites were selected, and soil sensors (Tensiomarks) were installed to measure the soil water tension at 8 microsites in three different depths at each site.

The results of the soil water tension support the findings of the morphological classification of the moist humus forms which occur at the study sites. Typically, it also becomes apparent that soil water tension fluctuates over the course of the year. Especially in the winter months, the sites are waterlogged up to the organic layer (pF = 0). In the summer months of August and September, the sites reach pF values of >4.2.

Special classification features typical for moist humus forms are identified. Additionally, the correlations between humus forms and the soil parameters pH, C_{org}, N_t are important to characterize moist forest stands in Northwestern Germany. Further, the expected effects of climate change on the soil water balance and on the distribution patterns of moist humus forms can be better predicted. This will also provide information on the future functionality of today's moist forest ecosystems, which is of great importance for forestry practice with regard to necessary and sensible adaptation measures to climate change.

New AI maps as decision support tools for multifunctional management of forested wetlands

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Understanding how to manage the 1.2 million km of Swedish ditches dug to drain forests to increase their productivity is one of the biggest challenges facing forest managers. Here, we apply two recently AI-developed maps; a detailed peat map developed with machine learning and a ditch map developed using deep learning to better understand the effect of ditching on the entire Swedish landscape. These maps were based on high-resolution (1-2 m) digital elevation models generated from aerial laser scanning and surpassed the quality of previous maps. The new peat map had a recall of 80 % compared to the previously available map of peat in Sweden (70%). Furthermore, we automatically mapped 82% of the ditch networks, in comparison to 9% on current topographic maps. Combining the new maps with field data from the National Forest Inventory we found 4 126 sites within 100 m from a ditch. This allowed us to investigate the effect of the historical ditching of forested wetlands and how drainage has affected soil properties, tree stands and plant diversity across Sweden. A recent meta-analysis found that the water table drawdown of a ditch decreases exponentially with distance from the ditch. Based on this, we hypothesized that soil properties and vegetation around ditch networks would also change exponentially with distance to the ditch. In short; on drained wetlands bulk density, N, pH, and Al increases while C:N-ratio, C, K, Mg, and Mn decreased towards ditches. For trees; average height, basal area, total volume, birch volume, total growth, spruce growth, and birch growth increased towards ditches. We found a decrease in wetland mosses and an increase in forest mosses and broad-leafed grasses toward ditches, however, the Shannon-Hill diversity index was higher towards ditches. We are now developing a decision support system for multiple purposes (timber, hydrology, biodiversity).

Regional scale effects of wetland restoration on aquatic carbon

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Wetland restoration (WR) is currently made in Sweden to reduce carbon dioxide emissions, improve biodiversity, and mitigate hydrological floods and droughts. However, limited information exists regarding the effects of WR on other ecosystem services such as aquatic carbon export. An emerging issue from a water quality perspective is the brownification of many surface waters caused by increasing dissolved organic carbon (DOC) concentrations. Also, stream networks are strong emitters of greenhouse gases (GHG), and where wetlands are a main source for downstream emissions. Literature on WR effects on surface water DOC and GHG is scarce and with divergent results. Hence, science-based knowledge is urgently needed to make well-founded decisions about WR efforts, including an aquatic C perspective. In this study, WR effects on aquatic C have been explored across the forested landscape of Sweden by sampling 33 restored and 33 non-restored wetlands that have historically been drained. The wetlands were selected to cover a large latitudinal gradient as well as differences in nutrient status. Wetland outlets were sampled in spring and autumn 2022 for a full set of water chemistry variables, and with particular focus on DOC and GHG. Independent on season, DOC and GHG concentrations were significantly higher in the outlets of restored than non-restored wetlands, and the difference was especially pronounced in northern Sweden. These results will contribute to improve our understanding on how WR affects the landscape C balance and the quality of surface water resources.

Trade-offs between freshwater biodiversity and the local communities' livelihood: Insights from freshwater ecosystems in Democratic Republic of Congo

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Democratic Republic of Congo (DRC) is among the most diverse countries in the world both biological and culturally. The country holds a large assemblage of biodiversity that includes a multiplicity of habitat types, different fish, mammal, bird and plant species, etc. Multiple habitat types, comprising mountain forests, lowland forest, northern and southern savannahs and lakes and rivers that form freshwaters habitats, provide multiple ecological services that benefit to local communities at different scales and different ways. However, DRC is also among those whose human populations are increasing at an alarming pace. This situation makes it difficult to accommodate both the need for preserving the country's important biodiversity while also addressing human needs, given the country's poverty levels. This presentation focuses on freshwater ecosystems and presents how valuable these are to support the livelihood activities to sustain local economy. Using field examples from the Lake Tumba Landscape (Western DRC), the talk with present some methods that have been applied to bring communities to agree on taking action to preserve not only the freshwater biodiversity but also the essential ecological functions that are beneficial to themselves and the wider community.

Tree dynamics in rewetted genuinely wooded peatlands in Southern- and Central Finland

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: This thesis was a part of the RESPEAT project (PI Kari Minkkinen), which aims to assess the climatic impacts of boreal peatland rewetting. The project is a joint effort by the University of Helsinki and the Finnish Meteorological Institute. I investigated the impact of rewetting on tree mortality in genuinely wooded peatlands, such as swamps and wooded bogs in Finland. I examined the effects of site fertility, tree species and the years since rewetting on tree mortality.

I conducted tree measurements in 14 different rewetted peatland sites. I set up 54 circular sample plots in the 14 sites. I estimated the volume of standing and fallen trees with a diameter greater than 7 cm. The sample plots were placed in genuinely wooded sections of the rewetted peatlands, and their fertility levels were categorized according to the Finnish classification system: herb-rich type (Rhtkg, n=15), *Vaccinium myrtillus* type (Mtkg, n=24), *Vaccinium vitis-idaea* type (Ptkg, n=8), and dwarf-shrub type (Vatkg, n=7).

Based on the results, site type had a statistically significant effect on the proportion of the dead tree volume of the total tree volume. A linear mixed model, controlling for peatland type, estimated the following dead tree volume proportions for different peatland types: Rhtkg 32.8% (standard error ±5.8%), Mtkg 15.9% (±4.7%), Ptkg 10.9% (±7.8%), and Vatkg 7.3% (±8.4%). The number of years since rewetting did not appear to have a cleat effect on the proportion of dead trees, but the sample size was too small to draw conclusions.

Picea abies displayed the highest mortality, especially in herb-rich peatlands, where 49% of spruce volume was dead. In other site types, the proportion of dead spruce was only slightly higher than that of birch (approximately 13%). *Pinus sylvestris* also had the highest proportion of dead tree volume in herb-rich peatlands (22%), and the proportion of dead tree volume decreased gradually with decreasing site fertility, reaching only 8% in dwarf-shrub peatlands. This reduction is probably partly due to the larger total volume of pines in the poorer site types. For *Betula pubescens* the proportion of dead volume was approximately 10% regardless of site type.

Will wetland restoration cause elevated methylmercury in surface waters?

T3.15 Forest Wetlands as Nature Based Solutions for Water, Biodiversity and Climate

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Abstract: Sweden has extensively drained forest wetlands over the last 150 years to improve forest productivity. However, this action had severe environmental consequences, affecting biodiversity, and carbon and water retention. There is a strong societal interest in restoring drained wetlands and reversing the negative impact caused by previous drainage. However, a key question is whether it's possible to fully achieve the many societal and environmental benefits associated with natural wetlands or if restoration efforts will induce other environmental risks.

One potential risk is increased formation of MeHg when water-saturated soils become reduced and thus favorable for specific groups of anaerobic microorganisms capable of methylating Hg. Flooding of soils may also release legacy Hg from soil to water environments, increasing also total Hg (THg) concentrations in water. Earlier studies have shown soil inundations to caused elevated MeHg concentrations in water and aquatic biota, but it is less known where and how wetlands can be restored to reduce the risk of elevated MeHg in water.

Here we include a set of 33 restored wetlands and close-by references, i.e. non-restored drained wetlands, from north to south of Sweden. The sites encompass variation in landscape factors and wetland design factors. Samples were collected in the outlet of the wetlands during seasonal campaigns in spring and autumn of 2022. During one campaign we also sampled runoff water from beaver ponds to be compared with restored wetlands. Two of the restored wetlands were included in the Trollberget Experimental Area (TEA), where sampling was done on a monthly basis 2 years before and 2 years after restoration.

THg concentrations were elevated in restored wetlands compared to references, both in the spatial sampling sites and in the TEA sites. In the TEA sites, the concentrations of THg more than doubled after wetland restoration. The concentrations of MeHg did increase in one of the TEA sites, but not in the spatial sampling sites. Instead, MeHg concentrations increased in the beaver ponds. These results indicate that restoring drained wetlands did not promote the formation of MeHg to the same extent as inundation of other terrestrial soils, including upland soils, by beavers.

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

Bridging the Policy Gap: Enhancing Socially Innovative Forest and Landscape Restoration in Brazil

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: Governments and markets worldwide have grappled with mobilising stakeholders and resources to restore degraded landscapes and foster sustainable livelihoods. This study explores the potential of socially innovative forest and landscape restoration (SIFLR) driven by organised landscape stewardship groups, including local communities, rural workers, women, and youth, to address these challenges. By harnessing social innovations, SIFLR can effectively enhance the resilience of livelihoods and the invaluable contributions of nature to society, benefiting governments, markets, and communities alike. Through a comprehensive content analysis of 64 Brazilian policy documents, we identified a total of 102 policy instruments that possess the potential to support SIFLR initiatives. However, these policies were found to be dispersed within a complex organisational structure, characterised by weakened governance mechanisms and limited experimentation by local actors. This situation underscores the need to bridge the policy gap and strengthen governmental support for SIFLR in Brazil. Based on this analysis, we propose three key strategies to broaden Brazilian government support for SIFLR: 1) Reconnecting politics to existing environmental policies and laws: By aligning political agendas with established environmental frameworks, policymakers can integrate SIFLR objectives into existing policy instruments, fostering coherence and synergy between different levels of governance. 2) Bringing decision-making closer to local needs through landscape governance: Encouraging decentralised decision-making processes that involve local communities, stakeholders, and institutions can enhance the relevance and effectiveness of SIFLR initiatives. Such an approach empowers local actors to address specific landscape challenges and enables context-specific interventions. 3) Establishing a a robust legal framework to enable innovation and science structures, that support local civil society, is crucial for driving social-ecological innovations. This framework should encourage experimentation, knowledge-sharing, and collaboration among diverse stakeholders, fostering adaptive management approaches. By implementing these strategies, Brazilian policymakers can effectively bridge the policy gap, creating an enabling environment that supports and promotes socially innovative approaches to forest and landscape restoration. This comprehensive approach holds great potential for enhancing sustainable livelihoods, bolstering nature's contributions to people, and achieving long-term environmental and socio-economic benefits for Brazil.

China's ecological protection redline: A solution for future socio-ecological adaptation

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: Continuing environmental degradation globally has led to many countries strengthening their systems of protected areas. The 10th Convention on Biological Diversity (CBD) in 2010 set global targets for the areal extent of protected areas (PAs) that were partially met in 2020. However, a more ambitious target is needed to halt ongoing global biodiversity loss. To supplement its growing system of PAs, the Chinese government has adopted a strategy of Ecological Conservation Redlines (ECRs). ECRs are designed to be integrated and scientifically sound, providing a systemic management mechanism. The goal of ECRs is to support the formation of a comprehensive ecological conservation system to ensure effective conservation of the most ecologically valuable and fragile ecosystems. However, ECRs not only involve the area but also the degree of protection, which poses challenges in balancing ecological protection and economic development, overlapping with farmers' living space, ecological vulnerability, and poverty. Therefore, it is necessary to clarify the degree of protection of ECRs, establish clear negative lists for industrial admission, and plan the future development direction and spatial layout of ECRs to connect with the value of ecological products and become a mutually beneficial entity. The implementation of ECRs can provide a valuable example for improving the adaptability of society and ecology in global forest management.

Delivering diversity for resilient restoration outcomes; Opportunities and Innovations

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: Global commitment to forest and landscape restoration are accelerating and attracting more interest from impact investors the private sector and philanthropists. A growing body of work highlights a complete mismatch between national commitments to restoration and capacity on the ground to deliver the billions of seeds, seedlings and planting material that will lead to climate resilient restoration, deliver local benefits, in terms of livelihoods and food security and enhance biodiversity outcomes. I present a summary of recent work to evaluate regional seed systems for native tree genetic resource. I will introduce innovations in species site matching and digital solution to improve the supply chain in genetic resource delivery and incentivize farmers to increase native trees in landscape restoration and agroforestry. Finally, I will discuss how new AI and machine learning can be applied to improve restoration outcomes.

European examples of Forest and Land Restoration innovative approaches to degraded and devastated forests

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: Forest and Landscape Restoration (FLR) interventions are becoming more and more important to speed up and support the recovery process of degraded and devastated forests (e.g. forests damaged by extreme events such as floods, landslides, wildfires, pest and disease outbreaks, windstorms, etc.). FLR interventions can consist in active forest management operations that might benefit from the use of artificial regeneration that relies on Forest Reproductive Material (FRM). The use of proper and adequate FRM and the design of management practices that consider genetic diversity is crucial to support ecosystem restoration while promoting biodiversity and the resilience of the full forest ecosystem.

We worked together with operators managing FLR interventions, some of them partners in an EU Horizon Europe project (OptFORESTS – 101081774), to explore innovative approaches that embed a holistic approach, considering the technical feasibility, ecological effectiveness, economic viability and institutional practicability for improving biodiversity and ecosystem services (ES). European examples of evolution-oriented management of declining forest stands, and forest biodiversity restoration interventions are studied with the aim to identify suitable management options and develop FLR strategies to halt forest decline and biodiversity loss, and to favor forest resilience in a context of changing climate.

Our examples aim to stimulate the attention of scientists, technicians, policy makers and the society, promote the discussion and raise awareness on the role of Forest Genetic Resources (FGR) in facing the challenges of FLR interventions in a context of climate change. Furthermore, we aim at underlining the importance of considering stakeholders as active and essential part of the social-ecological system to be restored.

Expert panel; comments from Robin Chazdon

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: I will contribute to the panel with comments on the previous presentations and lightning talks. I will emphasize areas of my expertise, which include tradeoffs between economic development and ecosystem services and governance aspects in the context of forest and landscape restoration. Nature-based solutions, such as forest and landscape restoration, must consider genetic resources as they influence both social and ecological outcomes of forest restoration. Ensuring the genetic diversity of trees is important for resilience to climate change, but may entail more costs and expertise involved in collecting genetic material and selecting genotypes that perform well in different locations. Involving local communities in seed collection of trees for restoration can support livelihoods and build social and human capital that strengthen restoration efforts.

Exploring forest genetic resources' contribution to forest restoration initiatives in terms of ecosystem services in Europe: a preliminary assessment

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: Aiming to restore 20% of the EU's land areas by 2030, the European Union Nature Restoration Law will require unprecedented efforts by the forest-related community in Europe, including conservation and sustainable use of Forest Genetic Resources (FGR). Forest and Landscape Restoration (FLR) is expected to create better forest landscapes that will provide ecosystem services (ES) flows, benefiting society. Nevertheless, the role of FGR in providing ES in this context and their associated values are still poorly considered within existing research.

To fill this gap, within the framework of the EU-funded Horizon Europe project OptFORESTS, we assess the role and value of FGR diversity in terms of ES supply vis-à-vis the challenges posed by climate change through an extensive literature review and an expert-based approach via Delphi method. FGR can be framed within the most common existing ES classification systems both as a service themselves - provisioning (e.g., seed collection from natural stands, tree selection for breeding, etc.), regulating (e.g., gene pool protection contributing to biodiversity conservation) and cultural (e.g., research and education) - and as a catalyst for additional services spanning various ES categories.

Most of the existing studies on FGR and ES focus on provisioning services, namely on wood production in both quantitative (tree growth and yield) and qualitative terms, thus emphasizing an increased capital value associated with the use of improved FGR. Moreover, the scope of existing European research is mainly concentrated in the Nordic countries (Scandinavia and Finland) and limited to a few economically important species (notably *Pinus sylvestris* L.), while there are no comprehensive studies assessing ES delivered by FGR across different species and regions in Europe.

Our research aims to analyse and systematize findings from existing literature on FGR and ES, and

to complement it via tailored expert-based assessments about the present and expected future value of a selected pool of FGR-related ES, thus investigating the points of view of experts from different fields/domains across Europe.

By doing so, our paper aims to provide policymakers, scientists and practitioners with useful insights supporting the selection of FGR for future FLR projects and initiatives.

Forest landscape restoration governance: social networks and institutional arrangements in three Brazilian watersheds

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: Forest landscape restoration (FLR) is a long-term process that takes place in private and public lands and generates private and common goods and services. In Brazil, several FLR initiatives are being planned and implemented to help the country achieve its Nationally Determined Contributions (NDCs) to the Paris Agreement. In order to achieve its goals, FLR involves multiple stakeholders with different interests and represents a challenge from the governance perspective. In socioecological systems, social actors interact through formal and informal coordinated networks, exchanging information, engaging in social learning, synthetizing and mobilizing knowledge and innovating. The properties of governance networks (size, number and type of connections, structure of the network) can influence the outcomes of governance processes. We used social network analysis to identify key stakeholders, analyze patterns of inter stakeholder connections and the flow of information, knowledge, seeds and seedlings in three Brazilian landscapes undergoing FLR (Paraíba do Sul, Doce, and Itaúnas-São Mateus watersheds). Our goal was to investigate how actors innovate by organizing themselves and cooperating to meet the challenges of FLR governance. Data gathering included a literature and document review, 59 semi-structured interviews with key stakeholders, participatory workshops, and social network mapping. Thirty-eight recent (2000-2019) FLR initiatives were identified, involving more than a hundred different stakeholders in each landscape, organized in networks responsible for FLR planning, project implementation and monitoring. The comparative analysis showed a diversity of governance arrangements in the three landscapes. Critical aspects identified included monitoring, extension services and financing FLR. Common to the three landscapes was the connection between the water management and FLR agendas, and the appropriation of existing institutions designed at the landscape level for water management governance as a strategy to accelerate and upscale forest restoration.

Governance aspects fostering or hindering forest and landscape restoration's social innovation potential

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: Restoring degraded landscapes to either increase the supply of ecosystem service or to secure their provision in the context of climate change has become one of the premises of several policies within the European Union Green Deal initiative. The Nature Restoration Law and its proposed directions is an ambitious one, and thus needs a wide support from not only decision makers, but the public and landowners as well.

Having a broad consensus is one of key elements needed for a policy or a program to be successful, and that is why we have designed a set of participatory workshops to be implemented ahead of different nature restoration actions being implemented in six protected areas of forested landscapes throughout Slovenia. Project ZAGON (Norway Grants) is designed to develop and test innovative governance approaches, where aspects of climate change, provision of ecosystem services, and stakeholder engagement are to be integrated into management of protected areas, with a focus on restoring ecosystems. Those approaches are being implemented in a variety of management documents (plans, guidelines, positions, etc.), which are relevant for each protected area within the project.

Participatory workshops in local environment are proving to be a rich source of information, especially in terms of (1) relevant local challenges related to nature restoration (affecting farming and forestry activities, urbanization and pollution), and (2) potential solutions provided by local stakeholders (drivers of change in ecosystems and ecosystem services, responsibility attached to those drivers, means to control drivers of change, desired future trajectories, etc.). However, involving local people into innovation of governance of protected landscapes is not only providing data, but also strengthens connection among locals and managers of the protected areas and gives people a chance to have their say. Both are essential not only to develop a relevant governance approach reflected in a management plan, but also to build an environment for its successful implementation.

Key lessons learnt is to approach local people with challenges that are relevant for them, to ensure that they feel free to speak out, and to pinpoint how restored nature will be an asset in future.

Revisiting tropical forest and landscape restoration governance in fragile countries: Ethiopia's Tigray as a case

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: Introduction/Background

With growing armed conflicts and associated factors like weak institutions in Sub-Saharan Africa (SSA), deforestation, and consequently loss of important ecosystem services is a great concern in the region. In conflict zones such as the one observed in Tigray, some belligerents intentionally destroyed ecosystems and governance institutions. Inherently, the conflict itself also fostered institutional decay of resource governance systems. Despite the Tigray region in northern Ethiopia gained international recognition for its efforts in forestland rehabilitation and landscape restoration, these conflict-induced forces combined to significantly harm the forest governance systems. Understanding the mechanisms of forest governance in a conflict environment and how these governance systems evolve in conflict environments helps better understand the mechanisms through which the overall process of rehabilitating and restoring forests can be facilitated.

Objectives: The objective of this paper is to analyze the impact of the war on formal and indigenous governance systems of forests and natural resources.

Methodology: the study employed desk review of over 50 documents, discussion with 10 experts, focus group discussions across several conflict areas, survey of forest communities, on-site visits to damaged sites and documentation from 12 sample sites. The collected data were analysed using content analysis.

Result: As a result of the decades-old efforts before the war, restoration and rehabilitation of environmental resources using indigenous management systems was scientifically documented. These documented results point to the decent success of such governance systems in promoting sustainable use of environmental resources. In this regard, Tigray's governance systems for environmental rehabilitation and restoration were acknowledged. During the war, the restored areas and governance institutions (formal institutions, indigenous governance, belief and management systems) were intentionally destroyed, which affected the effectiveness of communities to use, protect and conserve environmental resources.

Implication/conclusion: With decades-old centralized management, in Tigray, a mix of centralized and local institutions working in harmony was documented to be more effective in addressing the resource management challenges. The war destroyed these with grave consequences to the environment and the evolution of forest governance systems in the regional context, which still require in-depth studies.

Keywords: damage; ecocide, governance, recovery, rehabilitation, War, Tigray, Ethiopia

The transformational potential of community forestry and traditional forest-related knowledge for climate-resilience

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: This contribution to the round table will comment on previous talks based on my expertise on forest governance, community forestry and traditional knowledge. The Kunming-Montreal Global Biodiversity Framework recognizes the stewardship role of Indigenous Peoples and local communities regarding biodiversity conservation and sustainable use. My participation will highlight the transformative potential of community forestry and traditional knowledge to catalyze forest landscape restoration and build resilience to climate change. A session description is already available, so there is no need to repeat it.

Unlocking Green Growth: Boosting the European Forest Tree Nursery Sector

T3.16 Fostering modern forest and landscape restoration based on climate-smart use of forest genetic resources and innovation: from policy to practices

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Abstract: The use of proper forest reproductive material (FRM) is vital for maintaining high-quality forest biodiversity and enabling sustainable forest management and wood production. However, various challenges affect forest nurseries and impede the provision of adequate FRM in Europe. The topic of FRM is generally of low priority among policy-makers and forest managers, leading to underinvestment in FRM production, resulting in inadequate supply and poor quality of FRM. Other obstacles include limited availability of certified FRM sources, legal constraints in transfer among countries, as well as environmental and biotic factors like climate change and the introduction of novel pests. Moreover, market-based hurdles, such as insufficient demand, financial constraints, and inadequate pricing mechanisms further compromise the availability and quality of FRM.

Over the last two decades these challenges have been exacerbated by wage and labor force disparities due to cost constraints at nurseries and narrow time constraints in grant schemes. Current information largely focuses on national or regional conditions while a comprehensive and systemic analysis of these problems across the European forest tree nursery sector is lacking. A better understanding of the structure, economic framework conditions and needs of the European forest tree nursery sector is thus of particular importance.

We conducted a comprehensive survey of the European forest tree nursery sector including an investigation of perceived challenges and trends in seed sourcing, market framework conditions, demand structure, the perceived impact of EU policies on the sector as well as barriers and needs for future collaboration. The survey is part of an in-depth analysis of the sector aggregating EU member state in four regions.

Our analysis contributes to a better understanding of impediments on provision with FRM, provides suggestions for expanding the European capacities in FRM production and examines pathways of

potential cooperation between nurseries thus being an important contribution to implementation of the European Green Deal.

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

A crossroad of post-glacial migration haplotypes of Tilia cordata at Lithuania

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: We used five chloroplast microsatellite markers to study postglacial migration haplotypes of Tilia cordata in Lithuania. We sampled and genotyped 266 adult trees of Tilia cordata in natural forest stands with dominance of Tilia cordata in Lithuania. We constructed microsatellite markers identifying the postglacial migration haplotypes of Tilia cordata based on the NCBI GenBank accessions submitted by Semerikova et al. (2019). The genotyping revealed presence of four main European postglacial migration lines of Tilia cordata: (a) a western haplotype from the Balkan refugium (t5/Hap5/H4 notations from different studies), presently common in south-western Europe and in southern Lithuania; (b) an eastern haplotype from the Balkan refugium (t1/H3), presently common in south-eastern Europe (Ukraine, southern Russia) and in eastern Lithuania; (c) a haplotype from the Italian refugium (t3, Hap 1-3, H6) common in northwestern Europe and most common in Lithuania, (d) a north-eastern refugium (centered at about present-day eastern Ukraine), which presently is common in western Russia and north-eastern Lithuania. Such haplotypic diversity is favorable reserve of genetic diversity for a sound spreading of Tilia cordata that has notably intensified in the Baltic region over the last decade. The visual abstract is given below.

AI-Assisted Object Detection for Biodiversity Assessment in Forest Ecosystems

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: This study highlights the potential of artificial intelligence (AI) in supporting forest policy and planning by facilitating biodiversity assessment through object detection techniques. Specifically, we focus on two aspects: leaves detection for flora analysis and insect and vertebrate detection for fauna analysis. Advancements in computer vision and AI algorithms have opened up new possibilities for automated identification and monitoring of forest flora and fauna. Leaves detection plays a crucial role in understanding the composition and health of forest ecosystems. By utilizing AI algorithms, leaf identification can be automated, enabling efficient and accurate species classification, disease detection, and overall ecosystem assessment. It's started by digitizing the leaves from herbarium using scanners and hi-def scanners. Similarly, AI-based object detection techniques can aid in identifying insects and vertebrates in forest habitats. By analysing images or video footage captured from camera traps, AI algorithms can detect and classify various species, allowing for population estimation, habitat mapping, and ecological research. This information is vital for forest management and conservation efforts. Furthermore, in the context of forest canopy analysis, drones equipped with AI-powered systems can provide valuable insights. By capturing high-resolution imagery and using AI algorithms for canopy identification, it becomes possible to estimate forest parameters like canopy cover, canopy height, and species distribution, aiding in forest inventory and planning. Additionally, legged robots equipped with AI-enabled algorithms can be utilized to measure the diameter at breast height (DBH) of trees. These robots can autonomously navigate forest terrain, detect tree trunks, and accurately measure their dimensions, enabling efficient forest inventory and growth monitoring. The adoption of AI systems in Precision Biodiversity could foster responsible research and innovation that respects these diverse perspectives. By doing so, we can envision a future where AI systems contribute to improved forest management, conservation, and sustainable utilisation.

Ash tree genomics - providing solutions to global pest and pathogen threats

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Ash (*Fraxinus*) is a broadleaved tree genus of major importance in the Northern Hemisphere, encompassing species of ecological, economic and cultural significance. Since the 1990s, the survival of global ash populations has been threatened by invasive pest and pathogen outbreaks. The first draft genome for an ash species was released just over 10 years ago, in response to an urgent need for genomic resources to help to tackle the ash dieback disease epidemic in Europe. Our recent research has encompassed the generation of improved genomic resources for European ash (*F. excelsior*), comparative genomic analyses including the majority of diploid taxa in the genus *Fraxinus*, and population genomics for individual ash species, in efforts to better understand the basis of susceptibility to ash dieback disease and the equally damaging emerald ash borer. This talk will present results outlining the latest developments in our understanding of the genomic basis of susceptibility and the evolutionary response to these threats, and highlight the broader implications for the health and resilience of forest ecosystems under increasing biotic and abiotic stress.

De novo assembly of the Ulmus minor genome

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Elm populations in Europe and North America suffered a severe decline during last century, whose main agent was a clade of tree pathogens of the genus *Ophiostoma*, responsible of the Dutch elm disease (DED). It is estimated that only 1% of the ecosystems formerly dominated by elms remain. To the date, detection of disease resistant lingering elm genotypes has been the most successful action for elm recovery. However, current molecular knowledge of the species remains oddly scarce to allow the development of specific genetic tools to cope with the disease. The absence of a reliable reference genome limits in-depth genetic conservation and evolutionary studies, gene expression analyses and modern genomic-assisted breeding approaches. Here, we present a high-quality *de novo* genome assembly of an Iberian *Ulmus minor* resistant genotype, as a state-of-the-art resource to pursue new approaches against DED.

This work delves into the specific assembly techniques for this species genome, which is large, highly repetitive and highly heterozygous, features shared with some other forest tree genomes. To tackle these challenges, different sequencing technologies and assembly software were combined to generate the final assembly. Wengan ultrafast assembler was used to decide the combination of sequencing reads and their parameters in an optimal fashion for the assembly methodology, which allowed efficient use of time and computational resources. Once decided, the hybrid software MaSuRCA assembled the Illumina and PacBio reads, the latter previously corrected and trimmed with Canu. The polishing of the assembly was repeated in successive phases using Polca software. Haplotype refinement was performed using purge haplotigs software. PacBio Hi-Fi data were then integrated to the resulting assembly to improve continuity and quality; and finally, by using Hi-C data, the pseudo-chromosomes were obtained. Annotation of the repetitive content reported that more than 70% of the genome corresponds to repeat elements predominantly the retrotransposons of the *Gypsy* and *Copia* families. By using retrotransposons and highly conserved protein sequences, phylogenetic studies were performed.

This *Ulmus* reference genome represents a substantial leap forward, not only to help tackling DED, but also as a due resource for the research in Ulmaceae and Urticalean rosid genomics.

Dendrogenomics - a new interdisciplinary approach to study genetics of adaptation and individual tree response to biotic and abiotic stresses

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Dendrogenomics is a new interdisciplinary field of research that integrates dendrochronology, dendroecology, dendroclimatology, genetics and genomics. This novel approach allows joint analyses of dendrological and genomic data and opens new ways to study temporal dynamics of forest treelines, to delineate spatial and temporal population structure and to decipher individual tree response to the abiotic and biotic stresses and to evaluate the adaptive genetic potential of forest tree populations. These data are much needed for prediction how climate change will shape distribution of boreal forest species and for mitigation of negative climate change effects. It will be presented how an association analysis of the variation of individual dendrophenotypes, reflecting the individual response of a tree to stress, with variation of a large number of DNA markers identified genome-wide via genotyping-by-sequencing (GBS) allows to locate genome regions and genes whose variation is associated with variation of important adaptive traits using as examples the studies of Siberian larch and Siberian stone pine populations.

Digital Twin with Artificial Intelligence and Data Science for Precision Biodiversity

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Malaysia is committed to conserving its biological diversity, promoting its sustainable use and ensuring fair and equitable sharing of the benefits arising out of the utilization of biological resources. Therefore, one of the national flagship projects is tapping into artificial intelligence (AI) which has emerged as a powerful tool in various scientific disciplines, including forest biometry. AI models are used for predicting forest-related variables such as tree species classification, biomass estimation, growth prediction and stand prescription. Furthermore, AI will be used with remote sensing data, such as satellite imagery and LiDAR, to provide a comprehensive view of forest dynamics at various spatial and temporal scales. The project focuses on the development of a digital twin system for precision biodiversity that allows ecology monitoring, analysis, prediction, and simulation for the purpose of biodiversity management. As AI models advanced, researchers shifted their focus toward understanding the underlying processes driving forest dynamics through descriptive, predictive, and prescriptive analytics. Therefore, the interpretability and explainability of AI models became critical to gaining insights into the relationships between different variables and their impact on forests for supporting proactive forest strategies (digital twin). The pilot implementation is in Pasoh Reserve Forest, a nature reserve located about 8 km from Simpang Pertang, Malaysia, and around 70 km southeast of Kuala Lumpur. It has a total area of 2,450 hectares, with a core area of 600 ha surrounded by a buffer zone. We have developed a framework for stand prescription and biodiversity analytics dashboard. A national alliance on biodiversity evaluated the framework and the system is aimed to be used by several entities such as the Forest Research Institute Malaysia, departments of forestry and Ministry of Natural Resources, Environment, and Climate Change. The digital twin system is hopeful to facilitate further discovery in biodiversity research and increase the efficiency of forest management.

DNA GENOTYPING REVEALS STRONGLY DIFFERENTIATED GENETIC GROUPS WITHIN NATURAL POPULATIONS OF SCOTS PINE IN NORTHERLY FORESTS

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Earlier phenology observations in natural stands of Scots indicate that the mating among the trees within the stands may not be random but rather clustered into groups with synchronized flowering. In our study we tested this hypothesis by genotyping 890 mature trees of Scots pine in six natural populations of Scots pine located in different parts of Lithuania. We considered the level of population differentiation as a point of account for estimating the differentiation strength of the within population genetic groups. We used 11 genomic SSR markers to genotype the trees selected at a fine grid within ca. 2 ha sampling areas within each population (ca. 150 individuals per population). The STRUCTURE Bayesian clustering revealed two to six distinct genetic groups within the populations. These genetic groups were spatially intermixed. Genetic differentiation indexes among the within-population genetic groups were almost 10-fold greater (D_{est} = 0.012-0.081) than the differentiation indexes between the populations (D_{est} = 0.003). Our results indicate that there is a markedly stronger structure of genetic variation within populations than between populations of Scots pine in large forest tracts of northerly Europe, which presumably contributes to most of genetic variation residing within populations. It is likely that mating of individuals within Scots pine populations is not completely random but rather is stratified into genetic clusters. Our study provides a new approach and novel key insights into fine-scale genetic structuring within Scots pine populations. It has implications for population genetics studies, and conservation and sustainable use and management of forest genetic resources (FGR) for the most stand forming, wind pollinated monoecious tree species.

Evaluation of Ion Torrent-based Variant calling for the analysis of tree NGS data by validation against the common variant calling algorithms

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Next-generation sequencing (NGS) has revolutionized plant research in many ways, including new high-throughput genotyping methods. Genotyping by sequencing has been proven to be a robust and cost-effective method capable of producing thousands or millions of SNPs in many species. Undoubtedly, the greatest barrier to its wider use is the challenge of data analysis. With the advancement of technology in recent years, different sequencing technologies (Ion Torrent, Illumina, and PacBio) have emerged, resulting in different methods to obtain reads and thus different data types. Frequently applied pipelines often start with the pre-processing of sequence reads, followed by the alignment (mapping) of these reads to a reference sequence. Finally, the identification (calling) of sequence variants is performed based on alignments. Each of these three steps can be carried out by various alternative programs using different algorithms, which influence the accuracy and sensitivity of the resulting variant set. Genomic variants like single nucleotide variants (SNVs) or small insertions/deletions (InDels) can be inferred by variant callers based on sequence read alignment. Popular variant callers like SAMtools/BCFtools, CLC-GWB, FreeBayes, GATK, LoFreq, SNVer, VarDict, and VarScan use a variety of different approaches to call variants. Consequently, resulting variant sets differ depending on the employed methods (Bayesian, likelihood, or machine learning), which come with strengths and weaknesses concerning the identification of specific variant types. As shown in recent comparative studies, despite the undoubted performance, there are no software that, with equal analysis efficiency, can be used to complete all the tasks to be done for genomic variant analysis. The purpose of this study is to analyse the performance of a direct pipeline, based on Ion Torrent technology, that allows obtaining genomic variant analysis (SNVs, MNVs, InDels) as a direct sequencing output, without the use of external software: *Torrent suite software*. In this study, we compared the performance of Torrent suite's direct variant calling pipeline with the most commonly used pipelines on target sequencing data from 18 genomic regions of *Fagus sylavtica* L. genome in 7 Italian populations. Our results demonstrated variant calling efficiency comparable to the various workflows that are commonly adopted by the scientific community.

Expansion of black poplar genetic resources to ensure sustainability and stability of carr and riparian forests

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Riparian stands are irreplaceable part of the nature that is nowadays threatened by human activity but much more by invasive pathogens that reduce populations of key species (ash, elm, alder) rapidly resulting in significant changes in the composition and structure of these stands with impact on whole ecosystems. One of the possible solutions could be the substitution of these species for black poplar (*Populus nigra*, PN) in suitable condition for its growth. PN is an autochthonous European woody species that is endangered not only in the Czech Republic. This species is easily crossed with non-native poplars. This endangers the gene pool and, moreover, obtained hybrids have bad technical and ecological properties. Another risk is fragmentation of the population that can lead to inbreeding.

In the last century more than 200 trees from different parts of the Czech Republic were selected for in situ or ex situ conservation. From that time some of them died. To get better situation of black poplar populations and also the riparian stands, the project focusing on the black poplar conservation and its application in water management and forestry was financially supported by the Ministry of Agriculture of the Czech Republic (project QK22010142). The main aims are i) identification of residual trees of black poplar; ii) selection of genotypes that meet the desired characteristics and their species purity is confirmed with DNA markers; iii) propagation of them and iv) specification of factors to successful reintroduction of the species to riparian forests.

During the recons mainly the residues of local populations have been found. Only the small part of the identified trees is healthy. More than one half of identified trees is older than recommended coppice age for poplars. In the surroundings of the most identified trees there is presence of other poplars (mostly *P. ×canadensis*). Negative effect of inbreeding on seed germination and growth characteristics was observed in trials.

The identified trees enlarge the PN genetic resources. The obtained findings have important implications for reintroduction of PN into riparian forests and can help to assist its self-reliant and long-term survival in landscape.

Exploring the genomic and metabolomic bases of differential pollution symptoms in fir trees from a peri-urban forest under chronic ozone exposure

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Urbanization modifies both ecosystem conditions and evolutionary processes. Such changes include air pollution, mostly in the form of tropospheric ozone (O_3), which leads to urban and peri-urban forest decline. Such is the case of fir (*Abies religiosa*) forests in the peripheral mountains west of Mexico City (CDMX), which have been severely affected by O_3 pollution since the 1970s. We developed a participatory monitoring system with local community members to record ozone damage and other morphological traits in trees within these forests. We observed that more than thirty-five percent of the trees ($n = 1,765$) had ozone damage, with younger trees having a lower percentage of foliage damaged by ozone than older trees ($p < 0.0001$). Interestingly, we also observed some young individuals with low O_3—related damage within a zone of great O_3 incidence; these trees were smaller than symptomatic individuals of the same age, and might be reflecting rapid tolerance/adaptation to this pollutant. We observed significant differences between asymptomatic and damaged plants using histological, metabolomic and transcriptomic methods. For instance, we observed thicker epidermis and more collapsed cells in the palisade parenchyma in needles from symptomatic than from asymptomatic individuals; such differences increased with needle age. Furthermore, damaged individuals had lower concentrations of various terpenoids and differentially expressed genes related to carbohydrate metabolism, plant defense, and gene regulation, when compared to asymptomatic trees. Landscape genomic analyses finally revealed significant spatial and environmental components acting on heritable variation, which could explain the development of putatively tolerant phenotypes. Such elements may provide the raw material for future forest survival and could set the bases for possible genome-guided forest management. Involving the local community in pinpointing mature asymptomatic individuals and use them in reforestation is thus of high priority.

Genetic diversity and population structure of African sandalwood (Osyris lanceolata) in Kenya: implications for conservation

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Abstract

African sandalwood (*Osyris lanceolata* [Hoscht. & Steud.]) is a multipurpose and drought tolerant, African tropical tree species of *Santalaceae* family. The species is valued globally for it has important ornamental, medicinal, and economic value. The population of *O. lanceolata* is declining in Africa due to overexploitation and increased demand for its essential oil and other products, but information on population dynamics across its entire range of distribution is limited. In this study, the genetic variation and population structure were evaluated for 288 individuals from 10 discrete Kenyan populations based on 10 polymorphic SSR primers. The total number of alleles detected was 178 with a mean of 7.10 alleles per locus. The average observed heterozygosity (*Ho*) across all loci varied from 0.112 to 0.815. The gene diversity among the loci ranged from 0.226 to 0.869. There was strong genetic differentiation among populations (F_{ST} = 0.250), likely resulting from low gene flow (*Nm* = 0.79). The polymorphism information content (PIC) ranged from 0.896 to 0.968, with an average of 0.931, which indicated that the markers were highly informative. Analysis of molecular variance (AMOVA) indicated that the principal molecular variance existed within populations (62%) rather than among populations (38%). A high level of genetic diversity was inferred from the genetic diversity parameters (*He* = 0.587, *I* = 1.302 and *PPL* = 97 %).). Multivariate analyses with the unweighted pair group method with arithmetic mean (UPGMA) and principal coordinate analysis (PCoA) grouped the 228 individuals into two major groups, which was also supported by the Bayesian STRUCTURE analysis. This is the first study of the genetic diversity and population structure of *O. lanceolata* using SSR markers in Kenya. The microsatellite markers developed in this study will be useful for future breeding programs and genetic studies aimed at developing conservation plans. We recommend both *in situ* and *ex situ* conservation strategies to protect the species from population decline and further genetic diversity loss.

Keywords: *Osyris lanceolata*; genetic diversity; microsatellites (SSR); population structure

Genetic Diversity and Prediction Mapping of Pyracantha crenulata in Northwestern Himalayan Region of India

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: *Pyracantha crenulata*, an evergreen and perennial shrub, is a socio-economically important and underutilized forest genetic resource of the northwestern Himalayan region of India. The population of *P. crenulata* is declining due to the human-driven activities leading to habitat destruction. The present study was carried out in the Indian Himalayan State of Uttarakhand to analyze the genetic diversity within and among the populations and to predict the potential occurrence of *P. crenulata*. Total genomic DNA was extracted from the leaves using the modified CTAB method. The genetic variation in four natural populations of *P. crenulata* was analyzed using 13 ISSR markers. A high genetic diversity was recorded in the sampled populations (h = 0.223; I = 0.337) as well as at species level (h = 0.3174; I = 0.4821). Besides, high level of genetic differentiation (G_{st} = 0.295, *PhiPT* = 0.271) with the low gene flow ($N\text{-}_{m}$ = 0.191) among the populations were detected. Two significant clusters were separated by the UPGMA-based dendrogram, revealed that the populations are also geographically diverse. Bayesian model based clustering method was employed to assess the genetic population structure and detect gene pools which revealed that the populations were clustered according to their geographical distribution. This study will provide adequate information on genetic and geographical variability in *P. crenulata*, contributing to evolutionary dynamics, plant breeding, efficient use of germplasm resources, and plant conservation. Further, species mapping and prediction modelling would be an effective tool in species restoration, management, conservation, and utilization planning under the threats of human and climate change scenarios.

Genetic Resource Conservation Value and Climate Change Adaptation Potential of Old-growth vs Second-growth Populations of Keystone Eastern White Pine

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Conservation, sustainable management, and climate adaptation of genetic resources of keystone forest trees are essential for their forest ecosystem stability, functioning and provisioning of ecosystem services because many faunal and floral associations depend on the existence of keystone forest tree species. Biodiversity, especially genetic diversity, provides the foundation of ecosystem resilience, stability, and functioning. Whether old-growth forests have higher genetic diversity and effective population size, consequently higher genetic resource conservation value and climate adaptive potential than second-growth forests, remains an unresolved issue. We have tested the hypothesis that old-growth forest tree populations have higher genetic diversity, effective population size (N_e), climate adaptive potential and genetic resource conservation value and lower genetic differentiation than second-growth forest tree populations, employing a keystone, long-lived and extensively logged conifer, eastern white pine (*Pinus strobus*). Genetic diversity and population structure of old-growth and second-growth populations of eastern white pine (EWP) were examined using microsatellites of the nuclear and chloroplast genomes and SNPs in candidate nuclear genes putatively involved in adaptive responses to climate and underlying multilocus genetic architecture of local adaptation to climate in EWP. Old-growth and second-growth EWP populations had statistically similar genetic diversity, inbreeding coefficient and inter-population genetic differentiation based on nuclear microsatellites and SNPs. However, old-growth populations had significantly higher chloroplast microsatellites haploid diversity than second-growth populations. Old-growth EWP populations had higher coalescence-based historical long-term N_e than second-growth EWP populations, but the linkage disequilibrium-based contemporary N_e estimates were statistically similar between the old-growth and second-growth EWP populations. Analyses of population genetic structure and inter-population genetic relationships revealed some genetic constitution differences between the old-growth and second-growth EWP populations. Overall, our results suggest that old-growth and second-growth EWP populations have similar genetic resource conservation value. Because old-growth and second-growth EWP populations have similar levels of genetic diversity in genes putatively involved in adaptive responses to climate, old-growth and second-growth populations may have similar adaptive potential under climate change. Our results could be generalized across boreal and temperate conifer forest trees. Our study contributes to addresses a long-standing issue, advances research field and knowledge about conservation and ecological and climate adaptation of forest trees.

Genomic Insights and Sustainable Propagation Strategies for the Conservation and Enhanced Saponin Production of Oplopanax elatus

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: *Oplopanax elatus* Nakai, a small thorny shrub belonging to the Oplopanax genus in the Araliaceae family, holds considerable significance in Eastern Asia as an ethnomedicinal plant. The plant's therapeutic value stems primarily from the abundant lupane-type triterpenoid saponins found within its leaves and roots.The survival and propagation of wild *O. elatus* present significant challenges due to its specific habitat requirements. With a considerably narrow natural distribution range and low germination rate, along with over-harvesting by humans, the plant's population is sparse. These factors have led to its classification as an endangered species and its recognition as a nationally protected species in China. To sustain the utilization of *O. elatus* resources, we have developed an in vitro propagation system using its adventitious roots, supplemented by a suspension culture system for its expedited propagation. To decode the biosynthetic mechanism of lupane-type triterpenoids, we performed genome sequencing of an allotetraploid *O. elatus* individual from China. The resulting de novo assembly is 1.45 Gb, with a contig N50 of 6.3 Mb, spanning across 24 chromosomes and comprising a total of 61,842 annotated genes. Employing an agrobacterium-mediated transient expression assay in *Nicotiana benthamiana*, we identified multiple enzymes, including 5 oxidosqualene cyclases (OSCs), 6 cytochrome P450-dependent monooxygenases (P450s), and 9 UDP-glucosyltransferases (UGTs), involved in *O. elatus* saponin biosynthesis. The present study offers crucial resources for the future genetic improvement of *O. elatus*, particularly in enhancing saponin production. Moreover, it establishes the groundwork for the sustainable exploitation of lupane-type triterpenoids via large-scale root cultivation, thereby contributing to conservation efforts.

Geographical patterns of forest genetic diversity to tackle conservation needs: insights from genomics approaches

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Advanced DNA sequencing technologies have expanded our ability to estimate genetic diversity and differentiation parameters genome-wide, and to address crucial biological questions concerning conservation and the fate of forest tree populations in the face of strong environmental change. Here, we estimate geographical patterns of genome-wide genetic diversity in five European conifer species (*Abies alba*, *Pinus cembra*, *P. halepensis*, *P. nigra*, *Taxus baccata*) that cover different geographical ranges and ecological requirements. For each species, 9-15 populations (19-25 trees per population) were used for Allegro-SPET genotyping to produce several thousand SNPs (ranging from 7k to 17k after filtering). *Pinus nigra* and *P. halepensis* showed a clear East-West geographical pattern in genetic structure, while the remaining three species had either weak geographical subdivisions, or no structure. A bioinformatics pipeline was constructed, using R and UNIX environments, to automatically analyse the data with three different types of datasets (all SNPs, 1 SNP/Contig, Haplotype Phasing) and estimate genetic parameters, such as expected (H_s) and observed (H_o) heterozygosity and the inbreeding coefficient (F_{IS}). The spatial structure of each species was investigated using the ConStruct R package. Values of the diversity statistics were regressed against geographical coordinates (while controlling for genetic structure), revealing those that showed statistically significant geographical patterns. Consistent trends with longitude and latitude were observed for both measures of mean and standard deviation of the genetic diversity parameters. Genetic diversity and inbreeding values at the genome-level presented an overall trend towards higher values in the south-east and lower values in the north-west. The geographic patterns of the estimated genetic parameters not only revealed significant trends, but also effectively highlighted populations with original gene pools. Our approach opens the way to more efficient *in situ* conservation and sustainable forest management decisions, especially in non-model, large genome conifer species, and when sampling effort is increased.

Geospatial population mapping and genomic research advancement in vulnerable Dalbergia latifolia

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: *Dalbergia latifolia* (Family: Fabaceae) is considered vulnerable (VU A1cd Ver. 3.1) to extinction according to the IUCN Red List. The heartwood is very hard, weighing about 850 kg m^{-3}, used to make premium-quality furniture, paneling, and veneers. It is distributed predominantly in deciduous forests of the Asian, African, and American subcontinents and has gained acceptance as an agroforestry tree variety, possessing luxury wood traits. The *D. latifolia* population and ecological distribution are scarce in the wild, and there is limited availability of baseline genetic information and genomic data. Surveys were conducted in the northern, central, and southern Indian forest divisions to reveal their population structure and generate geo-tag maps for exotic and indigenous ranges. There are 50–80 trees, with an average of ~35 showing a restricted distribution of *D. latifolia*, with plantation forests comprising more than 200 trees. The tree height (5–40 m; av=~25 m) and girth at breast height (0.15–5.40 m; av=~0.65 m) data across different divisions, it was noted that fruiting occurs non-synchronously and location-specific. In the genomic data analysis, low-depth next-generation sequencing (NGS) of *D. latifolia* yielded 13.33 Gb raw data with 21x coverage on the Illumina high-throughput platform. The developed *de novo* assembly has a total read length of 8,88,65,132 with ~619 Mbp genome size covered in 4,45,006 contigs, with an average size of 150 bp. Assembly has N50 and L50 values of 2,873 and 50,876, respectively. Through MISA, a total of 1,05,226 SSRs were identified in 4,45,006 contigs with 66,407 designed SSRs. Di-nucleotide SSRs were the most abundant motif 69.31%, followed by tri- 27.57%, tetra- 2.47%), penta- 0.48%), and hexa-nucleotide 0.17%) repeats. Furthermore, BUSCO analysis revealed ~67% completed and single copy expected gene content of a genome assembly. The contigs were used to predict genes using Augustus, which showed 1,25,658 for each protein, CDS, and mRNA. KEGG and COG annotations were obtained by submitting the protein sequences of each sample to KAAS and WebMGA, respectively. Overall, research work enriched *D. latifolia* basic knowledge of germplasm availability and applied biotechnological aspects for long-term tree improvement to fulfil the timber demand across the globe.

Inferring molecular signatures of climate adaptation in Santalum album (Indian sandalwood) using landscape genomics approach

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Natural selection is the driving force in determining the genetic makeup of populations over time, resulting in locally adapted genotypes with higher relative fitness in their resident environment. Identifying, monitoring and managing this locally adapted genetic variation is essential for conservation and genetic improvement programs. *Santalum album* L. (commonly known as Indian sandalwood) is one of the most over exploited tropical tree species due to its use in fragrance and essential oil industries and is an invaluable commodity in international trade. The species is approaching commercial extinction due to illegal harvest, lack of natural and artificial regeneration, habitat loss and sandal spike disease, resulting in erosion of gene pool and reduction in genetic diversity in the natural populations. However, understanding on genetic basis of adaptation is presently limited in sandalwood. Hence, a study was taken up to infer the adaptive potential in the species; document geographical patterns of genome-wide variations and predict environmentally adaptive alleles. Twenty three natural populations spanning 7 Indian states were surveyed and inter population variations in leaf functional traits, biochemical traits and leaf spectral indices were recorded. Low depth whole genome sequencing in 29 individuals predicted 1.1 million polymorphic SNPs and structure analysis revealed that natural population from Thiruvannamalai (Jawadhu hills) in Tamil Nadu was distinct from other populations. Mantel test and correlogram provided an evidence of a weak but significant correlation between genetic and geographic distances. Concurrently, outlier analysis predicted 667 outlier SNPs which were correlated with 19 bioclimatic variables. Association analysis predicted significant correlation of 667 outliers distributed across 57 scaffolds of *Santalum album* genome with 18 climatic variables with a p-value less than 0.001. Functional annotation of the environmentally associated outlier loci revealed that genes like HMG-CoA synthase from sesquiterpene pathway, strictosidine synthase, transcriptional regulator SLK2, RNA binding protein 18, heat stress transcription factor B-2a-like protein (*HsfB2a*), ubiquitin ligase SUD1 and zinc finger protein ZAT10 may govern climate adaption in sandalwood. Interestingly, ZAT10 harbored maximum outlier SNPs and was associated with several climatic variables. Overall, the study improves the current understanding on genomic basis of local adaptation in sandalwood.

Natural variation in birch as an untapped resource for tree research

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: We are currently developing on a novel resource for forest tree genetics. Our focus is on silver birch (*Betula pendula*), one of the most fast- growing, widely distributed, and economically important boreal hardwood trees. Silver birch has a small (440 Mbp; sequenced, assembled and annotated) diploid genome. Furthermore, birch flowering can be accelerated under greenhouse conditions, and already 2-year-old seedling can be induced to flower. We have thus far sequenced ca. 400 genotypes from both natural and breeding populations, and have been able to identify that over 10% of the annotated genes have potentially deleterious mutations (e.g. an early *STOP* codon) in the annotated genes (in a heterozygous state). We will cross-breed the trees that harbor these heterozygous mutations in the same gene, and/or back-cross the progeny trees from the mutants to their parent through an accelerated flowering approach. Our first goal is to verify this approach through producing homozygous mutant lines for known regulators of e.g. tree architecture, where we will be able to phenotype the branching pattern already in young trees. The opportunities are nearly unlimited, we may e.g. produce trees with a higher carbon sequestration effectiveness (through modified stomatal conductance), or trees producing less pollen allergens. Our ultimate aim is to develop a genetic tree resource similar to Arabidopsis, where people can order for their gene in interest a homogygous loss-of-function mutation genotype.

New Ideas on Genetic Conservation and Sustainable Management of Southeast Asia's Valuable Tropical Rainforests

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: The timber industry in Southeast Asia is a major contributor to regional economy but the connection between scientific research and application and development of policy is weak. Knowledge on the evolutionary biology of tropical rainforest trees and how management systems interact with these natural dynamics is critical for sustainable forestry. Understanding the historical dynamics of climate change, anthropogenic threats to genetic viability and the important role of wildlife in maintaining genetic diversity will promote a deeper appreciation of not only the economic value of forests but also their mystery and intangible values. Advanced intelligent systems, drone technology, 5G collars and sensors, and blockchain are some of the high-end advanced technologies that can be deployed for precise monitoring and predicting impacts of climate change and anthropogenic threats for timely mitigation measures.

Phylogenomic analyses shed new light on the spatiotemporal evolution of global larches: implications for the dynamics of boreal forests

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Global warming is already causing significant impacts on forest ecosystems, threatening the ecosystem integrity and their component species. However, given the complex interactions between biotic and abiotic factors and migrational lags of forest trees, projecting the dynamics of forests is very challenging. Therefore, to understand the long-term dynamics of modern forests, knowledge of past forest changes is very essential to inform current predictions and conservation options. In this study, we reconstructed a highly resolved and robust phylogeny of *Larix*, a keystone genus of the boreal forests, using plastid genomes and 1301 orthologous genes (OGs) generated from transcriptomic data. On the basis of a solid phylogenetic framework, we investigated the spatiotemporal evolution of global larches and the determinants of species diversification. In sharp contrast to previously a genetic divide between the New World and the Old World or a morphology-based dichotomous classification of sects. *Larix* and *Multiserialis*, our results demonstrate a deep split between the high-latitude circumboreal and low-latitude QTP larches. Within each lineage, two geographically distinct clades were further resolved. Biogeographical analyses suggest that *Larix* might have an origin of Eocene high-latitude uplands in North America, and at the end of Eocene, it has expanded into the two sides of Beringia. Global climate deterioration starting from the late Eocene onwards, especially the sharp shift from greenhouse to icehouse climate at the Eocene–Oligocene Transition and the uplift of QTP played an important role in shaping its large-scale geographical pattern and species divergence. The evolutionary differences among the three keystone conifer genera (i.e., *Larix*, *Abies* and *Picea*) of boreal forests were also discussed, providing some clues of the origin and dynamics of the boreal forests. The proto-boreal forest probably had a relative old origin, at least prior to the early Miocene. As global temperature continuously declined, the composition of the proto-boreal biome was gradually winnowed and altered, resulting in the extant young and depauperate boreal forests. This work also confirms the significance of a robust phylogeny in study of evolutionary biogeography and accurate species delimitation and conservation.

Reference based genome assembly and comparative genomics in Calamus brandisii for identification of gender linked polymorphisms

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: *Calamus brandisii* is an endangered rattan species indigenous to the Western Ghats of India. It is extensively extracted in the furniture and handicraft industries owing to its strength, durability, and elasticity. The dioecious nature and longer flowering time limit conservation in rattans. Hence, the development of markers for early gender detection in seedlings can facilitate and ensure viable populations for *in-situ/ex-situ* conservation. Presently, there are no reports of sex chromosomes or gender-specific genes in *C. brandisii*. Hence, the present study aimed to conduct comparative genomics between the male and female genomes of *C. brandisii* to identify polymorphism in gender-specific genes. The raw data of ~99 Gb and ~120 Gb was generated and reference-based male and female genome assemblies were ~1.96 Gb each with 5109 and 5112 scaffolds respectively. The haploid genome size predicted for male and female genomes was ~691 Mb and ~884 Mb respectively. The female genome had higher GC content (39.07%), heterozygosity rate (1.18%), and repeat elements (36.09%) when compared to the male genome. The male and female genomes were predicted to contain 39,276 and 47,949 protein-coding genes respectively. The male genome assembly was mapped to the female genome as a reference to predict the polymorphisms between the genomes. The variant calling predicted a total of 12,476,774 SNPs and 707,542 InDels across the genomes. Further, a total of nine gender-determining genes were mined from the draft genomes and sequence alignment predicted a total of 106 SNPs and 16 InDels in *TPP*, *NAC*, *KAS-III*, *FCMO*, *FCMO-3*, *ET01*, *YABBY*, *EST,* and *LOG*. The gender-specific variations in *Flavin-containing monooxygenase* (*FCMO*) and *FCMO-3* were validated in a limited number of male and female plants of *C. brandisii.* The identified gender-specific markers will aid in early gender determination for efficient restoration of the species and science-based conservation programmes. Future studies on the gender-biased genes linked to floral development will help to unravel the molecular mechanisms of dioecy in rattans.

Study of genetic diversity of forest trees in Czech Republic by microsatellite markers

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: With consequence of climate and environment changes are gaining importance one of the priority tasks under state forest policies of the Czech Republic, which is conserve biodiversity in forest ecosystems while promoting the principles of sustainable management. Determination of genetic variability in ecologically and economically valuable stands and populations is essential for the possibility of fulfilling this goal and international obligations. The Simple Sequence Repeats (SSR) method of DNA analyses were used to determine the genetic variability and diversity of selected forest tree species populations (Scots pine, Norway spruce, European beech, silver fir etc.) in the Czech Republic. PCR were optimized with the selected polymorphic specific primers. The data from fragmentation analyses were processing by the statistical programs (GenAlEx, Structure etc.) to obtained genetic characteristics, especially an overview of the level of genetic diversity, heterozygosity, genetic differentiation genetic compositions and genetic distance between forest tree species populations. Based on analyses of nuclear microsatellite loci, a relatively high degree of diversity was shown in the monitored populations of forest tree species. The representation of heterozygotes in the populations ranged from 56 to 82%. Spruce populations appeared to be the most polymorphic and differentiation between ecotypes was detected, too. The differentiations between the populations were not negligible and thus indicate the structuring of valuable regional populations. Significant differences between populations of individual species were manifested in the frequency of representation of specific alleles. The genetic distances in the evaluated populations of Norway spruce and white fir corresponded approximately to the geographical distances. For the other observed species, the dependence between genetic and geographical distances was low or very low for European beech, oaks and Scots pine. The Scots pine marginal populations located on serpentines was clearly separated by the others. The genetic diversity of forest trees is crucial for adaptation of forest to climate change and for sustaining forest ecosystems. Knowledge based on DNA analyses regarding the variability of genetic resources will contribute to the quality of the reproduction material and to creating optimal species composition in forests.

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The central-periphery hypothesis as applied to some European forest tree populations

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: According to the central-periphery hypothesis, marginal populations should be less genetically diverse and be more genetically differentiated, than core ones. Regarding forest trees, this pattern has generally been considered as the norm. Nevertheless, there has been an accumulating line of evidence suggesting that an increasing number of species do not follow this model. In this work, several results are presented that consider the amount and structure of genetic diversity in marginal forest tree populations of south-eastern Europe *vis-à-vis* central European populations, for *Abies alba*, *Alnus glutinosa, Betula pendula, Fagus sylvatica, Quercus petraea, Picea abies* and *Prunus avium*. These results are largely non-concordant with the central-periphery hypothesis. The roles of historical events, such as glacial - interglacial cycles, long-term rotations of migrations cycles, position of refugial and post-glacial range expansion areas, and of different species characteristics (gymnosperms vs. angiosperms, stand-forming vs. scattered, temperate vs. boreal, hybridizing vs. non-hybridizing), in shaping extant genetic diversity and structure, are examined . Discussion focuses both concerning the results observed and in terms of the application of the hypothesis in general.

Understanding genetic correlations and trade-offs of fire adaptive traits in a Mediterranean conifer: key for more resilient management strategies

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: Life history theory assumes that there are trade-offs between life functions, expressed as costs in terms of survival, growth, and reproduction. Both individual tree and population fitness depend on different characteristic interactions, which are also highly dependent on the environment. Genetic correlations measure the shared genetic effect between two traits in a given population, but they can differ depending on multiple factors such as population, environment, age, selective pressure, etc. Genotype-environment interactions may also influence the expression of trade-offs since the magnitude of plasticity may be heterogeneous among different traits and, therefore, correlations among traits may disappear or even change sign depending on the context. In recent years, there has been a growing interest in fire adaptive traits in forest species, mainly due to the new conditions of fire frequency and intensity in many parts of the world. Different studies have shown that fire adaptive traits vary among species under different fire regimes. However, there are hardly any studies carried out on forest genetic trials with a genetic structure as suitable as provenance-progeny trials. Our previous studies using provenance-progeny common garden experiments of *Pinus halepensis* have shown the existence of genetic variation within populations with moderate heritability for serotiny degree. Moreover, we found trade-offs between serotiny degree and bark thickness, since the first is associated with abundant post-fire recruitment and the second with greater survival of adult trees in the face of low-medium intensity fires. In addition, we found that these key fire adaptive traits are environment-dependent: low water availability decreases both serotiny degree, bark allocation, and absolute bark thickness in *P. halepensis*. Our objective is to (1) determine whether there are genetic correlations among fire adaptive traits on this species, and with other vital traits, and (2) verify if these traits respond equally or with changed-sign among and within provenances of *P. halepensis*.

WILDOBST: Using Genetics to Inform Conservation

T3.17 Genomics of Keystone and Underused Forest Genetic Resources for Their Climate Adaptation, Resilience, Conservation and Sustainable Management

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Abstract: As climate change progresses, so does our need to bolster forest resilience in order to lessen the burden of climate change in the future. So too, does our need to maintain the genetic diversity of drought resistant species capable of acting as ecosystem anchors. The WILDOBST project focuses on understanding just that: the genetic diversity and connectivity of scattered Rosaceae trees that are projected to expand their range as climate change continues. The focal species of this project are Sorbus torminalis, S. domestica, and Pyrus pyraster, all of which are light-dependent, tolerant species with high economic and environmental value. However, all of these species currently exist in Austria in small, scattered populations and are never the dominant forest species. With such a scattered distribution it is unlikely that the functional connectivity of these species is adequate to maintain healthy genetic diversity levels into the future. In this project we analyzed the genetic diversity, population structure, gene flow, and spatial genetic structure of each of the three species in order to understand not only the levels of structural and functional connectivity that exist across Austria but also to identify which populations may be of higher conservation priority. Using the insights from this analysis we will be able to provide more targeted conservation and management plans for foresters and forest owners across Austria with applications across the broader European region.

T3.18 Improving biosecurity measures to better protect forests

Detection of viable Phytophthora and other oomycetes from soil using eRNA and its potential use a diagnostic tool

T3.18 Improving biosecurity measures to better protect forests

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Abstract: High-throughput DNA sequencing (HTS) of environmental RNA (eRNA) can provide information on soil communities that differ from those observed with environmental DNA (eDNA). RNA has a very short half-life compared to DNA and is found in living and active organisms, whereas DNA can persist in environmental samples long after an organism has died. In this way, eRNA gives a snapshot of the living organisms in an environment which may be more biologically relevant than relying on eDNA. In a warming climate it has been predicted that fungal pathogens will increase in prevalence, including soil-borne pathogens. Detection of soilborne pathogens is hampered by inefficient and often ineffective diagnostics which rely heavily on soil baiting, can take weeks to perform, and do not provide an accurate diagnosis when unculturable organisms are involved. These essential tools underpin current and future biosecurity systems. In this study comparative eDNA/eRNA HTS approach was employed to determine the diversity and viability of *Phytophthora* species and other oomycetes following fumigation of a *Pinus radiata* nursery bed. These results were compared to those from soil baiting. We found that the detected oomycete populations differed between eRNA, eDNA and soil baiting. Notably, some *Phytophthora* were detected in the eRNA samples that were not detected in the eDNA. In addition, this study revealed that soil fumigation was not completely effective at eliminating oomycetes from nursery soil. This work demonstrated the utility of eRNA for identifying viable oomycetes in environmental samples. This will be expanded upon to develop new and much needed tools for soil diagnostics. Innovate new tools will contribute to earlier detection and improved risk assessment of pathogens leading to better outcomes for healthier forests.

Emerging pathogens in urban forests in Germany causing an increased safety risk due to stem and branch cankers

T3.18 Improving biosecurity measures to better protect forests

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Abstract: Raising temperatures, less precipitation, and more extreme weather events cause trees to suffer from stress, such as drought. While the trees invest their energy in compensating for suboptimal conditions, they weaken the host tree, making it more susceptible to pest and pathogen infections.

On the other hand, insects, invertebrates, and microorganisms are emerging in areas with warmer climates, finding ideal conditions to infest and infect host trees that are too weak to defend themselves, thus becoming highly susceptible.

Starting early in 2023, red-colored bleeding cankers have been detected in various cities in Germany, primarily affecting plane trees. The symptoms of the stem and branch cankers are caused by a combination of bacteria and fungal pathogens originating from warmer climate areas, insects and invertebrates. Plane trees in urban areas undergo regular pruning measures, and observations suggest a correlation between these cuttings and increased bleeding. Raising awareness about the importance of using disinfected pruning tools may be crucial in preventing the further spread of these symptoms.

Additionally, there has been a concerning increase in stem cankers among urban tree species such as Yew Tree, Maple, Beech, and Horse Chestnuts in recent years. Wood density measurements have linked decay to the canker symptoms. The isolated fungi belong to atypical genera in relation to their corresponding host trees, indicating a broadening infection spectrum of fungal species expanding into new areas.

From a safety standpoint, close monitoring is crucial for identifying initial indications of fungal infections, as fungi often remain latent within their hosts and are not visible from the outside, posing a safety risk. When environmental conditions change, their lifestyle switches to pathogenic, and they begin to degrade the wood inside their hosts. Only in the later stages do cankers appear in the stem, indicating the unstable condition of the host trees.

These findings underscore the importance of closely monitoring urban forest trees to identify potential safety risks in a timely manner.

Landscape configuration matters in the spread of invasive tree pests

T3.18 Improving biosecurity measures to better protect forests

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Abstract: The risk posed by invasive pest species is so great for the vitality and functioning of forest ecosystems that makes it urgent to study all the measures to prevent their introduction to new areas or limit their spread. While the initial stages of invasion are particularly targeted by biosecurity measures, the epidemic propagation phase is often less well addressed. And yet a better understanding and prediction of the behaviour and rate of spread of invasive species is invaluable in predicting areas at risk of invasion, optimising the application of surveillance tools and trying to slow their spread. Simulation models are used for these purposes, often based on reaction-diffusion principles, but they rarely take into account the structure and composition of the landscapes crossed by the invasive species. We hypothesised that the proportion of host and non-host plants and their spatial distribution could either speed up or slow down the invasive species spread. We tested this hypothesis on two cases in Europe: the pinewood nematode and its insect vector *Monochamus galloprovincialis*, and the African citrus psyllid *Trioza erytreae*. By using mark-release-recapture data experiments and spread models, we were able to compare spread rates in homogeneous and heterogeneous landscapes. For *M. galloprovinciallis*, the results obtained showed that the presence of patches of non-host tree species, slowed down their flight dispersal and increased their risk of mortality. We also found that isolated host trees in urban and peri-urban areas were likely used as stepping-stones by the African citrus psyllid, accelerating its dispersal. These results suggest that explicitly considering the effects of the distribution of host and non-host trees on insect dispersal in the landscape can improve our understanding of processes and the accuracy of range expansion models, making them more useful for the monitoring and control of invasive tree species.

The challenge of managing an alien invasive forest insect pest-a successful case of classical biological control in Croatia

T3.18 Improving biosecurity measures to better protect forests

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Abstract: Classical biological control against invasive forest pests is sustainable pest management solution in large natural forests and protected forest ecosystems. Introduction and use of classical biocontrol agent *Torymus sinensis* (Hymenoptera; Torymidae) for control of invasive sweet chestnut gall wasp *Dryocosmus kuriphillus* (hymenoptera; Cynipidae) is one of recent examples of effective strategy to control a highly invasive forest pest in Europe. *T. sinensis* is a univoltine, host specific parasitoid, phenologically synchronized and morphologically adapted to *D. kuriphilus*. *T. sinensis* has good dispersal ability, builds up populations quickly and effectively controls the pest already few years after the release. Seven years after first releases and natural dispersal in Croatia, we have evaluated the impact of this classical biocontrol agent on invasive population of *D. kuriphilus*. *T. sinensis* has shown traits of very effective biocontrol agent: the methods for raising and release are not difficult to apply, it disperses very quickly when released, it lowers the population of its host for more than 90% in only few years, suffers no bottleneck -induced founder effect phenomenon and leads to recovery of chestnut vigour and yield in natural sweet chestnut forests. Seven years after first releases, an ecological equilibrium between the pest and classical biocontrol agent has been reached. In the last few years mismatch between *T. sinensis* adult emergence and the gall formation on chestnut trees has been observed that has been caused by warmer winter temperatures caused by climate change. This has caused resurgence of insect pest infestations and absence of parasitoid regulation.

Using reproductive ecology to guide the selection and release of biological control agents within forest ecosystems

T3.18 Improving biosecurity measures to better protect forests

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Abstract: Classical biological control is defined as the intentional introduction of predatory and parasitic alien species to control invasive organisms. Even though classical biological control has been a popular regulation tactic for decades, the success rates of these programs is not showing significant increase. In fact, many introduced agents either never establish, or fail to regulate the target population. In plants, reproductive biology is recognised as a reliable predictor of establishment capacity as it influences generation time, genetic diversity, or the capacity of single individuals to start new populations. As such, reproductive biology is regularly considered for risk assessment and management of invasive plants. However, while insects exhibit a wide range of reproductive traits (i.e., embryogenesis, sex determination, reproductive parasites, mating behaviors or mate choice strategies), the effects of these strategies on establishment and spread are still misunderstood. The BIOCAT2010 database is the largest database of information on biological control programs globally. By cross referencing information available in the database on the establishment success of biological control agents with information available in the literature regarding their reproductive traits, we aim to construct a predictive framework to guide the selection and release of insect biological control agents in forest ecosystems.

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

A global alliance for assisted natural regeneration: generating and sharing knowledge, advocacy, and technical support

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: The Assisted Natural Regeneration (ANR) Alliance[1] was created in 2022 to stimulate wide adoption and provide technical and policy guidance for ANR as a low-cost and effective restoration practice in rural communities across the world. Although ANR has strong links to agriculture, forestry, conservation, climate change mitigation and adaptation and sustainable development, it is not formally integrated into these sectors and lacks adequate financial support from donors, investors, and governments. Currently, the ANR "community" is highly fragmented across disciplines, sectors, and geographic regions with no unifying support platform. The ANR Alliance is an international and multisectoral coalition to promote the exchange of knowledge and experiences between countries, regions and stakeholders to support the technical and political adoption of ANR as a strategic restoration methodology aligned with sustainable development**,** integrated landscape management and forest landscape restoration. The governance structure includes membership of individuals, organizations, and partnerships with other networks. The ANR Alliance provides a vehicle to identify and address key challenges and opportunities, synthesize information and propose solutions and actions at subnational, national and international scales and to raise awareness of issues of common interest within regions and around the world. The ANR Alliance is composed of three regional nodes in Asia-Pacific, Africa, and Latin America-Caribbean, global leadership with support of regional co-leaders team and an administrative secretariat hosted by World Resources Institute, Colombia. A series of virtual workshops held in 2023 engaged 130 ANR stakeholders, including implementers, practitioners, researchers, and decision-makers. Regional workshops provided input for a five-year action plan under participative development orientated to explore window opportunities and overcome challenges. The ANR Alliance will collaborate with other networks, restoration and nature-based solutions initiatives that intersect in their focus on ANR. Activities organized by the ANR Alliance will include presentations at international, national and subnational conferences, workshops, webinars, synthesis workshops for working groups, training opportunities, fundraising support, R&D coordination, cost-benefit analysis, development of an ANR hub and document archive, policy briefs and blogs, and study tours.

[1] Support for initiating the ANR Alliance was provided by a grant from the Norway Climate Fund to World Resources Institute

A mix of active and passive restoration improves early-stage succession after forest fire in Brandenburg, Germany

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Climate change is leading to an increase in forest fires in Germany. Restoration of disturbed areas and forest stands is equally affected by climate change impacts and land use intentions. As functioning forest ecosystems also mitigate the effects of climate change, restoration of a value-creating forest stand becomes a challenge. To date, fire-damaged forest stands in Germany have been actively and artificialy restored, primarily through full clearing, leaving a completely empty area. With application of such fully active and artificial approaches foresters and land-owner intend to increase control over future forest structure. However, since these areas are particularly exposed to extreme weather conditions and erosion, the success of regeneration and target tree plantings is at stake. To improve reforestation of fire-damaged forests, knowledge of the processes of early succession and the effects of different restoration measures on plant communities in temperate forests is needed. Early successional communities set the basis for forest regeneration and are formed by both mosses and herbaceous plants that pioneer in fire-damaged areas, followed by pioneer tree species like poplar trees. In order to investigate short term effects of artificial and natural restoration practices on early stage succession, we studied plant communities that underwent passive, purely active (full clearing), and combined restoration actions three years after a forest fire in Brandenburg, Germany. Our inventory of early successional plant communities revealed the effects of applied restoration measures on the respective communities. Diversity and abundance of vegetation increased from active (artificial) to passive (natural) restoration approaches in fire-damaged forest stands. Nonmetric multidimensional scaling indicated an increase in vegetation diversity and from active to passive restoration gradient. Furthermore, examination of the functional characteristics of the vegetation layer in areas under combined restoration revealed particularly short-lived herbaceous species that can be used for topsoil regeneration but also for the introduction of target tree species. Overall, we conclude that a combination of active and passive restoration measures, such as partial clearing and site preparation in small-scale sections, can mitigate vegetation diversity loss while promoting restoration success.

Advances in fostering natural regeneration in the Eastern Brazilian Amazon

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Naturally regenerating forests are a promising strategy for large-scale restoration of tropical areas in the Brazilian Amazon, given its high natural propensity for regeneration and low intensity of land use following recent deforestation. By 2019, 7.2 million ha of secondary forests (≥ 6 years old) regrew following land abandonment and poor management across the Brazilian Amazon, of which 5.2 million ha are on land unsuitable for agriculture. Regenerating areas are often cleared within 5–10 years of regrowth, emphasizing the urgent need to strengthen protection.

Recent actions and articulations demonstrate some progress towards the valuation of secondary forests as a restoration strategy in the Eastern Brazilian Amazon. Pará state, which holds 42% of Amazonia's secondary forests, passed two pieces of legislation to protect regenerating forests in more advanced stages of succession. In 2020, Pará launched the Amazônia Agora State Plan (PEAA), with an aim of net zero greenhouse gas emissions. To meet this target, the State of Pará is following a strategy to regenerate 5.65 million ha of secondary forests, along with a reduction in deforestation. A state plan is being designed to guide forest restoration more broadly. Opportunities for protecting natural regeneration from the rules set by the national forest legislation are advancing slowly in most Amazonian states.

New programs led by NGOs focus on capacity building, material support, and technical assistance to help landowners and communities apply assisted natural regeneration toward deficits in legal reserves and permanent protection areas in compliance with national policies. The FloreSer Platform mapped secondary forests in the Amazon to guide decision making, the multi-institutional Alliance for Restoration in the Amazon is conducting a social network analysis of restoration, and WRI Brazil is offering field-based training workshops with Landless Movement (MST) settlements provide technical assistance on how to manage regenerating vegetation and agroforestry in their land holdings. Imazon's Floresta para Sempre project supports family farmers in southeast Pará with agroforestry and implementation of assisted natural regeneration approaches for environmental and productive restoration. The ANR Alliance aims to promote wide implementation of ANR interventions across Amazonia and globally through integrating practice, policy and scientific research.

Drivers of colonization, species richness, and structural variation during the initial three decades of natural forest colonization in abandoned soils

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Natural colonization of abandoned agricultural soils has been proposed as a cost-effective strategy for simultaneously mitigating the climate crisis, restoring ecological integrity, and promoting the re-establishment of native biodiversity. The success and speed at which forests develop in the presence of land-use legacies are highly variable, and empirical knowledge on the drivers of the initial phase of temperate forest colonization in a range of site conditions is lacking. We analyzed and compared drivers of the initial three decades of natural forest colonization in 33 afforestation sites laid out between 1990 and 2018, in Denmark. We analyzed how the age of colonization, size of the area, soil type, topography, and abundance of neighboring woody vegetation influenced woody vegetation cover, species richness, and variation in vegetation structure of the colonizing woody species. We found that woody vegetation cover, species richness, and structural variation increased significantly with time since abandonment. Woody vegetation cover was significantly higher in sites with abundant neighboring vegetation and on loamy soils compared to sand or clay. Woody vegetation cover tended to be higher in sites with sloping terrain. Species richness increased significantly in sites with loamy or clay soil and sites with sloping terrain. After accounting for the other drivers, none of the elements were influenced by the size of the area. The results suggest that time since abandonment, neighboring mature

woody vegetation, soil and topography are key drivers of the different elements of

colonization. This knowledge can be used to prioritize areas for natural regeneration.
The presentation will suggest active afforestation methods and designs depending on if the aims are production, stability or biodiversity.

Effect of selective cutting on natural regeneration of oak in mixed structurally complex forest in southern Sweden

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: There is a worldwide crisis regarding biodiversity loss and ecosystem degradation, with serious implications for the capacity of biodiversity to meet increased needs of resilience and ecosystem services in the future. Oak-dominated and mixed oak forest are widely distributed across Eurasia and North America. However, despite their importance as foundational species for many ecosystems, oak dominance is declining worldwide. One of the main explanation for the decline in oak forests is failure in oak regeneration and its inability to grow and reach into the overstory. So far, research has focused on influences of e.g. browsing and fire on the early stages of natural regeneration. Thus, there is a knowledge gap regarding the stand structures and light conditions necessary for the regeneration layer to develop into the canopy. We analysed stand structural complexity in mixed oak-dominated forests across Southern Sweden with regards to change in light availability, competition of surroundings and the recruitment of the natural regenerated oaks into the canopy. For this, twelve experimental sites in 60-80 years old, mixed broadleaved forests were used. They all originated from abandoned pastures and at each site, one treatment (selective cutting) and one control plot (no intervention) were installed. The treatment was carried out in winter 2016/2017 in one hectare plots, and about 25 % of the basal area was removed. Early results suggest that selective cutting enhances the recruitment of seedlings and small diameter oak trees while larger oak trees are unaffected. Additional analyses will enable us to answer questions concerning the most favourable stand structures to sustaining growth and recruitment of natural oak regeneration into the canopy. Further, results of this research will be foundational to develop practical guidelines for managing stand structures to create and sustain critical, oak-dominated habitats valued for biodiversity conservation.

Effects of Land Restoration Activities on Productive Land Access and Women's Participation in Rural Kenya

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: The aim of this study is to assess the extent to which households have adopted a wider range of land restoration and management practices as a result of the rural Kenyan project. In addition, it aims to determine whether households that have implemented a greater number of land restoration and management activities have better access to productive land and higher levels of women participation compared to households that have implemented fewer activities.

We used repeated cross-sectional data collected from the rural Kenyan project to investigate the relationship between participation in training programs, awareness of climate change risks, 9 types of land restoration and management activities, household income, women's involvement in household and community, and access to productive lands among beneficiary households. Multiple linear regression analysis was conducted to test the association between those variables.

During the project, 250 community members, including 43 female-headed households and 207 maleheaded households, participated in land restoration and management activities such as tree planting, FMNR, invasive species removal, bare land rehabilitation, and agroforestry.

At the endline, 77.05% (n=141) of households had at least one member trained in land rehabilitation and management, compared to 18.38% (n=25) at the baseline. The training program focused on land rehabilitation and management activities, including FMNR, agroforestry, and women's participation. On average, program participants adopted three types of land rehabilitation and management activities, improving from 1.58 types at the baseline. Additionally, 42.3% of the land was productive or undergoing restoration, up from the baseline value of 29.79%. The women's participation score increased from 2.95 (in-house) and 2.58 (in the community) to 3.11 and 2.89, respectively.

A multiple regression analysis considered factors like the household head's gender and educational background, household size, climate change awareness, training program participation, agricultural income, women's involvement, and access to productive land. The analysis revealed that training program participation and types of land rehabilitation and management activities were significant factors contributing to increased productive land and women's participation score.

The results of this study could help NGOs and policymakers in developing and implementing effective approaches to tackle climate change and land degradation in rural Kenya.

Effects of reforestation and site preparation methods on early growth and survival of Scots pine (Pinus sylvestris L.) in south-eastern Poland

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Successful tree regeneration is a key process in ensuring forest sustainability and one of the most crucial investments made in silviculture. This study compared the effects of three reforestation methods (planting, direct seeding, and natural regeneration) and three mechanical site preparation methods (double mould-board forest plough (FP); active plough (AP); and forest mill (FM)) on biometric parameters, survival, and density of Scots pine (*Pinus sylvestris* L.) seedlings in the first 4 years of growth in a clear-cut area in south-eastern Poland. Planted seedlings were higher, thicker in root collar, and had higher survival rates after the fourth growing season than trees from natural regeneration and direct seeding. Site preparation methods did not affect the density of planted seedlings. After natural regeneration and direct seeding, seedling density was lower and less homogeneous (plots with no seedlings) in FM soil preparation in comparison to other methods. The survival of pines in all reforestation methods was not affected significantly by site preparation methods. Our results indicate that the best mechanical site preparation method for planting is FM, as this is the one that least disturbs the soil environment. For direct seeding the best results were achieved after AP preparation. Natural regeneration of Scots pine was most effective after FP use, and in relatively wet years also after AP use.

Effects of thinning on growth and regeneration in threatened and socio-ecologically important southern African woodland ecosystems

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: The application of silviculture can contribute to the growth and productivity of forests and woodlands. Yet, active silvicultural practices are largely absent in southern African woodlands despite continuous decline and degradation. The absence of silvicultural practices is a consequence of a lack of knowledge and understanding of the growth patterns of these species-rich, and structurally diverse woodlands. Effects of an important silvicultural practice, namely thinning, on the growth and regeneration of socioeconomic and ecologically important woodland ecosystems in northern Namibia were investigated along a precipitation gradient. The thinning considered all wood utilization needs and encompassed all tree species and sizes. Growth and regeneration responses to thinning are assessed through measurements and statistical analyses of stem diameters at breast height of all trees equal to or larger than 5 cm, and the total number and heights of seedlings, saplings, and stump sprout shoots of the thinned-out (cut) trees.

Stand basal area growth increments correlated with rainfall. Growth responses to light and heavy thinning were more pronounced at the site with higher initial relative stand density, correspondingly averaging 24.0 – 52.6% more than the stand basal area growth increments of non-thinned stands. Tree recruitment represented an average of 27.2% of stand basal areas, of which 35.1 and 47.1% are correspondingly from light- and heavy-thinned stands in contrast to 17.8% from non-thinned stands. All cut tree species coppiced, with over 70% of all stumps having coppice shoots already on the first growing season following thinning implementation, averaging 5.3 shoots per sprouting stump. Height growth of coppice shoots averaged 50.2 and 64.4 cm annually for light and heavy thinning respectively. Seedling regeneration pattern was comparable across sites, abundantly pronounced in the 0 – 0.5 cm height class in the second and third growing seasons, averaging 49% more seedlings than in the first growing season. The amount of seedling regeneration in the 0 – 0.5 cm height class shows abundant regeneration patterns in light- and heavy-thinned stands, averaging 22 – 34 % more seedlings than in non-thinned stands. This intensive utilization-oriented thinning yielded encouraging results in these woodlands without compromising forest integrity but rather stimulating abundant coppicing and recruitment.

Forest regeneration after stand-replacing disturbances in the Italian Alps: regeneration dynamics and innovative approach for artificial restoration.

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Recently, we are witnessing changes in disturbance regimes mainly driven by climate change, that expose the ecosystems to compound or cascading disturbances. Alpine forests are highly sensitive, and such modifications affect forest ecosystem dynamics, structure, species composition, and consequently the provision of forest ecosystem services. It is thus important to restore as soon as possible the forest cover. In this scenario natural regeneration is considered the key factor in restoring forests: it covers large areas and is cost-effective. In some situation, it can be hard for natural regeneration to establish in short time. It is therefore important to deeply understand natural regeneration dynamics and drivers to create the best situation for regeneration to establish.

In this contribution, we analyzed the drivers of natural regeneration after stand-replacing disturbances in the Italian Dolomites. We focused on the role of site characteristics, soil cover, and deadwood in creating favorable microsites for regeneration establishment. Post-disturbance management strategies have been included in the analysis. The results show a negative correlation between the elevation and the seedlings' presence, as well as the increase in the distance from the green islands. High percentages of deadwood soil cover have a mulching effect lowering seedling establishment, while a high number of wood debris increases seedling occurrence. At microsite scale deadwood contributes to more favorable conditions for regeneration establishment, decreasing soil temperature and increasing the survival of planted seedlings. Deadwood presence moreover contributes to protect seedlings from browsing.

Understanding the drivers of natural regeneration in damaged stands helps define where the regeneration could have a better chance to establish. This information is valuable to decide the intervention strategies to mitigate the impact of natural disturbances on alpine forests. As a real case of an application, we present case studies from the project LIFE VAIA: the aim is to reduce the impacts of windstorms on forest and local communities, restoring damaged areas by implementing agroforestry practices (berry cultivation and bee breeding) within the afforestation sites. The restoration protocol is based on the concepts of applied nucleation and assisted regeneration, providing space to natural regeneration dynamics within the pilot site areas.

Gap-based Silviculture in Temperate Secondary Forests: From Standard to Application

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Forest gaps, characterized as small- to medium-scale disturbances, are prevalent in forest ecosystems and play significant roles in driving forest dynamics. Due to their widespread occurrence, forest gaps have been used as a crucial silvicultural approach in forest restoration for several decades, including natural forest protection projects in China, close-to-nature silviculture or continuous cover forestry in Europe, and ecosystem management in North America. We systematically studied the temperate secondary forest in Northeast China, which originated from severe deforestation before the 1950s. Our study mainly focused on four aspects: (1) establishing objective standards for gap-related profiles; (2) quantifying the 3-D structure of forest gaps and the light environment within them; (3) examining natural regeneration and succession patterns and dynamics of main tree species after gap formation; and (4) assessing the potential for converting larch plantations into mixed stands through gap treatments. Various methodologies, including permanent plot monitoring, large-scale inventory, terrestrial laser scanning, and remote sensing imagery, were used during the study. Our research findings will advance gap-based silviculture and provide practical management guidance for restoring temperate secondary forests.

Guideline for the restoration of degraded and damaged forests in Germany with natural regeneration of pioneer tree species

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Large-scale damage of forests due to biotic and abiotic disturbance events have many negative ecological consequences for the forest ecosystem. The forest loss lead to the decoupling of water and nutrient cycles, the drastic alteration of habitats and species communities, and the reduction of functional processes and ecosystem services. Pre-forest structures of ecologically important pioneer tree species, which occur naturally as a result of succession processes, are able to mitigate the negative effects within short periods. They are also able of increasing the performance of degraded sites.

For this reason, a practical guideline was developed to help foresters to assess the probability of intense and vital regeneration of damaged areas by pioneer tree species *Alnus glutinosa*, *Betula pendula*, *Populus tremula*, *Salix caprea*, *Pinus sylvestris* and *Larix decidua* based on site conditions and regeneration ecology requirements. For site conditions, the most important parameters are information on the location, shape, size of the damaged area, climatic conditions, soil properties, previous stocking trees and seed tree locations. Regarding regeneration ecology requirements of the pioneer tree species, information on age and vitality of seed trees as well as species-specific knowledge on seed production, mast years, seed dispersal distances, seed longevity and microsite requirements are crucial parameters. Only on the basis of these parameters it can be assessed whether a specific damaged area can be completely or partially successfully natural regenerated or whether it needs support by artificial regeneration.

For example, *Betula pendula* trees can produce 0.6 to 10 million seeds depending on mast years and non-mast years. Seeds can be dispersed over 40 to 360 m depending on relief, wind direction and strength, whereas *Salix caprea* can produce high seed amounts of more than 22 million seeds more or less annually, which are dispersed over 200 m to 3 km regardless of wind direction, strength and relief. *Betula pendula* is able of building up a soil seed bank of up to 13 years, whereas *Salix caprea* can only regenerate from annual seed rain. *Betula pendula* seedlings proved to be significantly more drought stress resistant in the first year of growth than *Salix caprea* seedlings.

Modelling changes occurring in secondary succession silver birch stands (Betula Pendula roth.) on post-agricultural lands in central Poland

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Because of socioeconomic changes in Central Europe, many farmers abandon their farms, which subsequently are overgrown by forest pioneer tree species, such as silver birch (Betula pendula). Despite the significant scale of this phenomenon, its impact and future scope are unknown; therefore, research studying the production capacity of the young birch stands growing on post-agricultural lands is vital. We intend to develop a whole-stand model for the new young birch stands encroaching on agricultural areas. The model will help to predict future growth and yield of the new birch populations based on their stand-level attributes. The data for the proposed model development comes from 120 pure silver birch stands growing on former agricultural lands in central Poland. We have performed no silvicultural treatments preceding the plot measurements. Stands' ages vary from 1 to 19 years. Each plot is about 200 trees and their sizes vary from 4 to 731 m2, depending on stand age and density. Because of the relatively simple structure of young silver birch stands, we used the whole stand model approach to describe the dynamics of the pioneering birch ecosystems. The main state variables are dominant height and number of trees per hectare. The interim sub-models cover the competition index, the development of quadratic mean diameter, volume, and the aboveground biomass based on biomass expansion factors. We test several functions in model development and evaluate the results using such fit statistics as the sum of square residuals (SSE), residual mean square error (RMSE), mean error (ME), and coefficient of determination (R2). Validation of the model is based on repeated K-fold cross-validation. We have carried all analyses out in R software.

Natural regeneration of main forest species in Romania: approaches, best practices, limits

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Romanian forests (about 6.6 milion hectares) are dominated by broadleaves (74% of total forest area, of which European beech *Fagus sylvatica* cover 32%, and oaks - predominantly sessile oak *Quercus petraea* and pedunculate oak *Q. robur* - cover 18%), found predominantly in mixed stands. Conifers cover 26% of national forestland, of which Norway spruce *Picea abies* (19%) and silver fir *Abies alba* (5%) are the most important forest species, and are found in both mixed and pure stands.

Over 90% of Romanian forests are regenerated naturally by seed (high forests), and only about 5% of them (forests of black locust *Robinia pseudoacacia*, native poplars *Populus* spp., native willows *Salix* spp., and alders *Alnus* spp.) are treated as coppice and regenerated by stump stools or root suckers. Less than 5% of the forests (with Norway spruce, pines *Pinus* spp., and European larch *Larix decidua*) are regenerated artificially by planting, after small-scale (maximum 3 hectares) clearfelling. On a small scale (when the natural regeneration by seed is not complete or enrichment of regeneration with non-existing valuable species, predominantly native, is targeted), planting is complementary to natural regeneration.

The natural regeneration by seed is achieved mostly through silvicultural systems providing the establishment of main forest species under shelter (e.g., single-tree and group selection system, irregular shelterwood system, uniform and group shelterwood system).

Based on such background, the paper will show the main features of natural regeneration of most important forest species in Romania, focusing on both advantages of this regeneration method as well as the specific challenges such as rare seed years (case of pedunculate oak), high competition of admixed and competitive tree species, threatening the survival and early growth of most important ones, low inner accessibility of stands, increasing the logging damages to the established regeneration, shortage and high cost of labour for silvicultural interventions in young stands, etc.

Natural regeneration of Quercus via a multi-phased shelterwood in eastern upland hardwood forests, USA

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: The Heathy Forests Restoration Act of 2003 spurred a long-term study in the Cold Hill area of the London Ranger District on the Daniel Boone National Forest (DBNF), KY. USA. This study included regeneration and intermediate stand treatments to assess silvicultural prescriptions designed to curtail susceptibility and vulnerability of *Quercus*-dominated stands from spongy moth and *Quercus* decline. One treatment targeted recruitment of natural *Quercus* reproduction using a multi-phased shelterwood. In 2006, midstory stems of non-desirable species in six stands were deadened with an herbicide to improve understory light conditions for *Quercus* growth. Ten-years post-treatment, competitive *Quercus* reproduction, those 1.2 m tall up to 3.8 cm DBH, increased to 66 stems per ha. In this same size class *Acer rubrum*, a less-desirable species, increased to over 114 stems per ha. We did a pre-harvest "site preparation for natural regeneration" treatment in 2019 (cut-surface herbicide treatment of *Acer rubrum* stems) prior to a commercial harvest in 2020 that retained 5.7 square m of basal area per ha. *Quercus* reproduction two growing seasons post-harvest release showed significant increases in stem densities across all reproductive size classes, from 1,1105 stems per ha to 3,436 stems per ha, but the largest stem sizes were only 58 stems per ha. Concurrent increases in *Acer rubrum* occurred, and competitive *Acer rubrum* dominated the reproduction cohort at 197 stems per ha. Applying these intensive prescriptions at the stand-level is predicated on plot-level studies that showed promise for *Quercus* reproductive success. However contemporary upland hardwood stands in the eastern United States have remained undisturbed for over 50 years, creating closed-canopy conditions, and promoting the establishment of a robust mesophytic understory, including *Acer rubrum*. Sustaining *Quercus* dominance in these forests will require herculean efforts.

Naturally regenerating the primary southern pines of the United States

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: While many see forestry in the southeastern United States as driven by large-scale plantings of loblolly pine (*Pinus taeda*), most pine-dominated forests in this region are still regenerated naturally. Over a century of work has been dedicated to the development of naturally regenerated silvicultural systems for the four primary southern pines (loblolly, longleaf (*Pinus palustris*), shortleaf (*Pinus echinata*), and slash (*Pinus elliottii*)). While the earliest such investigations included both even- and uneven-aged silviculture, by the mid-20th century interest focused more on even-aged systems to better accommodate the relative shade intolerance of southern pines and landowners' desire for higher stocking levels. The success of these silvicultural systems suggests a high degree of functional similarity among southern pines; however, decades of research have identified important differences in life history traits that strongly influence treatment effectiveness. For example, seedling establishment of all southern pines generally improves following prescribed fire due to the creation of favorable seedbeds. Yet southern pine response to fire in the early developmental stages varies widely due to differences in early growth strategy such as the grass stage in longleaf pine and shortleaf's ability to resprout. Such differences contribute to varying patterns in post-fire stand development, which has important implications for southern pine overstory recruitment, restoration success, and delivery of desired ecosystem services. Moreover, subtle-to-pronounced differences in the susceptibility of southern pines from regeneration to maturity to biotic pests and abiotic disturbances produce important management considerations across a range of scales. This paper reviews the processes that affect natural regeneration of the primary southern pines including silvics, forest threats, and treatment responses. Collectively, this information gathered from observation, trial-and-error experiences, and controlled experiments across the southeastern US can inform forest managers and landowners about potential options and alternatives to more costly and resource-intensive approaches to artificial regeneration.

Passive and active afforestation of degraded mine lands – towards succession to naturalization of ecosystem

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: With the current discussion on biodiversity and the restoration of ecosystems (Proposal for a Regulation of the European Parliament and of the Council on nature restoration, 2022/0195 (COD)), as well as the assessment of the response of forest ecosystems to climate change it is important to consider different scenarios for ecosystem restoration on degraded land and large scale disturbance. An additional issue is the role of the forest ecosystem in increasing retention at the risk of drought. In human-made forest management dynamic and spontaneous succession are still being discussed. From one point of view, post-mine and post-industrial sites are the consequences of civilization development and using fossil fuels in the energy mix, but on the other hand, these areas are connected with total deforestation and extreme changes of water availability and site conditions. Therefore, post-mine sites can be a case study for assessing the dynamics of regenerated ecosystems and the ecosystem's reaction to environmental stress and climate change. We present various aspects of active and passive restoration with the role of succession in the reclamation of mine sites and forest ecosystem restoration.

Patterns and dynamics of land change in swidden systems across highland forest-agriculture frontiers in Laos, Southeast Asia

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Swidden—the cyclical practice of land clearing, cropping, and leaving fallow for forest recovery—is an integral land use in the highlands of Southeast Asia, a region also identified as the leading global hotspot of highland forest loss. While it is generally understood that swidden is being increasingly replaced by cash crops (e.g., tree plantations), the actual extent of this process has been difficult to determine owing to challenges in the detection of swidden, a highly spatiotemporally dynamic form of land change. As a result, our understanding on the effects of this regionwide sedentarization of agriculture on the sustainability of highland forests remains limited. This is a problem because different post-swidden land uses can have varied environmental consequences, not just for highland systems, but also the lowland agrarian populus who depend on water regulation from the highlands. Here, we leverage on an existing land cover dataset to investigate the dynamics of swidden replacement in Laos, a developing country with the largest rural population in SE Asia where swidden remains widely practiced. By applying a rule-based classification to constrain our analysis to areas where at least one swidden cycle was observed, we found that from 1990–2020, the total area of swidden-affected forest in Laos was 7,147 km^2. Of this amount, 37.2% (2,660 km^2) remained under swidden (stable) while the remaining 62.8% (4,487 km^2) were eventually replaced by other land uses. Over time, the annual area of swidden replacement increased at an exponential rate, with more than half (52.2%) of total swidden replacement occurring in the last 3 years (2017–2020). The overall contribution of tree plantations was much lower than expected (<5% of total), and the vast majority of replacement (95.5%) involved a permanent conversion into non-forest types. Annual replacement area by non-forest increased throughout the 30-y period, whereas replacement by tree plantations only increased after 2003. Overall, our findings provide weak evidence for tree plantation establishment as a key driver of swidden replacement in Laos. More research is needed to accurately determine the various land use trajectories driving swidden replacement, in Laos, and the wider SE Asian region.

Potential salt tolerant species for degraded land restoration

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Expansion in the areas affected by salinity is predicted in the coming decades with areas under the risk of salinization through 2079–2099 being the drylands of south America, southern Australia, Mexico, south-western United States, and south Africa. Reclamation of such lands through planting of salt tolerant species is not only a cost-effective strategy but would also ensure the long-term biodiversity of the area. Species selection is curcial because introducing alien species to the ecosystem would be harmful, with native species preffered due to their adaptability and economic value to the local community. The aim of this work was to determine such salt tolerant species estimated through spatial inverse distance weighted (IDW) interpolation. Ground truth salinity data was obtained from the WoSIS (World Soil Information Service) soil profile database (https://www.isric.org). To isolate species growing in salinity affected areas, multiple plant databases were combined to form a database with over 10000 unique species. Spatial surface of salinity distribution and used to extract EC_e values at the median geolocations of the species. Based on the predicted salinity levels, species at high and severe levels were classified based on their presence in locations with EC_e of more than 8 and 16 dS m^{-1}, respectively. Through this procedure, we isolated 261 species as being present in at least highly saline environments, out of which 208 species had either salt tolerant mechanicms such as salt glands or were salt tolerant. Out of these 261 species, 4 in Africa (*Geranium lucidum*, *Guibourtia coleosperma*, *Moringa ovalifolia*, and *Catophractes alexandri*), 23 in Asia (*Syzygium oblatum*, *Tamarix passerinoides*, and *Heliotropium bacciferum*), 38 in Australia (*Acacia saligna*, *Allocasuarina huegeliana*, and *Acacia scirpifolia*), 101 in Europe (*Salvadora persica*, *Vachellia tortilis*, and Tamarix nilotica), 53 in North America (*Carex strigosa*, *Chaenactis douglasii*, *Stipa speciosa*, and *Deschampsia flexuosa*), and 4 in South America (*Casimiroa edulis*, *Colletia spinosissima*, *Pinus nelsonii*, and *Pyrus nivalis*). Confidence interval around the predicted ECe values of the potential salt tolerance of such species could be quantified to determine their maximum level of tolerance. Additionally, dosage response experiments should be carried out on such species.

Practices and guidelines to restore evergreen forests in Kenya: after changed fire regimes, degrading uses, and introduced tree species stands

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Natural evergreen forest systems in Africa have developed various strategies over millennia to recover from diverse types of natural disturbances at various scales and regimes. Such systems in most cases provide more cost-effective recovery with higher biodiversity, productivity, and diverse resource use value than artificial planting systems. The natural forest systems have canopy tree species that range from fast-growing, strongly light-demanding, early regrowth species to slower-growing, shade-tolerant species in the more advanced stages. They also vary in their fruit-seed dispersal strategies. Such characteristics contribute to a succession of species from the early to advanced recovery stages, and in use value. Forestry plantations and most invasive introduced species represent the tree species of the early recovery stages.

We present concepts for restoring such evergreen forest from three case studies and indicate how thousands of local rural resource users could form part of and benefit from such recovery actions. In the Ngong Forest Reserve people settled in dense numbers at the base of Ngong mountain. This reduced the incidences of fires from the lowlands, causing development of natural forest tree species in former wooded grassland, that are used for firewood and poles by the surrounding people. The Chapalungu forest in Bomet County was cleared/destroyed by locals during 'political' interferences, leaving only few scattered trees with hanging beehives (by local believes/myths such trees may not be cut). This concept is used to restore this forest. The natural Karura forest within Nairobi city is surrounded by planted trees of introduced tree species. A combination of resource use by adjacent rural people with planting clusters of useful indigenous tree species can be used to restore and expand the Karura natural forest system.

In the three cases, resource use through selective stem thinning (of suppressed stems of light-demanding tree species) and branch pruning of remaining stems, as in plantation forestry, is advocated. Where necessary, group-felling can be applied to facilitate better regeneration of secondary natural forest species to speed up the recovery process. Forest landscape restoration is synonymous with active resource use, to the benefit of both the forest recovery and resource users.

Promotion and management of mixed natural regeneration in single layer Scots pine forests

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: In the pure Scots pine stands of the Northeast German Lowlands, the establishment of naturally regenerated mixed tree species is of particular importance to strengthen these forests against damaging abiotic and biotic factors in the future. But mixed tree species have been removed over the decades, and establishing natural mixed regeneration is proving to be a major challenge. This is especially true for the mostly poor sites with low water supply. Our research project investigates the development and growth of naturally regenerated mixed tree species considering: (a) pine canopy, (b) associated vegetation, (c) competition among regeneration plants, and (d) local precipitation. For this purpose, we recorded all tree positions of pines in the upper stand and of all regenerating tree species. We conducted intensive growth and quality measurements on the regenerating trees to document their growth and development potential. In addition, to understand the influences of microclimate on regeneration, precipitation was recorded on a 1 m x 1m grid.

The spatial distribution of seed trees results in area-specific proportions of regenerated tree species with densities ranging from 3,200 to 32,700 per hectare. In all nine study sites, Scots pine, sessile oak, and European beech were the most common tree species in the regeneration layer. In dense pine stands, the proportion of pine in the regeneration layer was less than 5 %, whereas this canopy effect was low for beech and oak regeneration density. The results of the spatial point pattern analyses illustrate the species-specific and distance-dependent effects of old-growth pine and precipitation amounts on regeneration plants. The spatial statistical analyses also show greater intraspecific aggregation of regeneration with increasing age. Tree species-specific analyses of annual shoot length increment demonstrate the direct influence of stand basal area as a regulating variable and the influence of precipitation. In years with particularly low precipitation, annual growth of regeneration plants is significantly reduced. The absolute differences in increment result in competitive shifts, which are of additional importance for silvicultural planning.

quaxnat - An R package for estimating regeneration potential based on forest inventory and remote sensing data

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Nowadays, the integration of natural regeneration is an important goal in the restoration of degraded forests. Regional and local information on the dispersal potential of tree species is insufficient so far. Therefore, a potential analysis of natural regeneration for concrete areas is to be developed as a basis for silvicultural decisions on forest restoration.

Data basis for the determination of the regeneration potential are inventory data of the permanent forest inventory. Remote sensing data are used to determine the distance to the nearest potential seed tree. Meanwhile, high-resolution remote sensing data sets with tree species detection are available for Germany and worldwide. Thus, there are valuable information for the position of seed trees of the respective species.

The dispersal potential of tree species can be estimated using a quantile regression. The regeneration densities are used to parameterise the dispersal potential of a tree species as a function of the distance to the nearest seed tree. With the help of a quantile regression, a statistical relationship between the distance and the potential natural regeneration density can be derived. Spatial predictions for natural regeneration potentials can be calculated using the fitted models for the dispersal potential of the tree species. These potentials can be compared with forest restoration activities to identify rationalization potentials through the use of natural regeneration. In this way, limited funds, staff and resources can be used for artificial regeneration where no natural regeneration is expected.

The R package *quaxnat* offers the possibility to determine a dispersal potential for certain tree species and to calculate spatial predictions of the dispersal potential. The presentation will introduce the methodological approach and give a first introduction to the R package.

Rehabilitation of post-extraction cutaway peatlands – the role of natural regeneration

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Globally, wetland ecosystems (permanently or seasonally flooded habitats) make a disproportionally high contribution to ecosystem services. Yet, up to 50% of all wetlands globally have been lost or degraded since 1900 due to human activities. For example, Ireland's intact peatland area has declined from 1,200,000 hectares to approximately 100,000 hectares in the last century, primarily due to industrial-scale harvesting of peat. However, the last two decades have seen increased recognition of the need to rehabilitate Ireland's peatlands, particularly to restore their status as a carbon sink to aid climate change mitigation efforts. In peatlands where industrial extraction of peat has ceased, without intervention, these degraded bog ecosystems can rapidly transition to wooded landscapes due to the natural regeneration of fast-growing native trees. The overarching aim of this project is to assess the factors contributing to the successful natural regeneration of native forests on post-extraction peatlands. Earth Observation techniques have been used to quantify the area of natural forest development on post-extraction peatlands in Ireland over the last two decades. In addition, an ex-situ experiment is set to assess the role of seed input, soil moisture and nutrient status, and microclimate on the early establishment and growth of naturally regenerating native forests on post-extraction peatlands. Ultimately, this project will inform future peatland restoration and rehabilitation approaches in Ireland and beyond.

Remedy Towards Poor Natural Regeneration: Best Practice strategy for on-ground action for Forest Sustainability

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: India is the 10th highest forest cover country in the world, followed by the SFM principles in last 2 decades. In the past seven decades since independence, India has shown remarkable progress in key development areas, but still, about 250 million people depend on forest resources for livelihood and income generation. The current forest cover of India is 7,13,789 square kilometers which is 21.72% of the geographical area of the country and the per capita forest cover is less than 0.058ha. There is a very low capacity of natural forest regeneration, only about 42 % due to severe biotic pressure in the form of overgrazing, firewood and fodder collection and illicit felling, forest fire, invasion of weeds, climate vulnerability and pressure on land diversion for development purpose. Most natural forests have a limited number of potential seed-producing trees. The quality of the country's forest in terms of average productivity, per capita availability, growing stock, and forest composition have declined in the past three decades. To restore ecosystems resilience and increase the forest cover in the country, afforestation and tree plantation activities have been given high priority but the implementation result is far below the target to achieve an additional 5 million ha of forest and non-forest land plantation in the Green India Mission (GIM). All 29 states and union territories of India make a reasonable effort towards afforestation activities under various programs and schemes of line Ministry such as the Mahatma Gandhi National Rural Employment Guarantee Scheme, National Compensatory Afforestation Fund (CAMPA), National Bamboo Mission, Sub-Mission on Agroforestry, etc. towards responding to climate change.

This paper argues for major efforts required towards an innovative mechanism for *in situ* natural regeneration initiative which is much more cost-effective and practical for the country. A multi-prong strategy gives more emphasis on reducing the drivers of degradation and restoring degraded forest lands by strengthening participatory forest management. By strengthening age-old practices of joint forest management which assisted natural regeneration, enrichment plantation, contour trenching, native tree seed dissemination, soil, and improved water conservation practices with people's participation against millions of hectares of new plantation every year.

Restoration of degraded tropical forests by assisting natural regeneration of valuable plant species in the North of Vietnam

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Tropical forests are important terrestrial ecosystems in the world. They are not only the home of many species of plants and animals, but also a huge carbon reservoir. The loss and degradation of tropical forests lead to negative impacts on biodiversity, environment and climate. In Vietnam, there are about 14.7 million ha forests (covering about 42.0% of the area), but they are mainly secondary and poor forests (accounting about 67% of natural forest area). The restoration of these forest areas is becoming an urgent issue in government's policy. The structure of forests has been changed by humans, the ecological and biodiversity functions have been reduced. However, in the degraded forests remnants of mature trees are often left. Our concept of restoration in these secondary forests relies upon these remnants left as a source of natural regeneration. *Erythrophleum fordii* Oliver (ironwood) is a valuable timber species and widely distributed in the north of Vietnam. Our research focused on disentangling the main factors effected to natural regeneration of *E. fordii* species aiming to restore degraded tropical lowland forests in the North of Vietnam. The natural regeneration of this valuable species is impacted by the distance to the conspecific adult trees and percentage of ground cover. By taking maximum distance to source tree remnants into account and carefully manage cover of competing ground vegetation in the surrounding of naturally established seedlings, this species can have an increased proportion in the next generation improving the value of the secondary forests.

Strategies and experiences in increasing the rodent-mediated early regeneration of Pinus koraiensis in restoring temperate secondary forests

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Korean pine (Pinus koraiensis) is the constructive tree species in the primary broad-leaved Korean pine forest (BLKPF) in Northeast China. Due to long-term destructive disturbances, Korean pine has basically disappeared and the BLKPF has degraded into a secondary forest. There are natural regeneration obstacles of Korean pine due to the limitation of seed sources in secondary forests. In addition, after the cones of P. koraiensis mature and fall off, they must rely on rodents to achieve seed regeneration. However, due to the difficulty in tracking the seed dispersal and subsequent regeneration process by rodents, the mechanism of rodent-mediated seed regeneration barriers is unclear. Therefore, it is urgent to adopt artificial regulation methods (such as changing forest structure, increasing artificial regeneration methods, etc.) to promote rodent-mediated early regeneration of Korean pine in order to restore secondary forests.

By conducting field investigations with infrared cameras, we tried to reveal the reciprocal antagonistic relationship between rodents and P. koraiensis under the coupling of source restriction and forest structure. In the forest treated with gaps, the relationship between selection of spatial sites for animal storage/feeding of Korean pine seeds and the composition and distribution of understory vegetation was determined through ground based LiDAR scanning. Direct sowing and planting seedlings were conducted in gaps and thinning plots to clarify short-term response of rodent-mediated artificial regeneration to forest structure.

The results showed that the lack of P. koraiensis provenance caused a 17% increase in the proportion of rodents feeding on seeds, and the mutual relationship between animals and P. koraiensis tended to be antagonistic. Forest gaps and thinning changed the canopy structure, understory vegetation composition, and spatial distribution characteristics, which has a negative effect on the animal-mediated seed regeneration process. Therefore, there are serious obstacles to seed regeneration of Korean pine, and even by regulating the stand structure, it is not possible to accelerate its rodent-mediated seed regeneration. However, without considering economic costs, short-term results indicated that forming large forest gaps or 50% thinning treatment, and planting 3-year-old seedlings were the most effective ways to promote the replenishment of Korean pine in secondary forests.

The impact of restoration approach on diversity of vascular plants, bryophytes, lichens and soil fungi in birch stands on previous agricultural land

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Restoring forests on previous agricultural land can rely on passive or active restoration. We compared the impacts of restoration approach (passive = natural regeneration *vs*. active = plantation establishment) on different biodiversity groups in 21-28-year-old birch (*Betula pendula* and *B. pubescens*) stands (n=22) on former agricultural land in Estonia, using birch stands (n=11) on native forest land as a reference group. We further analysed the effects of past land use (field, grassland, forest), and soil, stand and landscape variables on biodiversity. In addition, we evaluated whether the recovery of forest understory follows similar pathways in passively and actively restored stands, based on data of two monitorings with 8-year interval on permanent plots.

Altogether 33 shrub layer, 182 field layer, 70 bryophyte, 63 lichen species and 2830 soil fungal OTUs were recorded in 33 stands. Restoration approach impacted the richness of shrubs and bryophytes that were higher in naturally regenerated stands than in plantations. At the same time the richness of field layer and lichens as well as the diversity of soil fungi were related to other environmental factors. PERMANOVA analyses and NMDS ordination based separately on vascular plant, bryophyte, lichen and soil fungus data revealed compositional differences between naturally regenerated stands, plantations and native forests. However, the effect of previous land use (agriculture vs. forest) was clearly stronger than the effect of restoration approach. The results of repeated understory monitoring revealed that the recovery of forest understory took place in similar ways in plantations and naturally regenerated stands as the numbers of herbaceous and bryophyte forest specialists slowly increased in both stand types. The overall share of forest specialists in composition was continuously low forming 12.4% of herbs and 31.1% of bryophytes in plantations and 20.8% of herbs and 25.0% of bryophytes in naturally regenerated stands.

To conclude, we found that fast-growing birch plantations and naturally regenerated stands harbour similar richness of several biodiversity groups, at the same time showing clear compositional differences from native forests due to agricultural legacy.

The interplay between the importance of natural regeneration in regular forest management and knowledge of the ecological processes underlying it

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: Based on the life cycle and its stages, we aim to provide an overview of studies and case studies that highlight past research successes and current research needs in the field of natural regeneration. Our focus is to establish direct links from phase-specific regeneration research to concrete measures of practical forest management.

Using two very contrasting characteristics of forest trees - pioneers and shade tolerants - as examples, we show the effects of flowering frequency, seed set, seed dispersal ability, seed bank ecology, and seedling development of tree species on restoration success. The examples show that both traits may vary in how well they are adapted to given restoration conditions. However, it appears that ecologically and economically valuable shade-tolerant tree species generally suffer more from a lack of source trees near restoration sites and their seeds and seedlings are more susceptible to predation than those of pioneers are. Pioneers, on the other hand, often fail to colonise a particular site because of the harsh climatic conditions their germinating seeds and germinants are not adapted to, while their seedlings are often very resilient once established. This phase-specific example of sensitivity to climatic conditions, such as moisture deficits that hinder seed germination, could lead to major problems in the near future due to climate change.

Forest management may well aim to create the appropriate favourable environmental conditions for the diverse tree traits, which would increase the success of restoration efforts through natural regeneration.

The potential use of natural regeneration for restoring temperate rainforests in Chile: examples from Patagonia, Chile

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: According to the 2020 updated Chilean NDCs, Chile is committed to plant 200.000 ha of planted forests by 2030, 35% of then with native species. However, if restoration focus is placed only on artificial regeneration, at current plantation rate (<1,000 ha/year) this commitment is hard to meet. Nowadays, in the Chilean temperate bioclimatic region, probably the place with greatest potential for ecological restoration in the country, there are only ~100 restoration initiatives, most of them using artificial regeneration and developed on a small scale (<10 ha), and with evaluations of early performance in terms of survival and early growth, considering in best cases the first 5 years since plant establishment. This situation contrasts with the over 2 million hectares of second-growth forests that naturally regenerated after anthropogenic and natural stand-replacing disturbances the last century in the same region. This can be seen as an indicator of the resilience of these forests if we give them the option to regenerate on their own. In this study, we discuss the potential use of natural regeneration (NR) for restoring temperate rainforests in North-Patagonia, Chile, showing examples of forest restoration after anthropogenic fires, conversion to grasslands, and high-grading practices. We emphasize the need of promoting NR in sites beneath a nurse canopy or closed to remnant trees, and of complementing NR with artificial regeneration in order to foster natural succession in open places or away from remnant seed sources. Also we highlight the need of evaluating restoration success by integrating the study of structural, compositional and functional aspects of ecosystem integrity in restored areas. Applied research on these topics will give guidance to restoration practitioners as to how to restore temperate rainforests and how to evaluate restoration success. It will also allow us to know if during the UN decade of ecosystem restoration, we are only summing area with established trees or if we are really restoring functional forests for the future decades.

The surrounding landscape as a modulator of forest ecosystems developing through natural colonization in former cropland

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: The area of abandoned agricultural soil has increased in Europe and it´s projected to keep increasing in the future. With the ongoing biodiversity and climate crisis, it is expected that a large fraction of this abandoned land will be converted into forest.

Natural colonization and regeneration are considered cost-effective methods to create and restore forests. Although multiple benefits to biodiversity are expected from these methods, other ecosystem functions as carbon sequestration, might not be as efficient when compared to forest plantations. A reason for this might be that natural colonization is in some cases slow and even arrested due to biophysical legacies in the soil and the characteristics of the surrounding landscape.

Although there is some evidence of this on the vegetation layer, it is unclear how forest communities from the different compartments of the forest develop in naturally colonized areas on how landscape vs stand factors interact to influence this development.

We used a research platform of 10 sites in Denmark, each consisting of 4 land use types: natural colonization (NC), planted beech forest, mature beech forest, and agricultural field, where the natural colonization and the plantation forests are all ca. 30 years old. Within this platform, we investigated the insect, soil-borne microbiome and vegetation biodiversity using eDNA and conventional methods. We complemented this with information on the forest structure measured with LiDAR. Additionally, we characterized the surrounding landscape deriving metrics of fragmentation, composition and quality.

Moreover, we supplemented this with information from the Danish National Forest Inventory to explore a wider range of stand and landscape conditions and to explore the interactive effect of them on the development of forest´s diversity, structure and function.

We will compare how the different forest communities and functions develop under natural colonization and forest plantations and will examine the degree to which these responses are mediated by the surrounding landscapes. We will identify trade-offs and synergies between biodiversity and ecosystem functions that can inform spatial prioritization planning.

Using natural regeneration to restore native forests from Pinus radiata plantations in south-central Chile: Effects of different harvesting treatments

T3.19 Increasing the potential of natural regeneration in restoring degraded forest and deforested lands around the world: concepts, strategies, experiences and guidelines

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Abstract: In south-central Chile, there has been a significant expansion of commercial plantations of *Pinus radiata* in the past few decades, often at the expense of natural vegetation. In accordance with recent commitments to certification programs, forestry companies have initiated efforts to restore the native ecosystems replaced through plantations of exotic tree species after 1994. The spatial extent of required restoration, encompassing hundreds of thousands of hectares, increasingly unfavorable and unpredictable climatic conditions, and a lack of suitable planting stock, have led to rising costs and uncertainties associated to planting. Yet, most research on reforestation and afforestation in this region has focused on artificial regeneration. Thus, the understanding of natural regeneration processes for restoration purposes is limited. We conducted a large-scale experiment in mature *P. radiata* plantations of the Nahuelbuta Coastal Range. Our aim was to assess the effect of different harvesting treatments (clearcut, strip-cutting, and unharvested control) on the development of natural regeneration of native tree species. These treatments were replicated across three sites at varying altitudes on both the western and eastern slopes of the Coastal Range. We employed 4 indicators to analyze the development of natural regeneration, which was monitored on multiple permanent plots per treatment over a two-year period: 1) basal area of saplings (>50 cm height), 2) maximum sapling height, 3) frequency of plots with free-growing regeneration, and 4) species diversity. Although treatment effects varied among sites, the clearcut generally resulted in the highest increase in saplings basal area, followed closely by the strip-cutting. A similar pattern was observed for the frequency of plots with free-growing regeneration, while the strip-cutting exhibited the highest increase in maximum height and species diversity. Despite the higher growth of native tree species in the clearcut, this treatment also showed the highest increase in basal area of *P. radiata* saplings, which may eventually outcompete native species. Thus, if clearfelling is chosen to initiate restoration with naturally regenerated native species, effective control measures must be implemented to manage the competing *P. radiata* regeneration. Alternatively, strip-cuttings appear to be a promising option for a restoration approach requiring less intervention in the regeneration layer.

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

A new index for assessing forest biodiversity based on tree-related microhabitats and forest inventory variables

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Hosting over half of worldwide biodiversity, forests are one of the biodiversity richest terrestrial ecosystems. The increasing pressure of society for even more services, fostered the depauperation of this ecosystem, resulting in a loss of biodiversity. To preserve forest biodiversity, different agreements have been implemented, but monitoring forest biodiversity under human strong pressure represents a critical challenge. In the last years, different biodiversity indicators were developed for forest diversity monitoring, among which tree-related microhabitats (TreMs). Defined as well-delineated structures occurring on living and standing dead trees, created by biotic or abiotic events, TreMs received great attention in the last decades as key elements for the indirect assessment of forest biodiversity. TreMs and habitat trees, i.e., living or standing dead trees with at least one TreMs, constitute a particular substrate or life site for species and become increasingly important as conservation elements of forest biodiversity in regularly managed forests. Despite there are several studies focusing on the abundance and diversity of TreMs in different forest categories and forest management systems, studies on their spatial distribution within forest stands are still missing.

This study aims to introduce a new biodiversity index, based on the occurrence, diversity, and spatial distribution of TreMs. The index was tested in 109 marteloscopes belonging to the Integrate network. The index was calculated at different levels of TreMs hierarchical typology (i.e., type, form, group), highlighting its suitability to be implemented at different levels of investigation. To verify its robustness, the index was compared with the two indices often used for the assessment of forest biodiversity, such as the Shannon diversity index and the Clark and Evans aggregation index, highlighting similar patterns.

Considering the importance of TreMs for assessing multi-taxon forest biodiversity, and the possibility to introduce TreMs as an attribute to monitoring through the national forest inventory, the index represents a very suitable tool for assessing forest biodiversity throughout forest ecosystems. From the practical point of view, it can drive silvicultural interventions to retain habitat trees ensuring an appropriate spatial distribution.

Adapting forests to climate change: evaluating opportunities and risks of non-native tree species on ecosystem services

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Forestry is facing unprecedented challenges due to increasing climate change threats and disturbances. Particularly, economically important tree species are being lost and it is often unclear if native or non-native tree species (NNT) can be used as alternatives. The choice of tree species for climate-smart forests should not only take productivity, carbon sequestration and economic efficiency of forests into account, but also forest biodiversity and the provision of other ecosystem services. Using species distribution models of native and NNT as well as data from the Austrian forest inventory, we modelled the provision of various ecosystems services of Austrian forests under current and future climate conditions and by applying various species selection scenarios. The ecosystem services encompass the productivity of forests, their protective function against avalanche and rockfall events, as well as their resistance to wildfire. Five different species change scenarios were evaluated: (1) no tree species change, (2a) replacement of lost species with native tree species which are climatically most suitable, (2b) replacement of coniferous with native coniferous trees and deciduous with native deciduous trees, if appropriate; (3a) replacement of lost species with non-native trees if they show a higher suitability to future climate; (3b) replacement of coniferous with non-native coniferous trees and deciduous with non-native deciduous trees, if appropriate. The results indicate that relying solely on native species would result in a decline in both productivity and biodiversity in terms of tree species composition. This negative impact can be mitigated by increasing the proportion of NNT. However, it is important to note that the selection of native or NNT has a lesser effect on the protective function of forests. Depending on whether productivity, the protective function (ecosystem service) or tree species diversity (biodiversity) are considered, different species selection scenarios can be recommended. Accordingly, a good balance of tree species is of particular importance in order to be able to meet the different requirements of climate-smart forests. Especially in the protection forest, different aspects are important than in production forest. Our results provide a knowledge basis for Austrian forest owners/managers to make decisions on a sustainable choice of tree species.

Assessing the impact of biodiversity indicators' scale and management diversification on biodiversity connectivity patterns.

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Biodiversity and ecological concepts are becoming an increasingly important component of forest planning. However, central concepts in ecology, such as spatial and temporal connectivity, are often neglected in forest planning studies. To appropriately incorporate biodiversity protection into forest planning, we therefore need to quantify how forest management practices impact connectivity patterns.

Biodiversity models used in forest planning often rely on broad-scale objectives that may ignore local specificities important for connectivity. Additionally, the traditional monospecific even-aged management applied in European boreal forests is another obstacle to habitat connectivity.

Our study investigates the impacts of (1) using local indicators in biodiversity objectives and (2) diversifying management on habitat connectivity. We simulated the development of a small, forested landscape in Norway as a case study. To investigate the impact of shifting biodiversity objectives from the global to the local scale, we defined two scales for biodiversity indicators: broad- and fine-scale. For broad-scale, biodiversity objectives are set at the landscape level, using indicators based on biodiversity policy in Norway. For fine-scale, biodiversity objectives are set at the stand level based on the conditions and biodiversity status at the beginning of the planning period. Through multi-objective optimization, we identified optimal prescriptions for increasing levels of management diversity, going from homogeneous to heterogenous treatments in terms of rotation ages, harvest and thinnings intensities, and types of regeneration. We then compared the impact of the optimal prescriptions on spatial and temporal connectivity to define which combination of scale and diversification results in the highest connectivity in the landscape.

Our preliminary results suggest that a combination of fine-scale biodiversity objectives and high diversification level will result in a higher spatial and temporal connectivity. However, this leads to a reduction in the net present value and timber extracted from the forest. We anticipate that our results will be valuable to determine the degree of indicators specificity and management diversification required for biodiversity policies to efficiently promote habitat connectivity.

Balancing biodiversity and recreation – the public's perspective

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Managing forests for society requires knowing and incorporating the perceptions, attitudes, and preferences of the local population. Among the cultural ecosystem services provided by forests, aesthetics and recreation belong to the most important ones in Switzerland. The urban populations' need for easily accessible forests for outdoor recreation makes management of these forests for recreation indispensable, and inadequate visitor management can cause conflicts between recreation and biodiversity, e.g., reduced biodiversity due to trampling of soil and vegetation. On the other hand, results from the Swiss Sociocultural Forest Monitoring WaMos – conducted as a representative online survey focusing on the relationship of the population to the forest – show that awareness concerning the general decline in biodiversity has grown over the last years and that the Swiss population has an increasingly positive attitude towards the ecological function of our forests. Consequently, acceptance of nature conservation measures in forests is high. Nevertheless, confronting forest visitors on-site with forest management aimed at enhancing biodiversity sometimes provokes contradictory reactions. A study concerning the attractiveness of various forest management forms revealed that different stages of coppice-with-standards – managed to enhance biodiversity – received lower ratings than other management forms, even compared to even-aged high forest consisting of a monoculture of coniferous trees. Forest management in multifunctional forests with recreational areas has to consider visitors' needs and preferences to avoid a lack of understanding, protests and (often unintentionally) damaging behaviour.

Co-creating forest management plans for better accommodation of biodiversity and a landscape perspective.

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Landscapes worldwide have become fragmented and degraded, posing a threat to biodiversity and ecosystems. In Sweden, companies or private forest owners orientated towards timber production for commercial purposes own most of productive forest. Thus, exclusive reliance on increased areas of set-asides for enhancing the status of forested landscapes would be costly and require an elaborate process to acquire acceptance. Rather, there is a need for approaches integrated into standard procedures for forest management and planning. The forest management plan (FMP) plays a vital role in Sweden's forestry, serving as an instrument for generating and implementing forest management alternatives. To effectively balance diverse objectives and consider different management options, including aligning estate management with landscape features, the current FMPs require improvement. Additionally, there is a need for advancing the planner's core capacity from production-oriented technical expertise to a wider skill-set, while matching the owner's multi-dimensional needs.

To address these needs, our study goes through three phases. First, we will conduct ethnographic observations of planning operations followed by semi-structured interviews with forest planners to examine their motivations, expertise, and planning procedures, including the accustomed ways to integrate the landscape perspective in FMPs. Second, we will create a low-cost, standardised method to assess how estate management affects landscape values. Finally, we are going to co-design novel planning procedures and pilot them on selected forest estates.

To achieve better consideration of biodiversity and multitude of ecosystem services in FMPs, we intend to produce procedural guidelines, a prototype plan that includes landscape features, and a training module for planners. Our approach is based on knowledge co-creation between scientists, forest planners and owners, enhancing the likelihood of practical implementation on a broader scale.

Development of plant and fungal communities after afforestation on agricultural soils – highlights form three chronosequences in Denmark.

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: The ongoing afforestation in North European countries like Denmark is often limited to agricultural soils. The creation of forested areas has the potential to foster rich and resilient ecosystems, providing services and habitats for specialist species. However, biodiversity recovery in forests planted on agricultural soils is hindered by land use legacies and fragmented landscapes.

This study investigates the drivers of biodiversity recovery in afforested agricultural land from the perspective of plants and fungi, in order to guide management choices and suggest new options tailored to the constraints of these habitats.

We studied three chronosequences in Denmark spanning 60 years of afforestation with three different tree species, surveying the vegetation and sequencing microbial DNA. The space for time substitution sampled in 2021 was supplemented with vegetation and soil surveys taken 20 and 10 years ago. We explored the effects of soil and tree development, tree species, forest structures, management, connectivity, and the influence of the communities on one another. We then modeled the impacts of these factors on forest specialists and the whole communities, using distinct models for variables describing the environment and management choices.

We found that plants and fungi respond to different aspects of forest development: the plant communities are shaped by light availability and disturbance, while fungi respond more strongly to soil development and tree species. Furthermore, structural heterogeneity, canopy cover, and vicinity of the reference forest drive the abundance of forest specialists. In the chronosequence, however, communities did not develop to resemble the old forest reference. Indeed, while many forest plant species appeared, only those with long-range dispersal capability colonized the plantations; on the other hand, soil physicochemical properties did not fully approach the reference, possibly producing the difference found in the fungal communities.

We, therefore, confirm that forest structural diversity and connectivity can promote potential biodiversity, but a lack of seed sources, dispersal limitation, and lingering soil legacies affect the establishment and recovery of specialist communities. Furthermore, we highlight the different needs of plants and fungi, remarking on the strength of the long-term effects of agriculture and the importance of assisted dispersal to overcome landscape barriers.

Effects of habitat tree retention on adjacent regeneration growth in continuous cover forests in Central Europe

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Habitat tree retention, a relatively recent but widely applied practice in temperate European forests, involves the permanent preservation of mature trees during the course of harvesting. The aim of habitat tree retention is to enhance biodiversity, maintain ecosystem functionality, and provide resources for a wide range of species in production forests. Retention of habitat trees benefits a range of forest-dwelling species. However, our current understanding about the effects of habitat tree retention on wood production and other ecosystem functions is rather limited, especially in Central European continuous-cover systems. Without this information, the costs and benefits of retention cannot be calculated and the tree growth of production systems cannot be accurately modeled. The goal of this study was to measure the effect of retained habitat tree groups on the surrounding regeneration and regrowth stands. We analyzed data from ca. 120 habitat tree groups in the state forests of Baden-Württemberg Germany. All stands were dominated by European Beech and Silver Fir. The surrounding regrowth was measured by means of linear transects into all four cardinal directions. Here we show how diversity, growth and quality of surrounding regrowth and regeneration changes with distance from habitat tree groups and how it is influenced by microclimatic effects, hemispheric direction, tree species traits (e.g. shade-tolerance), and condition of the habitat tree groups (size, vitality, density) and of the surrounding matrix. Our results are directly relevant to integrative forest management, by providing an evidence-base for synergies and trade-offs between biodiversity conservation function and other ecosystem functions of habitat trees.

Employing a dynamic approach for habitat tree selection in temperate forests of Europe

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Selection of living habitat trees in the multiple-use forests of temperate Europe is commonly done on the basis of their tree-related microhabitats (TreMs). TreM occurrence is largely determined by the dimension, vitality and species identity of the habitat tree. Thus, TreM assemblages and associated forest-dwelling species will be affected by changes in tree attributes such as those driven by increasing rates of climate change-related disturbances and tree mortality. So far, retention forestry approaches have been rather static, not considering the temporal dynamics of habitat trees and their TreMs.

Based on data describing TreMs borne by functionally-different trees, we provide the first evidence-base for dynamic habitat tree selection in temperate forests. We compared the TreM abundance and richness on trees with contrasting life-history traits: lifespan, growth and wood decay resistance. To identify how TreMs are changing over time, we estimated the rates of TreM persistence and loss based on longitudinal data from repeated inventories and employing methods of survival analysis and generalized linear mixed models. Further, we described how TreMs change after tree death by comparing their occurrence on dead and living trees.

Our analysis showed that pioneer tree species developed TreMs quicker than longer-lived tree species. Tree species such as *Populus* and *Betula* play an important role in accelerating habitat restoration. We also highlighted that living habitat trees had distinct TreMs, not found on deadwood. Even though overall TreM abundance and richness increased over time on living habitat trees, individual TreMs on those individuals were at risk of being lost. While dead habitat trees cannot substitute the habitat functions of living broadleaved trees, they complement them. The overall stand-level TreM diversity can increase, in particular through decayed, large snags.

Considering the temporal development of TreMs on functionally-different habitat trees can support a more continuous provisioning of resources for species that depend on them. We emphasize the importance of an abundant and stable supply of TreMs, in order to decrease the risk of losing rare TreM types over time.

Enhancing multifunctionality in European boreal forests: the potential role of Triad landscape functional zoning

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Land-use policies strive to enhance the sustainable use of natural resources. The Triad approach has been suggested to balance the social, ecological, and economic demands of forested landscapes. The core idea is to enhance multifunctionality at the landscape level by allocating landscape zones with specific management priorities, i.e., production (intensive management), multiple use (extensive management), and conservation (forest reserves).

We tested the efficiency of the Triad approach and identified the respective proportion of above-mentioned zones needed to enhance multifunctionality in a Finnish forest landscape. Through a simulation and optimization framework, we explored a range of scenarios of the three zones and evaluated how changing their relative proportion (each ranging from 0 – 100 %) impacted landscape multifunctionality, measured by various biodiversity and ecosystem service indicators.

The results show that maximizing multifunctionality required 20 % forest area managed intensively, 50 % extensively, and 30 % allocated to forest reserves. In our case study, such landscape zoning represented a good compromise between the studied multifunctionality components and maintained 61 % of the maximum achievable net present value (i.e., total timber economic value). Allocating specific proportion of the landscape to a management zone had distinctive effects on the optimized economic or multifunctionality values. NPV was only moderately impacted by shifting intensity of management from intensive to extensive, while multifunctionality benefited from less intensive and more diverse management regimes.

This is the first study to apply Triad in a European boreal forest context, highlighting the usefulness of this approach. Our results show the potential of the Triad approach in promoting forest multifunctionality, as well as a strong trade-off between net present value and multifunctionality. We conclude that simply applying the Triad approach does not implicitly contribute to an overall increase in forest multifunctionality, as careful forest management planning still requires clear landscape objectives.

Enhancing tree diversity for the mitigation of climate change-induced phenological mismatch between breeding birds and prey in temperate forests

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Climate change has caused a phenological mismatch between consumers and prey, reducing prey availability andhence leading to fitness consequences and their ecological service. In this study, we aimed to understand how the phenological mismatch on diet use and reproductive output of a forest songbird (Varied Tit, *Sittiparus varius*) were affected by the peakedness of caterpillar availability in temperate mixed deciduous forests with different vegetation covers. With two-year data collected in five plots across elevational gradients, we analyzed the change in in body conditions of nestlings and in two stable isotope values (δ13C and δ15N) of their blood samples related to the degree of phenological synchrony and peak season of caterpillar availability (peak prey season). We found that the peak prey season extended as the tree diversity increased in the forest. The higher δ13C values of nestlings with later peak timing indicated that their parents might feed less caterpillar which is the key prey of forest birds, and the δ15N significantly changed with the degree of synchrony only when the peak prey season was shorter. The nestling conditions decreased over the breeding season when the peak prey season mismatched. Consequently, these findings suggested that the effect of phenological mismatch on forest songbirds' prey use and reproductive output would be mitigated by a more extended peak prey season, which may be achieved by improving tree diversity in temperate deciduous habitats. Given the abundance and distribution of Varied Tits, forest managements enhancing the tree diversity may mitigate the negative impacts of phenological mismatch on ecological services of the most commont forest bird (such as seed disperser, insect pest control, etc.) through the improvement of prey-consumer interactions in the temperate forest ecosystem.

Forest and forest landscape planning and restoration for integrated multi-functional capacity in Swedish Ecoparks

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Swedish forestry relies on simultaneous realization of wood biomass production and environmental goals as reflected in the principles of sustainable forest management. To achieve this, operationally, tactically and strategically, forestry planning relies on four management-goal classes; PG – wood biomass production with general conservation consideration, PE – as the previous but with enhanced conservation consideration, NM – nature conservation with management, and NF – natural development without management. The two former classes focus on wood biomass production whereas the two latter strictly on nature conservation. This classification system is applied on 22 million ha forestland in Sweden. Following long-term intensive forestry systematically across the Swedish forest landscape, however, the outcomes for nature conservation, socio-cultural and other environmental values are deficient, as recently concluded in the evaluation of the national sustainable forestry environmental criteria. Thus, the needs for advancing restoration and multi-functionality in forests and forest landscapes are well established but also urgent to act upon. Applying 37 Ecoparks ranging from the subalpine and north boreal to the south nemoral on the Swedish State forest company Sveaskog holdings, this study aimed for exploring the extent to which these management-goal classes promote integrated multiple use planning. The Ecoparks, covering in total about 250,000 ha whereof 180,000 ha forestland, are areas where Sveaskog apply a higher nature conservation ambition than elsewhere in managed forest landscapes. We found that the Ecoparks provide extensive restoration opportunities favoring nature conservation, mainly within the PE and NM management-goal classes. We also found, however, that that many multiple-use values, e.g., reindeer husbandry and recreational values, are not reflected in the classification system. We conclude that a classification system that accommodate the sustainability principles needs to integrate values beyond wood biomass production and nature conservation, and that restoration, including also specific management favoring multiple-use values, needs to be better reflected. Hence, there is a need to revise the management-goal classification system for Swedish forests and forestry. Based on our findings, we propose and discuss an alternative system that include wood biomass, multiple-use and nature conservation oriented goals, with restoration embedded to secure forest conditions that better facilitate multiple-use capacity and hence sustainable forestry.

Forest Biomass for Energy: A Systems Assessment of Sustainability of the Strip Cut Forest Harvest Method

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Despite the interest in increasing forest bioenergy use, gaps remain in the understanding of how much, how often, and in which spatial pattern forest biomass can be removed from a site before it begins to adversely affect forest ecosystem resources. In this study, woody biomass yield, soil fertility, and the abundance and diversity of herbaceous plants and birds were quantified in a replicated design (n=3 sites) with Cut strips of different widths, Residual strips left between the Cut strips, and an uncut Control in a temperate, deciduous forest in the central Appalachian Mountains in West Virginia, USA. In 2020, at each of the three sites, stripcutting removed woody biomass from three, 30-m long Cut strips. Cut strips varied in width (2.4 m, 3.7 m, or 4.9 m – allowing one to two passes of harvesting equipment). Trees in the Cut strips were 6 years old (a prior cutting had occurred in 2014); in the Control and in Residual strips (2.4 m wide), trees were 17 years. Biomass yield differed significantly between the strips of different widths, with 0.046 t (dry weight) ha^{-1}, 0.31 t ha^{-1}, and 10.4 t ha^{-1} harvested from the 2.4-m, 3.7-m, and 4.9-m strips, respectively. Soil fertility, assessed via Soil Organic Matter content at 0–10 cm depth, ranged from 22% to 28% but did not differ between Cut strips, Residual strips, and the Control. In the herbaceous layer (vascular plants <1 m height), leaf area (LA), species richness (R), and Shannon diversity (H) tended to be higher in Cut strips regardless of width than in the Control. Comparing the Cut strips of different widths, no statistically significant differences in LA, R, or H, respectively, were detected. An edge effect also benefitted the herbaceous layer in Residual strips. Avian abundance and diversity were greater in the vicinity of stripcut sites than in the surrounding forest matrix. Thus, stripcutting, in lieu of pre-commercial thinning, appears to be suitable to produce woody biomass when strips are at least 4.9 m wide while simultaneously benefitting the herbaceous and bird communities without short-term deleterious effects on soil fertility.

Framing European forest management terms and definitions for effective forest biodiversity studies

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Plenty of forest classifications are inconsistently used in forest biodiversity studies. This hampers their comparability, and makes the assessment of forest management effects on biodiversity highly context-dependent. Improving the comparison of European forest biodiversity studies is pivotal for the implementation and monitoring of sustainable forest management policies and retrospective meta-analyses. Recent attempts to standardize forestry definitions mostly used a top-down approach, regardless of the information reported in scientific articles and of the perspective of forest biodiversity experts. With this contribution, we aim to define a common standard for silvicultural operations and types of vegetation to adopt in forest biodiversity studies coupling a novel bottom-up and a top-driven review process. The work results from the networking activities of the COST Action “BOTTOMS-UP” (CA18207), which gathered and standardized data on multiple taxonomic groups, forest structures and management from European forests in a single harmonized platform. We highlight strengths and weaknesses of the silvicultural and vegetation information provided in biodiversity monitoring studies. Most recent studies based their conclusions on the analysis of the relationships between forest biodiversity and a given management regime or silvicultural system. While quantitative data on forest biomass and dominant tree species are frequently reported, specific information on silvicultural activities and vegetation composition is often lacking, superficial, or based on broad and heterogeneous classifications. We propose to: i) increasingly pay attention on the terminology used in research projects dealing with forest management and biodiversity; ii) use a common set of terms and data classification; iii) integrate specific terminologies with in-depth descriptions and ancillary data. The proposed standard could be adapted to other continents’ requirements and extended to other types of interventions in forests, bridging the gap between practice and science.

How integrated forest management caters to recreationists

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Integrated forest management (IFM) mainly revolves around the combination of production and conservation targets within a single area. The related forest management measures, such as the promotion of natural regeneration, selective harvesting and a continuous forest cover, do however also provide additional positive externalities, like aesthetically pleasing forest stands. The COVID-19 induced lockdown provided a prime example of this. Using long-terms visitor counts as well as hundreds of on-site interviews in the Kottenforst near Bonn, Germany, we studied forest visitors'perceptions of the forest and its management before and during the pandemic - when we identified a tremendous boom in forest visits.
One of the focal points of the study was the impact of various forest magament measures that compose IFM and how they affected the attitudes of the interviewed recreationists. IFM turned out to be a key factor in the high appreciation of the forest landscape, but the results also showed that the interviewees were generally not aware of the active management behind it. The selected forest stands were broadly perceived as being natural, despite their long and ongoing managment. IFM thus shows a potential to not just safeguard ecological processes and habitats in management forests, but also to cater to the ever evolving expectations of an increasingly urban populace.

Impacts of future forest use on biodiversity, ecosystem services and climate

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: We aim to identify pathways of sustainable future forest management that develops the bioeconomy and multifunctional forests by mitigating climate change, delivering non-woody ecosystem services and preserving biodiversity. This will be based on analyses of synergies and trade-offs among alternative uses of forest biomass for Sweden the coming 30 and 80 years. Our methodological approach is to simulate many forest management alternatives for the national forest inventory plots and then apply multi-objective optimization to identify future pathways that fulfil objectives to be specified for the Swedish forest. This optimization will concern harvest level, ecosystem services, biodiversity and climate chance mitigation, the latter based on life-cycle assessment. In the work, we will further utilize models for different non-woody ecosystem services and a wide range of species representing different organism groups. I will present our starting work on joint optimization of objectives on these wide-ranging responses of forest biomass use. In the presentation, I aim to answer these questions: How should we manage and harvest the Swedish forest to make red-listed species increase with 50%, retain current levels of non-woody ecosystem services and obtain maximal climate change mitigation? This will consider both the alternative of storing carbon in the forest or substituting fossil-based products for bio-based products. Will the management be different if the time horizon is year 2050 or 2100? Moreover, can we reach the 50% increase of red-listed species and what will be the effect on climate if we apply BAU forestry and today's protection for conservation versus if we apply forestry according to the EU Biodiversity Strategy (10% strict protection and 20% closer to nature forestry)?

In times of change: Water and forest policy integration in Germany

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Worldwide we are facing an increased frequency of disturbances related to global warming. Drought and its consequences have led to water scarcity and forest cover losses, floods have caused many casualties and polluted water bodies further reduce access to clean water resources. Water ecosystem functioning is highly dependent on forests, as especially forest biodiversity is crucial for a sustainable provision of high quality freshwater. It is thus, that throughout the last decade the interlinkages between water and forest has gained increasing attention in the scientific debates, commonly referred to as the water-forest-nexus. In order to govern these interlinkages and develop integrated water forest management approaches, scholars call for cross-sectoral policy integration. Policy integration is understood here as the joint development of policies across sectors. In the case of water and forest interlinkages, scholars deem it crucial that representatives of both sectors jointly engage in the development of policies that manage disturbances like drought, low water quality, and flood events. In our research we follow the implementation of water-forest policy integration by analyzing the respective sectors of Germany. In Germany, institutional and ideational policy integration of water and forest sectors were previously observed as low. With the publication of the German National Water Strategy in March 2023, however, forest concerns are for the first time integrated into water policy making. Our research aim is thus to analyze the corresponding policy change, which we deem necessary for the development of integrated management practices. Via a discursive-institutional analysis, we identify causes for the (late) implementation of water forest policy integration. The analysis is based on policy documents as well as expert interviews and follows the question how policy integration between the German water and forest sectors has entered the policy debates.

Managed forests and their ecological integrity: a case study in Central Mexico

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Timber production is not the only forest management objective to fulfill today; essential to sustainable use are also the conservation of biodiversity and the provision of other ecosystem services and functions. In this study, we set up and applied an index of ecological integrity (IEI) as a tool to assess the integrity status of managed ecosystems in a mountainous area of central Mexico. The study area had four vegetation associations: three under timber harvesting (with *Pinus montezumae*, *P. patula* and *P. pseudostrobus,* respectively) and one as a conservation area *(Pinus-Quercus*). The structure, composition, and function of these temperate forests were assessed at 79 sites using 20 indicators, corresponding to three ecological attributes: landscape, vegetation, and soil. The IEI was built to assess sites in the categories of excellent, good, fair, and low condition. The highest IEI value found was for the conservation area, within the excellent category, while the harvesting zones were classified as excellent (*P. patula)* and good *(P. montezumae* and *P. pseudostrobus)*. The IEI allowed for the characterization of the associations under management and the identification of indicators that required intervention or further research to maintain the IEI in an acceptable category. A baseline of knowledge was generated for the study area, and can be useful as a guiding sustainable forest management and harvesting practices.

Natura 2000 hemi-boreal forests in Lithuania – finding favourable management strategies towards meeting long term conservation aims

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Natural habitats are protected, but management recommendations are still missing: the practises vary from strict conservation to business as usual in various European countries. Long term conservation is challenging for forest habitats, most of stands have even-aged structure, low tree species diversity, are vulnerable to damages and natural development often tends unfavourably. Hemi-boreal conditions require specific forest management.
The proposed concept of forest habitat management is based on division of habitat types into two categories: (I) Unique, not abundant and sensitive habitats; (II) Wider spread and typical habitats for the region. Management planning for category I habitats should be limited to stand level (conservation management, forest protection and growth measures); category II – planning expanded to a whole protected area by imitating natural forest dynamics that provide wider platform for silviculture manipulations. To achieve favourable status of forest habitats at protected area level the overall stand age structure of habitats should be considered.
The aim of the *conservation measures* is to obtain or/and maintain favourable conservation status of habitat. Applicable to all habitat types. They include stand management by cuttings and other necessary actions: invasive species control, forest density and structure management, undergrowth limitation, inhibition of unfavourable succession, prescribed burning, hydrological regime restoration, etc.
Planning *landscape natural dynamics imitation cuttings* must be undertaken on a whole protected area. As a safeguarding mechanism, it is required to exclude 30% of the most valuable habitats for the patch conservation management level, the remaining 70 % are subject to cuttings. It is based on natural forest disturbances of a habitat type and depends on typical disturbance characteristics and includes single tree (<0.05 ha) cuttings, small gaps (<0.25 ha) and large gap formations (0.25-1.0 ha). Large gap formations are applicable only if new patches of that habitat type were developed and identified at the level of the whole area of conservation.
Forest protection and growth measures can be applied under critical situations at limited extent. Measures should support or improve long term favourable habitat conservation status, not contradict defined protection goals, positively affect habitat. It includes stand sanitary control, thinning, reforestation and wildlife damage prevention.

Prediction of tree-related microhabitats across the European forest ecosystems to support the integrative forest management approach

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Silviculture has traditionally been considered the science of growing and taking care of forests to promote high-quality timber production. However, over the years, there was an overall increase in awareness of the multifunctional role that forests play in human well-being, providing several ecosystem services. Among others, the conservation of biodiversity is considered of vital importance for which numerous forests are recognized as protected areas (e.g., strictly forest reserves and national parks), leaving the remaining forests for harvesting activities. The integrative forest management approach was introduced to balance timber production and the conservation of biodiversity of forests that are managed for commercial purposes. In light of this, tree-related microhabitats (TreMs) have gained attention over the past decade as a multi-taxonomic biodiversity indicator for retaining structural elements, such as habitat trees.

This study aims to predict TreMs across European forests exploring the existing relationships with dendrometric and topographic variables. Based on the European Integrate Network of marteloscopes, several generalized linear (or mixed) models were run to predict the occurrence, abundance, and richness of TreMs in different forest types.

Findings highlight the usefulness of TreMs as indicators of multi-taxonomic biodiversity, representing a suitable tool for assessing forest biodiversity and promoting integrated forest management. The predictive models can be tested with the forest inventory attributes to extend the assessment of potential biodiversity throughout European forests.

This study provides significant insights to promote the retention of high-value habitat trees, highlighting the need for developing a biodiversity-smart forestry toolkit, which can result strongly important for the management of forests within the Natura 2000 network.

Production forests in a changing climate - Balancing biodiversity and ecosystem services

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Climate change adaptation and mitigation strategies (CCAMS) are changes to the management of production forests motivated by the need to mitigate climate change, or adapt production forests to climate change risks. Fennoscandia is employing CCAMS with unclear implications for biodiversity and forest ecosystem services (ES). Here we report our findings from the SPARC project, in which we synthesized the outcomes of 54 published scientific reviews and evaluated the potential for balancing biodiversity conservation with a range of provisioning, regulating and cultural ES when adopting CCAMS relative to standard forestry practice. The CCAMS assessed were the adoption of i) mixed-species stands, ii) continuous cover forestry, iii) altered rotation lengths, iv) conversion to introduced tree species, v) logging residue extraction, vi) stand fertilization, and vii) altered ditching / draining practices. There were clear differences in the consistency of different CCAMS with their capacity to enhance the habitat provision of production forest stands and landscapes. As importantly for CCAMS uptake, CCAMS that had more synergistic outcomes with biodiversity goals have the potential to provide comparable or increased levels of biomass production or soil carbon sequestration. These CCAMS can also provide for a broader range of additional ES delivery than CCAMS incurring trade-offs with biodiversity. Nevertheless, there were no silver bullets. The adoption of specific CCAMS entails a suite of implications for biodiversity, biomass production, and stand recreational and aesthetics values, as well as highly specific trade-offs and synergies with respect to which abiotic and biotic disturbance risks are reduced or enhanced. Balancing these outcomes and making necessary trade-offs creates challenging conditions for decision-makers when choosing between alternative forest management strategies. Thus, there is a need for effective planning among decision makers and stakeholders to develop and implement landscape-scale CCAMS strategies that better integrate potential synergies and minimize trade-offs when balancing biodiversity and ES outcomes.

Simulating forest dynamics during field marteloscope exercises to analyze the effects of silviculture on ecosystem services and biodiversity

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Marteloscopes are forest plots used to teach tree marking and to discuss silvicultural strategies. They are popular with forestry professionals, students and the general public as tools that make silvicultural concepts concrete and stimulate discussion among participants. This is particularly the case in mixed continuous cover forestry and in situations of trade-offs between ecosystem services. Several computational tools have been developed to represent the forest plot before and after harvesting and to compare the markings of different groups of participants. We present here a complete processing chain that allows to simulate in the field with the Samsara2 simulator on the Capsis platform not only the proposed field marking, but also successive silvicultural interventions consistent with the field marking, and the stand evolution over 50 years. We present an application of this process on a marteloscope designed to raise awareness of the effects of silviculture on wood product supply, biodiversity conservation and carbon sequestration. We also show the economic consequences of different strategies for the forest owner, which could provide a basis for thinking about payments for ecosystem services. We discuss initial feedback from participants on the educational value of this approach and future developments towards the inclusion of other ecosystem services and the evaluation of silvicultural strategies in relation to climate change.

Strategic management of the portfolio of forest ecosystem services in public forest enterprises in Slovakia

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: The work identifies the difference between the current and future strategic management of the forest ecosystem services (FES) portfolio in Slovakia's public forest enterprises. We chose public forest enterprises in Košice, Banská Štiavnica, Kremnica, and Bratislava. These enterprises represent examples of the best practices in providing cultural services within the individual regions of Slovakia. The current portfolio of forest ecosystem services was analysed using a marketing decision-making model (BCG matrix). The input data were revenues for individual forest ecosystem services of respective companies. The content analysis of the interview was used to evaluate the future position of forest ecosystem services in companies' portfolios over the horizon of 10 years. Structured interviews were conducted with managers of selected forest enterprises. Currently, the portfolios of all companies are unbalanced due to the dominant position of revenues for provisioning services (especially wood production). Revenues for provisioning services account for 67-99%, cultural 0.33-32%, and regulatory and maintenance services 0-1.84% of total revenues. Revenues for regulatory and maintenance services are realized as compensation for the limitation of regular economic activity or finances to support non-production services. Company managers are of the opinion that no significant changes will occur in the next ten years. Enterprises will apply a combined management approach, and revenues for provisioning services (wood) will form the primary source of income. Cultural services will be provided similarly to today, while their financing will depend on the revenues from selling wood assortments again. At present, the exception is the public forest enterprise in Bratislava, which partially balanced its portfolio with the financial support of the city budget. Based on the content analysis of the interview, we can label the managerial approach of FES management in Bratislava enterprise as close to nature management.

Keywords: forest ecosystem services, urban/public forest enterprises, portfolio, BCG matrix, future

The ecological value and ecosystem services of young native woodlands

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Ireland has an ambitious afforestation programme aimed at increasing forest cover. While the overall forestry programme is still primarily focused on timber production, with conifer plantations remaining central to its delivery, recent targets include a significant proportion of native woodland afforestation. In addition to increased standard payments, landowners are now also being incentivised to plant native woodland for ecosystem service payments from public and private sources. Ecological structure and condition attributes for mature native woodlands are well established, however these do not represent the potential ecological values of immature woodlands which may align more with those of open habitats. There is a need for data to inform relevant indicators of ecological value of young woodland sites and to understand how these change as the woodlands develop. This presentation will describe the results of field research carried out in 2022 and 2023 in planted native woodland sites in Ireland aged between 2 and 20 years old. Data on the structure and flora within 100m^2 plots across a range of woodland sites were collected, and pollinating insect surveys were carried out at a subset of these sites. Based on the results of these surveys, we will discuss what factors may be driving the diversity and composition of species in the young woodlands, which aside from age may include former land use, management approaches or landscape influences. We will also explore how ecological data can be transformed into ecosystem service metrics. The success of native woodland establishment in Ireland is often summed up as 'the right tree in the right place', and so the implications of this research for current approaches to planting and management will be highlighted. The work forms part of the ongoing multidisciplinary FOREST project, which is aiming to explore different perspectives on the values of extending Irish forest networks with native species. Afforestation has consequences for environment, people, and economies, but is often only assessed through a single lens. Drawing on research from other team members, we will also touch on the broader challenge of evaluating trade-offs between the environmental, economic and social consequences of native woodland afforestation.

The response of forestry organisations to long-term and short-term factors influencing forest management

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Forests and their management are currently facing major challenges, in particular climate change, which is having a significant and long-term impact on forests. Other long-term factors include changing preferences in the use of ecosystem services of temperate forests. In Slovakia, society has begun to prefer the environmental and social functions of forests. In addition to these long-term factors, forest management is also affected by sudden changes such as the COVID 19 pandemic, the war in Ukraine and the rise in energy prices. The impact of these factors on the change in the organisation of work in forestry organisations was evaluated through a questionnaire survey in Slovakia. Interim results showed that forestry entities have not experienced changes in the forestry labour market caused by the above-mentioned factors, nor are they preparing changes in job positions. The forestry sector remains in the traditional management mode, where the priority is sustainable forest management, with a substantial part of the income based on the production of wood raw material. The forestry sector is not actively responding to the changes, not only at the organisational level, but also in the training of employees to faced these changes.

To Manage Or Not To Manage? Evaluating the Impact of Management on Ecosystem Function in European Forests Through Satellite Remote Sensing

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Forest management affects forest health and the provisioning of multiple ecosystem services, including carbon sequestration and biodiversity conservation. However, current scientific evidence concerning these relationships is not unequivocal, mainly due to a lack of unconfounded observational comparisons between managed and unmanaged forests. This gap in the literature, along with evolving societal expectations of our forests, poses great challenges for forest managers: How can we ensure biodiversity conservation within our European forests? And how can this conservation goal be integrated with economic (bioeconomy, timber…) and environmental (carbon sequestration, water regulation, soil protection…) goals that are expected of our forests? How can we simultaneously ensure our forests' resilience in the face of climate change? Within the Horizon Europe INFORMA project, we address these questions in three phases. In the first phase, the need for unconfounded observational comparisons between managed and unmanaged forests is addressed through the creation of the INFORMA Forest Management Platform. The Platform is a database of clustered forest patches across Europe comparing managed (including a management gradient) and unmanaged forest patches, excluding confounding variables (soil, topography, climate, species etc.) as much as possible. In the second phase, satellite remote sensing data are used to compare ecosystem functioning between these managed and unmanaged forest patches. Spatial General Linear Mixed Models (sGLMM) are employed to analyze the data. In the third phase, the stability of forest ecosystem functioning for both managed and unmanaged forests is addressed. Here, we will present the methodology behind the development of the INFORMA Forest Management Platform and discuss its potential for future forest management research within Europe. Furthermore, we will discuss the first results of the sGLMM by reporting on the differences in gross primary production and forest structural diversity between managed and unmanaged forests, as well as their stability. Lastly, we will reflect on the perspectives of the INFORMA Forest Management Platform for research relevant to EU policy.

Tree species selection has a major impact on understory vegetation species abundance and composition

T3.20 integrated forest management in temperate and boreal forests - balancing biodiversity and ecosystem services

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Abstract: Tree species composition and performance in the boreal forest is greatly formed by local climate, soil and water conditions. For the understory vegetation, not only these abiotic factors are important for the structure and composition, but also the selection of the overstory tree species has a great influence.

We hypotetised that the selection of the overstory tree species has a major impact on the understory vegetation on the same site, over long time.

In two long-term forest experiments in a boreal forest area, established in 1964 and 1968, respectively, five tree species, Scots pine, Norway spruce, Silver birch, Russian larch and European larch, was planted in monocultures with similar abiotic conditions. Each species were treated with thinnings for best practice for wood production. In 2021 and 2022, understory tree numbers and size, as well as the number of species and coverage of other vegetation was assessed in all plots.

The number of understory trees and their species composition varied significantly, depending on the overstory tree species. The ground floor vegetation was influenced in a similar way. The number of species found under the different tree species were quite equal, but species composition and coverage was significantly different. The extremes were in the Norway spruce and Silver birch plots, where the former had a higher number of moss and lichen species, while the latter had a higher number of herbaceaus species.

The differences could possibly be explained by the different biomass production levels, silvicultural treatments, below-canopy light conditions and the amount and quality of the litterfall, that the tree species produce.

The conclusion of the study is that we can greatly choose to form the understory in different directions, depending on the choice of tree species in the forest.

T3.21 Legacy tropical forest data: current status, uses, and securing them

Acquisition and use long-term observational data on forest dynamics to assess the impact on climate change in tropical seasonal forests in Thailand

T3.21 Legacy tropical forest data: current status, uses, and securing them

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Abstract: Forest dynamics have been observing since 1992 to the present, to assess the impact of climate change, established in a long-term monitoring site in dry seasonal forest Kanchanaburi, western Thailand.

Tree census have been carried out and the dominance of the understory vegetation type recorded at natural, secondary forest and site after slash-and-burn at 20x20m unit established in 4ha research plot each in a long-term monitoring site. Soil survey were also conducted.

Mixing with several bamboo species are characterized in the forest in this region, and gregarious flowering of three bamboo species occurred, followed by rapid changes in the vegetation type in the understory were observed during this period.

With regard to the mitigation function of forests in climate change, the contribution of bamboo biomass in carbon storage has been determined, and carbon dynamics have been assessed by observing carbon fluxes at a tower and soil respiration. It is also characterized by extreme dryness and frequent wildfires without rainfall in a dry season from November to March. So, there is no nutrient and water supply from the soil to the plants and then different mechanism of material cycling from the rainy season was also clear.

Furthermore, long-term observations have shown that the frequency and intensity of wildfires varies with the topography and associated environmental inclinations. This mechanism may be one of the factors defining the mixed distribution of some of the bamboo species characterized in the forest in this region. Recent climate change has altered the frequency and intensity of rainfall in Thailand, which may affect the distribution of bamboo in the future. Therefore, research is currently focused on this aspect, together with an assessment of the function of silicon on wildfire tolerance by species.

Thus, long-term observations in tropical seasonal forests contribute not only to the scientific clarification on forest dynamics, but also to new issues such as the evaluation of the impact of climate change on carbon dynamics. We would like to continue long-term observations to accumulate data, and we would like to research with researchers to publish and utilize the data to clear the new issues.

Dendrometric evaluation of Khaya grandifoliola C. DC. as a function of phosphorus doses in Brazilian Cerrado

T3.21 Legacy tropical forest data: current status, uses, and securing them

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Abstract: *Khaya grandifoliola* C. DC. is a tree of African origin belonging to the botanical family Meliaceae, popularly known as African mahogany. It is a species that has been standing out in forest plantations in Brazil, of great importance due to its high value in international trade and relatively fast growth. For plants to develop and express all their productive potential, a correct supply of nutrients is necessary. In Brazil, African mahogany is generally planted in acidic and nutrient-poor soils, such as Cerrado soils, making fertilization an essential practice for higher yields. In this context, this work aimed to evaluate the growth of *K. grandifoliola* plants in soils of the Brazilian Cerrado as a function of phosphorus (P) doses at planting. The experiment was carried out at Fazenda Espanha, located in the municipality of Pompéu, in Minas Gerais, Brazil, at latitude 19º 13' 28" S and longitude 44º 56' 07". Four doses of phosphorus applied in the planting were evaluated: 150, 200, 300, and 400 kg.ha^{-1}. The experimental design was randomized blocks, with eight replications. Every 180 days after planting, the height and diameter of the plants were measured, as well as the nutrient content in the soil and leaves. Plants subjected to the highest P dose (400 kg.ha^{-1}) showed the highest growth rates for all analyzed variables, as well as higher P levels in the soil in the 0-20 and 20-40cm layers. On the other hand, the lowest P rates used (150 and 200 kg.ha^{-1} a) resulted in lower P availability in the soil, negatively affecting plant development. Thus, for the initial growth of *K. grandifoliola* plants in the condition studied, in Brazilian Cerrado soils, the application of 400 kg.ha^{-1} of P in the planting is recommended.

Efforts to publish East African tropical forest insect data currently under the custody of Kenya Forestry Research Institute

T3.21 Legacy tropical forest data: current status, uses, and securing them

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Abstract: European explorers first undertook surveys of flora and fauna in Eastern Africa in 1862. The specimens they collected were housed in museums in Berlin, Vienna, London and Brussels. Germany then took control of contemporary Burundi, Rwanda and mainland Tanzania in 1891, which was followed by about 25 years of effective land tenure. German foresters made scientific contributions including extensive inventories and utilitarian assessments of native trees in addition to aggressive testing and distribution programs for mostly exotic tree species. They were also concerned with the protection of forest plantations and reserves from destructive agents. These colonial scientific interests were transferred to the British who later occupied Kenya, Uganda and Tanzania. By 1948, the East African Agriculture and Forestry Research Organization was formed with its headquarters in Muguga, Kenya to consolidate such past research efforts. During the post-independence era, these research interests were managed by the East African Community but it broke up in 1977 and Kenya Agricultural Research Institute (KARI) became its successor in Kenya. The Forestry Department of KARI evolved into the more specialized, independent Kenya Forestry Research Institute (KEFRI) in 1986. KEFRI subsequently holds over 50,000 analog records of insects on paper and associated specimens collected over time from Eastern Africa. These are preserved in an Insect Reference Collection as dried, pinned specimens or in industrial alcohol. KEFRI commenced efforts in 2016 to convert analog records of the collection into digital formats that can be widely shared electronically under creative commons licenses. Staff are trained in using SPECIFY software and about 1000 records are ready for uploading. The Institute registered in 2021 as a data publisher in the Global Biodiversity Information (GBIF) platform (http://ipt.kefri.org/ipt/). Future plans are to publish occurrence lists and data using the GBIF IPT. Other associated knowledge products include e-posters and training videos codifying tacit knowledge and curation skills necessary for the maintenance of the physical specimens. This collection holds valuable material for morphological and genetic, taxonomic identification with application in integrated pest management and advancement of restoration of tropical forests in response to climate change.

Key words: historical data, tacit knowledge, digitization, IPM

Progress in locating legacy tropical data and related resources

T3.21 Legacy tropical forest data: current status, uses, and securing them

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Abstract: Imagine information 100 years old or more, sitting on a multitude of old shelves or in filing cabinets all over the world, in print format and many, sometimes obsolete digital formats. Imagine that this hidden information could be critical for managing natural resources now and in the future, including under climate change. Such is the case with legacy tropical forest datasets. We have been on the search for these datasets and funding for their recovery for several years. These datasets are held by academic institutions, government agencies, international development agencies, and private individuals around the world. Without appropriate curation, the future of these data is precarious.

Recently the effort expanded to include related information. Living legacy tropical foresters are another endangered resource, some of whose careers can stretch back to the colonial era. Interviews have been conducted with several on their experiences and bodies of work. There are also numerous publications related to tropical forestry that are available only in paper or microfilm/microfiche. These include bulletins and reports from the colonial era and early development projects in various countries. With the help of university interns, the online library catalogues of the University of Oxford (former home of the Oxford Forestry Institute), and the British Library have been perused for these bulletins and reports. To date, over 2000 titles for about 200 countries have been compiled. We are now working to locate electronic versions of these publications.

The next step is to obtain funding for digitizing these datasets and related resources. We are getting interest from different foundations. This help may plant the seeds for attracting other resources. The goal is to get these datasets and important publications broadly available and used in restoration and management efforts.

TraitDivNet: an open global network advancing knowledge on above and belowground ecosystem functioning

T3.21 Legacy tropical forest data: current status, uses, and securing them

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Abstract: To understand ecosystem functioning, the use of plant traits related to their growth, resistance, and reproduction (e.g., height, stem density, leaf and root thickness, size of seeds) allows for defining how plants respond to competition, disturbances, and environmental conditions, which ultimately affects ecosystem processes (e.g., water and nutrient cycling, decomposition, pollination). There is a wide variety of studied traits following different sampling methodologies and focused on characterizing functions of aboveground organs, although they interact with belowground structures and both influence ecological processes. However, available information for belowground traits is particularly scarce to draw a complete picture of plant functions across the globe, which limits understanding of ecosystem functioning at large scales.

Considering this information gap, we promoted a global network to create an extensive trait database using standardized methods, a wide variety of dominant species, and the ten most informative traits to improve the knowledge on above and belowground plant functions and how they affect ecosystem processes under future climatic change. We developed a detailed protocol with a global standardized methodology using 10x10 m plots in natural and seminatural ecosystems to measure six aboveground (leaf area, specific leaf area, leaf nitrogen, seed mass, specific stem density, and total height) and four belowground traits (root diameter, specific root length, root tissue density, and root nitrogen) for the 20 most abundant vascular plant species. We included soil sampling to measure soil texture, nutrients, and microbiota and registration of coordinates, vegetation characteristics, human management regime, and topography.

Currently, we have a global network of more than 200 plots distributed worldwide, but some regions of Africa, Southeast Asia, and South America need to be represented, whereby we encourage potentially interested colleagues to join our initiative. We will use this information to describe the function of different plant communities and to predict how projected climate change may influence it and affect global ecosystem processes. We expect that our results contribute to a complete view of how different plant organs interact and affect critical processes in the atmosphere and soils that ensure habitats for all organisms worldwide.

Unearthing Past Sundaland's Legacy: The Savanna Corridor of Belitung Kerangas Forest, Indonesia

T3.21 Legacy tropical forest data: current status, uses, and securing them

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Abstract: Sundaland heath forest (Kerangas forests) hold significance within tropical ecosystems as they fulfill crucial roles in biodiversity conservation, climate change mitigation, and the provision of valuable ecosystem services to local communities. During the Last Glacial Maximum, the Kerangas forest was situated within the tropical grassland. Thus, this ecosystem possesses distinct characteristics such as acidic and nutrient-deficient sandy soil, along with unique flora and fauna. These forests today are common on the island of Belitung where during Permian - Triassic stages of suturing there was extensive granite magmatism and that holds the distinction of being the biggest primary tin-producing islands. We documented some carnivorous plants (i.e., *Nepenthes* spp. and *Drosera* spp.), various medicinal plants, and numbers of liana/ woody liana. *Cephalopachus bancanus saltator* is one of the endemic fauna species in Belitung Island Kerangas forest. This research highlights the need to reassess the significance of the Kerangas Forest in Belitung islands, Indonesia due to the high threat of forest ecosystems in small island areas. The Belitung island as part of Sundaland craton represents a segment of the main Devonian to Middle Triassic Palaeo-Tethys ocean in the Indo-Pacific Warm Pool that supplies a sizable fraction of the water vapor in Earth's atmosphere and plays a role in propagating El Niño cycles. To address this issue, it is strongly recommended to promptly establish a permanent dynamic research plot in Belitung to investigate the diverse ecological processes within the Kerangas forest (i.e., part of ForestGEO network). The identification of plant diversity integrated with paleobiography and paleoclimate in this area are still limited. Given its vital ecological function, the Kerangas forest status as a forest ecosystem of high conservation value deserves careful assessment. Kerangas forest might be the evidence of the existence of "Savanna Corridor " during the Last Glacial Period at times of lowered sea-level when the sand dominates the bottom sediments along the submarine. Thus, more research and studies are also encouraged to reveal the evidence that comes from geomorphology, relationship between biodiversity and biogeography, record of keys species of natural vegetation and palynology.

Using historical tree plot inventory data to investigate the biogeography of Tropical America

T3.21 Legacy tropical forest data: current status, uses, and securing them

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Abstract: Tropical America, including the Caribbean, harbours the highest species diversity compared to any other region in the world. However, this remarkable diversity is facing severe threats from climate and land use change. While plot inventory networks have been successful in generating syntheses on biodiversity patterns and ecosystem functioning; cross-biome, plot-based studies in the tropics are rare, preventing the identification of general vs biome-specific responses to global change drivers. To address this knowledge gap, the SynTreeSys project is utilising world-leading expertise in tropical ecology to conduct a comprehensive assessment of tree species diversity

patterns and its conservation status across the region. To achieve this, we are constructing a harmonised database to i) identify spatial patterns of tree diversity and dominance and the underlying causes of their variation, ii) detect zones of exceptional species turnover and, iii) to assess tree species conservation status in tropical America.

One of the challenges in tropical regions is ensuring the homogeneous representativeness of biodiversity datasets. In areas with limited information or extensive land use transformation, historical data becomes a valuable source. The SynTreeSys-generated database covers a time span of almost 90 years, with approximately 10% of the plot data collected before 2000. The oldest dataset available dates back to 1934, comprising inventory plots documenting the vegetation of Moraballi Creek in Guyana, published by T. A. W. Davis and P. W. Richards, and gathered by the Amazon Tree Diversity Network (ATDN). In SynTreeSys, we emphasise the importance of "old" data, not only for the inherent value it holds but also for the rich narrative of the studies and their ability to provide historical and detailed descriptions of habitats, vegetation structure, soil, and even species interactions.

Using legacy data in long-term tree mortality monitoring and forest dieback research

T3.21 Legacy tropical forest data: current status, uses, and securing them

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Abstract: Long-term monitoring of forest plots has been integrated into ecological research in montane forests of the Pacific island of Hawaii ("Big Island") since the 1970s. After widespread forest decline ("ohia dieback"), 26 permanent plots were established in 1976 in dieback and non-dieback forest patches to monitor the population structure of tree species. Twenty-five of these plots have been resurveyed five times during the following 27 years. Data suggested that forests affected by dieback have started to recover their tree canopy as a new cohort of young trees were growing back in these sites. However, it was not clear if these results truly represented the conditions across the entire former dieback area of ca. 50,000 hectare. We used those legacy data sets for long-term monitoring of individual trees, and to understand the landscape-level dynamics of forest dieback and regeneration in Hawaii´s rainforests. To assess the present status of the forest canopy across the eastern side of the island of Hawaii we analyzed very-high-resolution imagery collected between 2008 and 2015. The Pictometry (POL) imagery consists of three-band, true-color red-green-blue (RGB) digital photographs; the images have a spatial resolution of ~20 cm. To calibrate our assessment process we constructed POL plots around the locations for the 25 permanent plots that had been established in 1976, and then compared our new assessment of canopy dieback using POL imagery for these locations with the status from the most recent ground-based resurvey of these plots. The results were combined with habitat data to produce a spatial model depicting probability of canopy dieback within the study area.

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

Assessment of two contrasting French Douglas-fir seed orchards: potential for adaptation to climate change

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Douglas fir is an important tree species in France and represents the second species for reforestation. To meet the seed demand, eight seed orchards (artificial provenances) were planted between 1978 and 1989. A research network was established in 2009 to evaluate the growth and behavior of French seed orchard progenies. Two seed orchards with different genetic compositions (clones selected from progeny tests of the northern and southern provenances of the North American native range, respectively) are differentiated mainly by their contrasting vegetative bud burst and juvenile growth. In the context of increasing recurrence of droughts, we assessed the drought tolerance of these two seed orchards.

Several experiments were conducted in France, comparing progenies from the two seed orchards. In one of them, automatic dendrometers were installed to compare daily climate impacts on the growth dynamic of the two contrasting seed orchards progenies.

Results showed that progenies from the "southern" seed orchard had significantly smaller growth compared to the "northern" seed orchard under current optimal climatic conditions. However, under drier conditions, differences between these two seed orchards were greatly reduced or showed no significant growth differences. Current results and observations from controlled experiments and automatic dendrometers showed that the progenies of the two seed orchards have different strategies to cope with droughts.

Our findings extend current knowledge on the potential adaptation of Douglas-fir genetic resources to drought. Moreover, these results could be used in further studies to understand drought tolerance mechanisms and help breeders select genetic resources for future seed orchards.

Combined metabolomic and genetic profiling reveal optimal harvest strategy model based on different production purposes in olive

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Olive (*Olea europaea* L.) is internationally renowned for its high-end product, extra virgin olive oil. To further explore the genetic and breeding utilization of olive, an draft genome of olive was obtained using Oxford Nanopore thirdgeneration sequencing and Hi-C technology. Seven different assembly strategies were used to assemble the final genome of 1.30 Gb, with contig and scaffold N50 sizes of 4.67 Mb and 42.60 Mb, respectively. We assembled 1.1 Gb of sequences of the total olive genome to 23 pseudochromosomes by Hi-C, and 53,518 protein-coding genes were predicted in the current assembly. Comparative genomics analyses, including gene family expansion and contraction, whole-genome replication, phylogenetic analysis, and positive selection, were performed. Based on the obtained high-quality olive genome, a total of nine gene families with 202 genes were identified in the oleuropein biosynthesis pathway, which is twice the number of genes identified from the previous data.This new accession of the olive genome is of sufficient quality for genome-wide studies on gene function in olive and has provided a foundation for the molecular breeding of olive species.

Olive oil has been favored as high-quality edible oil because it contains balanced fatty acids (FAs) and high levels of minor components. The contents of FAs and minor components are variable in olive fruits of different color at harvest time, which render it difficult to determine the optimal harvest strategy for olive oil producing. Here, we combined metabolome, Pacbio Iso-seq, and Illumina RNA-seq transcriptome to investigate the association between metabolites and gene expression of olive fruits at harvest time. A total of 34 FAs, 12 minor components, and 181 other metabolites (including organic acids, polyols, amino acids, and sugars) were identified in this study. Moreover, we proposed optimal olive harvesting strategy models based on different production purposes. In addition, we used the combined Pacbio Iso-seq and Illumina RNA-seq gene expression data to identify genes related to the biosynthetic pathways of hydroxytyrosol and oleuropein. These data lay the foundation for future investigations of olive fruit metabolism and gene expression patterns, and provide a method to obtain olive harvesting strategies for different production purposes.

Comparative Study on Financing and Long-Term Planning of Forest Reproductive Material in Different European Countries

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: The forest reproductive material (FRM) sector (forest nurseries and forest tree seed suppliers) plays a crucial role in the artificial regeneration and restoration of forests, particularly in the context of climate change adaptation in Europe and worldwide. The use of appropriate FRM, including a diverse range of species and genetic variations, is essential for conserving and enhancing the adaptability of forests. However, the FRM sector faces significant challenges, primarily related to financial constraints and the impacts of climate change, which affect the long-term planning of forest nurseries and seed production.

To facilitate an improved legislative and financial framework for forest nurseries in Slovenia, this qualitative study provides an overview of legislative, contractual, and funding solutions for FRM production in different European countries, with a focus on Central and Southeast Europe. The study incorporates a literature review, consultations with EUFORGEN and other experts (web inquiries, online interviews), and a qualitative analysis of the results using the grounded theory method.

The findings of this study indicate that comparing different systems for FRM provision between European countries is challenging due to the specific organizational structures in each country. Long-term contracts between FRM dealers and forest owners or state entities are uncommon and rarely implemented in practice. However, such contracts offer a sustainable model for the provision of FRM, particularly in the face of large-scale forest disturbances. Long-term predictions of FRM needs, from the public to the private sector, are infrequent except in countries with large public forest companies.

In the end, we highlight several key findings and best practices that could contribute to better organisation and financing of the FRM sector in European and other countries and regions.

Conservation and sustainable utilization of forest genetic resources for livelihood of forest communities in Western Himalayas

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Forest genetic resources have been recognized as one of the key pillars of sustainable forest management that depend on conserving genetic diversity and ensuring its continuity among generations. India has four biodiversity hotspots, Himalayan region amongst which, is very unique that supports immense biodiversity and FGRs diversity. People inhabiting the Himalayan region have a unique and special relationship with the forests that directly support their livelihood, however they also contribute to initiatives in the conservation of forests which is based on their traditional knowledge. Himalayan forests have been under immense pressure of providing for an ever increasing population of the region which calls for conservation efforts with advanced research and technological support. A pilot research programme on conservation of Forest Genetic Resources (FGRs) with special focus on the FGRs of North-West Himalayas was implemented, under which, documentation of species populations, their characterization and germplasm storage, were done. The population of the prioritized species were explored, geo-tagged, their phenological observations and species associations recorded. After collection at optimal maturity, seeds were processed, quality-evaluated and desiccated to safe moisture levels for storage. The seed storage physiology of important Himalayan species like spruce, maples, *Carpinus*, *Buxus*, *Fraxinus*, pines, rhododendrons, walnut, hazelnut, *Hippophae*, medicinal species, etc. and few endemic species like *Pittosporum eriocarpum, Butea pellita*, etc. were standardized for chalking out a long-term *ex situ* conservation programme. Seeds of most of these species have orthodox storage physiology, which after desiccation to lowest safe moisture levels were vacuum sealed and stored in the National seed bank at -18^{0}C for conservation and periodic regeneration, in future. The germplasm of species so raised in the nurseries, will be planted back in their natural range, in collaboration with forest department and the local communities. Field germplasm banks of several species were also established for multiplication of germplasm. Knowledge generated from FGR conservation programmes will be utilized not only for conservation of the valuable genetic resources but also their sustainable utilization by the communities, in future.

EX-SITU CONSERVATION AND MANAGEMENT OF SHOREA LEPROSULA GENETIC RESOURCES VIA THE ESTABLISHMENT OF SEEDLING SEED ORCHARD

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: *Shorea leprosula* is a timber tree species in the family Dipterocarpaceae. It is native to Peninsular Malaysia, Sumatra, Borneo, Java and Thailand. In 1997, a progeny trial plot of *Shorea leprosula* was established in Forest Reserve Ulu Sedili, Johor, Malaysia via a collaborative research between the Forest Research Institute Malaysia (FRIM) and Forestry Department of Peninsular Malaysia (FDPM). This pioneer study involved seed collection from 40 half-sib families in five forest reserve (FR) areas in Peninsular Malaysia whereby selection of the mother trees was made based on the tree grading characteristic. The progeny trial plot consists of 1280 trees within an area of 2.05 hectares. At the age of 20 years old, the growth performance range for its height (HT) and the diameter at breast height (DBH) ranged from 17.2 m to 25.7 m and 21.5 cm to 27.4 cm, respectively. Genetic evaluation and DNA profiling were carried out for the establishment of Seedling Seed Orchard (SSO). A total of 15 Simple Sequence Repeat (SSR) markers were utilized to assess the genetic diversity and genetic relatedness of the trees planted in the plot. Findings showed that each profile is distinctive and can be used as a denomination for registration and verification of superior trees. The mean number of alleles per locus (Aa) for the entire SSO was 13 whereas the expected heterozygosity (He) was 0.7121. Values obtained were either comparable or higher for the species and other dipterocarps. The He ranged from 0.6762 (FR Bangi) to 0.7163 (FR Tranum) and the Aa ranged from 5.60 (FR Tranum) to 11.27 (FR Gombak). Results show that SSO of *S. leprosula* established has a diverse gene pool which amplifies its potential for application in future breeding programmes and for ex-situ conservation in the central region of Peninsular Malaysia.

Keywords: selection, plus trees, progeny trial, Simple Sequence Repeat (SSR), gene pool

Ex-situ genetic conservation at the leading edge: from genetic simulations to practical implications for multifunctional genetic conservation

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Conservation of forest genetic resources has become a target in international agreements such as the United Nations Convention on Biological Diversity (CBD) and as agreed upon during the Kunming-Montreal Global Biodiversity Framework (GBF). Under Forest Europe, conservation through in situ units is implemented and monitored in a systematic manner. Yet, meaningful indicators and measures for the evaluation of conservation success or identification of conservation gaps have been rarely put into action for *ex-situ* conservation of minor tree species, mainly because *ex-situ* genetic conservation has been considered less important than *in situ* programs. However, *ex situ* genetic conservation of rare and scattered tree species at the so-called leading edge (i.e the northern population margin) will be even more crucial in the future, because northward migration of these species will not be limited by the cold climate, but rather by sufficient levels of gene flow, and dispersal capacity.

We present here an integrative framework from the Finish conservation program of forest genetic resources for nine tree species, based on simulated population and allele sampling. Delineation of populations and estimation of population sizes (mean and variance) are determined from an exhaustive archive of field observations in Finland and combined with high-resolution geoinformation, such as the Finnish forest map and land use information, to reduce potential bias in biodiversity observations. We evaluate the current *ex situ* strategy by benchmarking captured diversity against the minimum number of individuals needed to conserve 95% of allelic variance considering species-specific allele frequency patterns. We also discuss the implementation of allele copy numbers for back-up purposes in existing *ex situ* archives and the effect of different sampling and conservation strategies (clonal copies vs. seed and dynamic vs. static conservation) for optimal long-term security of genetic diversity.

We conclude that the combination of genetic simulations and publicly available biodiversity databases can be a powerful tool for guiding forest genetic conservationists while planning and establishing next-generation *ex situ* archives and seed orchards.

Exploration and Documentation of Tree diversity and Ecosystem services of forest genetic resources of CHTs Village Common Forest in Bangladesh

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: This paper presents the tree diversity resources and ecosystem services of Kapru Para Village Common Forest (VCF) Bandarban Hill District, Bangladesh, which is managed by the *Murang* community. The present investigation is carried out for collection, identification, update nomenclature and documentation of tree diversity and ecosystem services for the first time for Kapru Para, Bandarban hill district, Bangladesh. A total of 92 tree species belonging to 76 genera under 39 families has been recorded from the VCF of about 50 ha. Euphorbiaceae has the maximum number of species (10 species). Meliaceae, Mimosaceae and Moraceae have 6 species each and Lauraceae has 5 species while both Sterculiaceae and Verbenaceae have 4 species each. The families Anacardiaceae, Myrtaceae, Rubiaceae, Sapindaceae have 3 species each, while Bignoniaceae, Burseraceae, Caesalpiniaceae, Clusiaceae, Combretaceae, Dipterocarpaceae, Fabaceae, Fagaceae, Flacourtiaceae, Myrsinaceae and Tiliaceae has 2 species each and the rest 17 families contain single species. All species are found to grow in natural forest landscape in VCF. The *Holigarna longifolia, Hymenodictyon orixensis, Polyalthia suberosa, Scaphium scaphigium, Diospyros pilosula, Parkia timoriana* and *Xerospermum laevigatum* are found the rare and near threatened species in IUCN categories. The ecosystem services are wild fruits, wild vegetables, ethno-medicinal plants, and timber and fuel woods ect. collect by the ethnic people from the VCF. The VCF of Kapru Para is exist still remnant of natural primary forest of the Bandarban hill district. This VCF is conserved by community effort for conserving the tree diversity and ecosystem services response to climate change . It is a one of the model of local level forest biodiversity conservation and ecosystem services in the Bangladesh.

Genetic fingerprinting as a tool for verifying the origin of forest reproductive material

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: The use of the appropriate forest reproductive material (FRM) is key to adapt forests to climate change. Thus the adequate labelling of FRM during production and trade is demanded by European law. At present, paper-based master certificates are usually the only evidence for the origin of FRM. At the Austrian Research Center for Forests (BFW), fingerprinting techniques have been developed and established, allowing for the control of the origin of FRM from harvesting, seed processing, trading, to plant stock at nurseries. The basis for these techniques is provided by reference samples (cones/seeds) that must, by Austrian law, be collected from each tree from which seeds have been harvested. These single tree specimens are stored at the BFW.

Routine genotyping protocols were established for nine tree species: *Abies alba, Acer pseudoplatanus, Larix decidua, Picea abies, Pinus sylvestris, Prunus avium, Pseudotsuga menziesii, Quercus robur*, and *Q. petraea*. For each species, eight pairs of nuclear microsatellite markers were selected and lab protocols optimized on different types of material (embryos, leaves, needles, pericarps, peduncles, scales, seedlings, testa). The first test run concluded that 98.6% of the seeds from known mother trees could be matched successfully. The subsequent analyses represented real-life scenarios and consisted of single tree specimens, representing the mother trees and a mix of progeny samples. Between 65% to 87% of the samples could be matched to the single tree specimens. The results strongly depended on the quality of the material. The best results were derived from fresh or frozen leaves/needles and seeds, whereas several year old and dry material was often unsuitable for analysis. The results also depended on whether single tree specimens had actually been collected from the full set of mother trees during the harvest.

The fingerprinting system can also be used to compare the single tree specimens amongst each other and thus validate if the harvest fulfilled the mandatory minimum number of mother trees. This is another important aspect of DNA fingerprinting of FRM, as broad genetic diversity provides the basis for adaptability and lowers the risk to establish new forest.

Genetic variability in Araucaria angustifolia seedlings from populations of State Parks in São Paulo

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Araucaria angustifolia (Bert.) O. Kuntze, a native from the South and Southeast of Brazil, has had its habitat reduced due to human action. As a consequence, it's listed as an endangered species by IUCN (2018). Numerous efforts have been made to conserve this species, given it's social, economic and ecological importance for the region. Population genetics studies have produced results that are being applied to define conservation strategies. As part of a research project conducted i*n situ* conservation units in São Paulo, the objective was to genetically characterize natural populations based on phenotypic traits in order to establish seed orchards through the cultivation of seedlings. Trees from two distinct natural populations were sampled, totaling 19 parent trees. Eleven of these, along with their respective progenies, originate from Campos do Jordão State Park, while the remaining eight, with their progenies obtained in Serra do Mar State Park - Cunha Nucleus. The produced seedlings were established in a coop experiment using a randomized complete block design, with 19 treatments (progenies) and multiple plants per plot (four blocks). Seedlings were evaluated at six and 14 months of age, respectively, after sowing, for growth traits such as height (cm) and stem diameter (mm). The data obtained were analyzed using SELEGEN REML/BLUP software (2014). The average values for total height and stem diameter were 21.5 cm at six months and 36.9 cm at 14 months. As for the stem diameter, values for the two periods were 3.5 mm and 4.35 mm, respectively. The coefficient of variation ranged from 14% to 27.1% for the evaluated traits, and phenotypic correlations between the traits were positive, with an average of 0.42. Significant differences were observed for all evaluated traits, particularly regarding height among the provenances and progenies. The individual heritability estimates were high, with an average value of 0.38, except for stem diameter at 14 months (0.16). The genetic divergence obtained from the cluster analysis revealed three progenies groups with a mixture of distinct provenances. Therefore, progenies exhibit interesting genetic variability for *ex situ* conservation, aiming at future use in tree breeding for wood and seeds (Acknowledgment: FAPESP 2019/19529-8).

Identification of Germplasm Resources in Dendrocalamus by SSR Molecular Markers

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Dendrocalamus brandisii, Dendrocalamus asper, and Dendrocalamus hamiltonii are widely distributed in Yunnan, China and Southeast Asian countries, with similar phonotypes and rich diversity. All three
species of bamboo shoots have good edible properties. MISA (Micro Satellite Identification Tool) technology was used to analyze and identify 231789 microsatellite markers evenly distributed on 35 chromosomes of D. brandisii. 800 pairs of microsatellite primers were designed for screening polymorphic primers. A total of 41 pairs of simple sequence repeats (SSRs) primers with clear and polymorphic amplification bands were obtained, Three species of bamboo and different provenances of
D. brandisii were identified using the high-throughput and high-precision fluorescent labeling TP-M13-
SSR method. 40 SSR loci amplified 134 alleles, with an average of 3.35 alleles per locus (range 2-12).
The Nei index and Shannon's information index were 0.3913 and 0.7108, respectively. The results showed that SSR201 can distinguish three species of D. brandisii, D. hamiltonii and D. asper. SSR84 can distinguish two new varieties 'Manxie No.1'and 'Manxie No.2' from D. brandisii. When SSR201 and SSR84 are used together, different provenances of D. brandisii can be identified, Therefore, SSR201 and SSR84 were used as core primers to identify these important different species and provenances, while the remaining 39 pairs were used as extended primers. And 41 SSR markers were used to construct genetic fingerprints of 17 important provenances, and an identification technology based on SSR markers was established. The number and size of alleles discovered in this study can serve as a basis for identifying three D. species germplasm resources. Microsatellite markers provide a basis for screening and identifying high-quality Dendrocalamus germplasm resources, exploring important genes, and molecular breeding.

Implications of management by rural families on the genetic and phenotypic diversity of populations of Euterpe edulis, an Atlantic Forest palm

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Monitoring plant populations is fundamental for designing long-term conservation and sustainable use strategies. In this sense, the evaluation of genetic and phenotypic diversity can be used as a useful indicator of changes in use and management by rural communities. In our study, we analyzed the case of *Euterpe edulis*, an NUS (neglected and underutilized species), multipurpose and threatened palm of the Atlantic Forest, a biodiversity hotspot. This species has a restricted distribution in Argentina, and an important part of the populations are found in private properties. Therefore, for these populations' conservation and sustainable production to be effective, it is necessary to have in situ information. We compared different management systems applied to wild populations of this palm by rural communities. These management systems were characterized from an ethnobiological point of view in previous studies. Our analyses focused on management involving fruit and apical bud utilization compared to non-management situations. Genetic diversity was examined using isoenzyme and microsatellite markers, while phenotypic diversity was examined using fruit and seed morphometric characteristics.

Our results reveal that the evaluated populations have a high conservation potential. We hope that the diversity indicators obtained will allow us to define priority areas for the conservation of this species and that the genetic characterization of these populations will help in the design of differentiation strategies for the products obtained from this species (fruit pulp), which is highly valued by the market.

INSIGHTS INTO GENETIC STRUCTURE AND DIVERSITY OF NORWAY SPRUCE (PICEA ABIES (L.)) POPULATIONS IN LITHUANIA

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Norway spruce produces high-quality timber and is a fast-growing, evergreen coniferous tree of high economic and ecological importance in Europe and covering 21.1% of total forest area in Lithuania. However, because of changing environmental and climatic conditions Norway spruce is facing increasing risks because of pests and diseases outbreaks. European Union Green Deal, Biodiversity strategy 2030 and EU Forest Strategy 2030 emphasize the importance of biodiversity in forest ecosystems and aims to increase resilience and adaption of EU forests to climate change. Hence, it is important to monitor the levels of genetic diversity of Norway spruce Forest Genetic Resource (FGR). Collected knowledge on effects of genetic drift, spatial genetic structure and of Norway spruce populations in Lithuania will help to manage FGR in more sustainable manner and to increase their resilience and adaptation to changing climate and environmental conditions. The aim of the PhD study is to determine the genetic structure, diversity, effective population size and spatial genetic structure (SGS) in naturally occurring Norway spruce populations (Forest Genetic Reserves) in Lithuania based on neutral DNA markers. In total 25 Norway spruce forest genetic reserves through the whole Lithuania will be sampled and genotyped based on 11 variable nuclear microsatellites. Collected phenotypic and genetic knowledge will enable us to propose updated FGR management strategies to increase their resilience to changing environment. First results of the PhD project will be presented.

Introduction of special germplasm selection of Aquilaria sinensis for easy agarwood inducing and high-quality agarwood production in southern China

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Agarwood, namely the resinous heartwood of *Aquilaria* species, is a highly valuable raw material for medicine purposes and the perfume industry. Agarwood has become scarce and precious because it is very difficult to induce agarwood formation from plantation trees of *Aquilaria sinensis* in southern China, meanwhile, the yields as well as the quality of formed agarwood was very poor. In recent years, a group of special germplasm of *Aquilaria sinensis* has been selected from the wild population and domesticated into clones by grafting with ordinary seed seedlings of *A. sinensis*. This group of special germplasm includes about 100 individuals, and the common characteristics of these individual trees are far more easier, faster to form higher oil content and high-quality agarwood. Compared to ordinary trees of *A. sinensis* from seed seedlings, they showed higher oil content, higher content of 2-(2-phenylethyl) chromone and 2-[2-(4′-methoxybenzene) ethyl] chromone, higher hormones levels of salicylic acid, jasmonic acid and ethylene, higher activities of antioxidant enzymes, more total phenols and terpenes, higher net photosynthetic rate and photochemical efficiency of PSII, more consumption of non-structural carbohydrates. In particular, 2-(2-phenylethyl) chromone and 2-[2-(4′-methoxybenzene) ethyl] chromone, which richness in agarwood essential oil was significantly higher in contrast with the ordinary agarwood from the trees of *A. sinensis*. In this paper, morphological and genetic diversity difference, agarwood formation process and agarwood composition differences, physiological and biochemical wounding-induced agarwood formation mechanisms between ordinary trees of *A. sinensis* from seed seedlings and clonal trees from these special germplasm were studied.

Is the performance independent from soil preparation methods for planted bred and unselected material of Scots pine in northern Sweden?

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Hardy reforestation material with improved traits of economic interest is a prerequisite for the stability of tree breeding in the north. Whether selected genetic background is the only requirement for the superior field performance of reforestation material, or it acts together with site preparation methods, is a central question of the present experiment. To answer this question, we analyzed vitality classes, height, and diameter of 4200 seedlings of three seed origins (stand, orchard, and controlled crosses) across three study sites in northern Sweden. One-year-old seedlings were distributed across 3 soil scarification methods and five planting positions. Measurements were taken at 1, 3, and 5 years since planting. A subsample of seedlings was measured at the nursery and the measurements were used in correlation analysis between nursery-stage and field-stage traits. We used linear (LM) and generalized linear models (GLM) to assess the contribution of each factor on the studied traits on within- and between-site levels, and pairwise contrasts of estimated marginal means to assess the differences between the levels of factors. The selected genetic background did not contribute to mortality but did affect the height and stem volume of seedlings at the between-sites level. The soil scarification method introduced the least variation compared to all other factors and was only a significant factor in the interactions with the planting position and seed source at the within-site level. Seed weight had strong positive correlations with height and strong negative correlations with root-shoot ratio across locations. Our results suggest that the use of genetically improved reforestation material results in an increase in height without compromising survival rates.

Nurturing the Tree Seed System in Austria from an Agricultural Innovation System perspective

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: Healthy forests are essential for Austria's society, providing protection, recreation, and climate change mitigation. Small-scale forest and farm-forest systems play a pivotal role in achieving the socio-ecological transition towards climate-resilient forests. However, climate change-induced shifts and seed shortages pose significant challenges for reforestation efforts. For example, differences in temperature and precipitation patterns, combined with disturbances drive increased seed demand while reducing seed quality, germination rates, and harvest success. This seed shortage constrains restoration projects, impacting forest owners' adaptive strategies and decision-making.

Two-thirds of Austrian forest owners are small-scale and predominantly practice rural forestry, particularly in mountain regions. Small-scale family farms continue to dominate the agricultural and forestry sectors, making them economically significant. Thus, the research recognizes the importance of examining the applicability of producing tree seeds on small to middle-scale farms (<50 ha), which serve as ideal spaces for testing new holding concepts and niche products.

Here, we use an Agricultural Innovation System (AIS) approach to examine the Tree Seed System in Austria, focusing on small to middle-scale farms. The study aims to establish a stable tree seed supply and distribution by identifying key actors, barriers, and potentials. A mixed-methods design combining qualitative interviews, participatory workshops, and a quantitative online survey will be employed.

Our findings reveal barriers such as limited seed processing knowledge, establishment of plantations, low control of seed imports, short-term incentives tied to funding, and lack of cooperation among actors. Identified potentials for improvement include the need for targeted extension services to increase seed stand harvesting activities and increasing awareness of networking opportunities among actors.

We provide policy recommendations for institutional and structural reforms that will improve the Austrian Tree Seed System by addressing its problems and leverage points. This research contributes to sustainable forest management, climate resilience, and the redefinition of the relationship between humans and nature in Austria.

Sapindus germplasm re-sequencing in China: diversity, genetic structure, evolution, and GWAS analysis

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: *Sapindus* L. is an important forest tree genus with utilization in biodiesel, biomedicine, biochemical, and multifunctional economic forest species. Here we report a whole-genome resequencing experiment of 100 *Sapindus* core populations. Genetic structure analysis reveals *Sapindus* can be divided into six subgroups: *Sapindus delavayi* subgroup, *Sapindus rarak* subgroup, northern subgroup, Southeast subgroup, Guizhou subgroup, and hybrids subgroup. We found that *Sapindus delavayi* and *Sapindus rarak* were not diploid but potentially tetraploid or hexaploid, and proposed hypotheses for the differentiation of each subgroup. Selective sweep analysis identified fixed alleles of the genes CYP716A, CAMTA, and HD-ZIP to be involved in triterpenoid saponin biosynthesis and stress response. In addition, GWAS analysis revealed the KCS, FAD, and FAB homologous genes participated in kernel fatty acid biosynthesis. Our findings elucidated the genetic structure of *Sapindus* in China and provided targets and materials for genetic improvement of *Sapindus*.

SOIL-CLIMATIC CONDITION REQUIREMENTS AND GENETIC VARIATION OF ENDANGERED TREE SPECIES IN TERENGGANU

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: There is a scarce of information on the soil properties, climatic condition requirements, and genetic variation of these endangered trees species in the forest reserves of Terengganu. This information is essential for effective conservation strategies, as the lack of data puts these valuable and endangered timber species at risk. This study aims to address these gaps in knowledge by assessing the soil properties, climatic conditions and genetic variation for the preservation of endangered tree species in Terengganu's forest reserves. The study was conducted in selected forest reserves managed by the Forestry Department of Terengganu, Malaysia. Soil sampling was carried out at the research plots of identified timber species. The soil sampling included soil profiling and soil quality samples. A soil pit with a depth of 1 meter was dug at each forest reserve to study the characteristics of the current soil profile. Information collected included the soil horizon, soil colour, consistency, roots, biological activity, and the aggregates and structures of the soil. The universal pipette method was used to determine soil texture. Soil pH was determined in a 1:2.5 soil to distilled water ratio. Carbon, nitrogen, and sulfur content were analysed using CNS analyser. Exchangeable bases (K^+, Mg^{2+}, and Ca^{2+}) were extracted using 1M ammonium acetate ($NH4OA_c$) and analysed using Atomic Absorption Spectrophotometer. The results of the soil analyses will provide valuable information about the soil properties required for the growth and survival of the endangered tree species in the forest reserves. Relative humidity, wind speed, light intensity at each sampling points will be measured using the Environ-mete. Leaves and bark samples of trees species were also collected for genetic variation studies. The analyses are currently ongoing, and the results are expected to shed light on the soil quality,climatic condition and genetic variation of the endangered tree species in Terengganu's forest reserves. The results will be presented and discussed during the congress.

Using muti-knowledge to guide conservation of a widespread forest species: a case study (Dalbergia hupeana Hance)

T3.22 Managing forest genetic resources for multi-purposes for forest products, ecosystem services and response to climate change

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Abstract: The use of limited resources to maximize conservation efficiency is the fundamental goal of forest genetic resources conservation practice. Making conservation priority is the key factor to improve the conservation quality and efficiency, especially to widespread forest species. These species may be more likely to be neglected, but climate change, human activities, and other factors may have a greater negative impact on them. To understand genetic variation of populations and their response to climate change will contribute to making a sound conservation strategy. In this study, we selected a widespread hardwood *Dalbergia* species *(D. hupeana*) in subtropical area in China, and infer population historical dynamics, revealed spatial pattern of genetic diversity, and predicted potential impacts under future climate change scenarios. The result showed the genetic diversity and genetic differentiation of *D. hupeana* was moderate ($H_e = 0.615$, $F_{ST} = 0.132$ & $G_{ST} = 0.112$), and the spatial structure of natural populations was significant, and the spatial pattern of genetic diversity provided evidences for Central-Marginal hypothesis; the climate change had a negative impact on the distribution of *D. hupeana*, part of suitable habitat will disappear in different future climate scenario, and highly suitable habitat become more fragmented. According to the genetic diversity of natural population, stability of habitats in climate change, we could make different conservation priority and strategy.

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

Seeding the Future: Exploring Bamboo Conservation through Seeds for Enhanced Diversity and Resilience

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Bamboo, a versatile and fast growing plant, offer numerous ecological, economic and cultural benefits. Bamboo can be propagated through various means, including rhizome division and culm cutting, the propagation through bamboo seeds create an opportunity for genetic diversity. The bamboo's flowering pattern demonstrates how infrequently seeds are available. Bamboo seeds are typically short lived and challenging to store. The development of seed storage protocols for various bamboo species helps to increase the viability, longevity, and quality of bamboo seed, supports ex-situ conservation and its availability for future uses. Our study investigated the propagation through seeds and its implications for bamboo diversity and cultivation. Through a comprehensive analysis of seed germination rates and growth patterns, we demonstrated that bamboo seeds were successfully germinated and we were able to produce healthy seedlings, providing a pathway for genetic diversity and the development of diverse germplasm. Furthermore, this research addressed the challenges and techniques associated with bamboo seed propagation, including seed collection, storage and germination protocols. The current investigation was conducted on various commercially important species of bamboos, including *Dendrocalamus sikkimensis, Bambusa polymorpha, Bambusa vulgaris*, *Dendrocalamus strictus, Bambusa bambos*. Our research shows that seeds of some bamboo species can be preserved for a long time without a significant lose of viability upon desiccation to a safe moisture level and low temperatures. The seeds of *Bambusa bambos* and *Dendrocalamus strictus* exhibited a germination rate of more than 80% and remained viable even after 24 and 21 months of storage, respectively. The seeds of *Dendrocalamus sikkimensis, Bambusa polymorpha, Bambusa vulgaris* were viable upto 7 months in storage. This study highlights the importance of harnessing the potential of diversity of bamboo seeds for the development of resilient bamboo forests, economic opportunities and ecological rehabilitation. The findings contribute to the knowledge and practices necessary for effective bamboo management and conservation on a regional scale.

Keywords: Bamboo conservation, Storage protocol, Germination, Viability, Resilience.

Agroforestry: conserving tree species diversity while reducing insect pest threats to farming

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Natural environments host broad diversity of genetic resources all over the world. However, with increased over-harvesting of tree species coupled with loss of forests land to urban and agricultural developments the loss trees biodiversity and extinction of important and iconic tree species has became prevalent. The situation is exacerbated by the shifting local climatic conditions. The global decline and extinction of tree species have triggered plummeting of associated fauna especially insect populations, with a reported decline of more than 40 % and a third being endangered. Commercial monoculture of trees has further accelerated their decline. Even though genebanks play a major role in conservation, ex-situ conservation in seed banks lacks the ability to sustain natural fauna populations associated with the forest trees. With destruction of their natural habitat, the insects are therefore pushed out of their natural refuge into cultivated lands where they may adapt to new hosts. The result is that this is interpreted insect pest threats. It is therefore important to deliberately design refugia for the insect populations forced out of forests. Apart from public gardens and arboreta, agroforestry presents an opportunity for reforestation, conservation, multiplication and restoration of native species through woodlots, windbreakers, living boundary fences, contour strips, etc. Trees on farms have the potential to act as insects refugia and help shift insect pests from croplands too. Studies have shown that insect pests and pathogen populations are regulated by a high genetic base of tree species which also foster survival of natural enemies. Encouraging diversity of trees on farm will not only result to more benefits to famers but also broad genetic resource conservation in the locality; and this will be beneficial in offering the insects a more suitable habitat hence less destruction to the crop on farms. There is therefore a need to establish the local indigenous tree species diversity and their associated insect species populations, to develop strategies that will enhance their conservation and at the same time reduce insect-pest threat to farm productivity. We explore these approaches in this presentation

Community engagement to accelerate research and learning about the dieback of western redcedar

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Western redcedar is a key cultural resource for many communities in western North America, but recent increases in dieback driven by longer and hotter summer droughts, have raised concern about its availability for future generations. For some indigenous communities, the dieback is comparable to one of their dearest relatives being sick or having a language disappear. Research to understand the dieback issue, prioritize management, and find solutions are critically needed for these communities. The Western Redcedar Dieback Map (https://www.inaturalist.org/projects/western-redcedar-dieback-map/) project on iNaturalist was co-produced with state and federal agencies to expand an interagency effort to broader audiences and address the need for more information over a wide distribution in a relatively short time. Nearly 300 individuals have shared more than 2300 locations of healthy and unhealthy redcedars in an open dataset. This presentation will summarize the community engagement and the approach to leverage these data for identifying important parameters for mapping where to protect, monitor or restore western redcedar for future generations.

Forest Genetics in Sustaining Biodiversity

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Forest genetics plays an important role in providing resilience to forests across the globe. This manifests in the genetic diversity of forest tree species and the biodiversity these species represent including their ecological associates. Keystone forest species may be considered for genetic improvement for conservation purposes with respect to genetic diversity as well as trait performance. Such traits may be selected to provide sustained fitness levels in changing environments such as those being currently experienced or anticipated. Options for forest genetic management and tree improvement will be considered in the context of climate change and the increasing exposure of forests to invasive pests and pathogens.

Genomics to the rescue: adaptive potential of keystone species provides crucial information for ecosystem service management under global change

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: To keep pace with the current speed of climate change, effective management of plant genetic resources must be developed. Keystone species such as *Populus* spp. are important targets in the study of resilience to future climate conditions because they play a crucial role in maintaining various ecosystem functions and may contain genetic material with previously untapped adaptive potential. They also exhibit some of the fastest inherent growth rates for temperate trees worldwide, with 17–30 dry Mg ha–1 yr–1 on 6–8-year rotations for certain hybrid poplars. These inherent fast growth characteristics can be exploited for short rotation management, a time and energy saving cultivation alternative for lignocellulosic feedstock supply. *Populus* spp. also have value for the rehabilitation of disturbed sites from logging or fire (i.e., land reclamation) or for the phytoremediation of soils polluted by hazardous waste. Based on our published and also ongoing research, the talk will provide a comprehensive overview of genomic regions showing signatures of adaptive potential in three important North American poplar species (*P. trichocarpa*, *P. balsamifera*, *P. tremuloides*) covering large longitudinal and latitudinal ranges across North America. The talk will also highlight species' phenotypic responses to environmental extremes to improve the selection for climate-resilient revegetation and identify appropriate management units. We are further investigating if populations within species with such large distribution ranges are genetically equipped to adapt to future climate conditions or are genomically vulnerable, and if specific populations are an option for assisted migration in Canada. The information on tree crops' genetic makeup is also useful for developing a novel wood tracking tool for which the most informative genetic markers (on species, population, and adaptive levels) will be made available to stakeholders involved in ecological restoration.

Global Tree Assessment – identification of threats to the world's trees

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Trees are essential to life on earth – playing important economic, ecological, and cultural roles. However, the threats to trees are many and diverse and there is a vital need for an increased conservation focus on tree species. Without the conservation assessments of trees how can we know what are the most pressing threats to specific tree species and their habitats?

The Global Tree Assessment has filled this knowledge gap for trees through innovative and collaborative methods. We engaged with over 500 experts, partnering with more than 50 institutions, including botanic gardens, forestry departments and universities, across all continents to produce IUCN Red List assessments for the world's tree species and identify the threats to tree species survival.

Now that we have comprehensive threat information for the trees most at risk, it must catalyse action to prevent extinctions. As funds for conservation are limited, the Global Tree Assessment data is being used to prioritise the most effective conservation actions, feeding directly into conservation planning, practical projects and monitoring.

While climate change is an emerging threat to tree species globally, other significant pressures vary by biogeographic realm and habitat type. For example, temperate tree species are more likely to be at risk from pests and diseases, while tropical trees are more frequently impacted by logging and land-use change. By identifying variations in threats at various taxonomic and geographic scales, conservation interventions can be better targeted, utilizing relevant expertise within the conservation community. Hence, the results of the Global Tree Assessment will have far-reaching positive outcomes in mobilising targeted action to combat threats to tree species.

Long-term Vegetation dynamics in forest habitats across four decades of accelerating global change

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Accelerating global change affects forest ecosystems, their composition and functioning at an unprecedented rate. While multiple drivers have a strong impact on forest ecosystems in Europe, our understanding of long-term ecosystem dynamics as a response to global change is limited, hampering an effective adaptation of conservation and management efforts. The Habitat concept is an important measure of biodiversity linking landscape, vegetation and species scales and thus a crucial target of European conservation efforts. Forest habitats are of key importance for European biodiversity. However, knowledge on trends in vegetation dynamics within and across habitat classes is scarce. We quantify vegetation dynamics within and across different EUNIS forest habitat classes throughout Germany using combined long-term time series data sets collectively covering a time period of over 40 Years. We analyse species cover and weighted Ellenberg indicator dynamics to explore trends in forest vegetation across strata, relationships between the velocity of change and within habitat class dispersion as well as between class distances over time. Our results will help to assess long-term dynamics in changing forest vegetation, aiding a better understanding of trends and directions of change in European forest habitats informing efforts to adopt conservation and management to global change.

Mobilizing midwives for the forest: volunteers, seed collection and tree planting

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Different organisations in the UK, most of them third sector with the support of public funding, have taken up responsibility for activities related to seed collection and tree planting aimed biodiversity resilience and climate change objectives. These are only loosely held together by emerging policy such as the Strategy for UK Forest Genetic Resources (2019) and the National Tree Improvement Strategy (2017) which themselves sit alongside country-level action plans for increasing the area of native woodland cover.

Much of the work is undertaken by third sector organisations such as botanical gardens, the Future Trees Trust and the Woodland Trust. As is commonplace in the third sector volunteers have often been recruited in the hunt for rare species and ‘plus’ trees and to collect seed and plant trees. In addition, third sector organizations depend on voluntary donations for core funding and increasingly use crowd funding for specific projects. The effect is that civil society is mobilized as a labour force and source of income for the “scientists” who prioritize species and decide what actions are most appropriate. Nevertheless, civil society itself is not passive and there is increasing activity led by putative volunteers seeking to achieve their own objectives within their local landscapes. This can take many forms including facilitation of tree planting to capture carbon, development of community woodlands, wholesale tree seed collection or securing ‘reproductive rights’ for individual mother trees.

This paper examines the internalization of activities which help to build resilience in the next generation of native trees by citizens, communities and third sector organization in Wales. We conclude that there is much to be gained by greater negotiation on priorities and actions between traditional decision-makers and volunteers.

Monitoring nucleated seed orchards and diagnostics for failure: improving propagation efforts for American beech.

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Beech bark disease has been present in Michigan (United States) for over 20 years, killing approximately 2.5 million trees to date, and impacting the forests of two National Lakeshores managed by the National Park Service. It is estimated that roughly 1% of American beech (*Fagus grandifolia*) are naturally resistant to the disease. These resistant trees provide source material for restoring this ecologically important species. This is especially important given additional challenges to the species, with beech leaf disease increasing across the eastern range of American beech (though not confirmed in the target areas of this study). Remediation within the National Lakeshores has begun via outplanting grafted trees under existing canopies. Local provenance, confirmed resistant trees are utilized as scion material for grafting propagation. Additionally, planting trials in forests just outside of American beech's native range in Michigan were conducted in 2021 and 2022 to compare variation in site preparation, seasonality, and other planting variables.

To date, we are unaware of other studies utilizing applied nucleation techniques for American Beech remediation. No significant differences in survival or growth have been observed in the trial plantings yet, however, it is generally understood that American beech is a challenging tree to propagate and plant out, especially as a grafted tree. Mortality has been documented at numerous monitoring points, leading us to develop a diagnostic guide for identifying points of failure during American beech propagation. The guide covers trees kept in greenhouse facilities, trees in pots awaiting planting, and planted trees. Planted tree necropsies can provide a "lessons learned" manual for other beech propagation efforts. Given American beech's life history traits as a late-successional shade tolerant species, we hypothesize that understory plantings will be successful. Continued monitoring of the existing plantings allows us to best implement future outplantings to increase resistant genetics.

Plant health research in South African botanical gardens: Current status and future directions

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: International trade and climate change, among other factors, have driven an increase in plant pest and disease outbreaks worldwide. Plant pests and diseases are often moved with plant material to new areas. Many become invasive, and management is commonly difficult or even unfeasible. This continuous influx of introductions represents a serious threat to biodiversity and sustainable development. One approach to improve our knowledge and ability to timeously respond to plant pests and disease is to monitor sentinel sites and sentinel plantings. The use of plant collections such as botanical gardens and arboreta for these purposes has been facilitated by various international collaborations, such as the International Plant Sentinel Network (IPSN). South Africa has 23 botanical gardens across the country, eleven of which are managed by the South African National Biodiversity Institute (SANBI). Within the framework of the IPSN, a project to improve the surveillance and identification of plant pests in South African botanical gardens was initiated in 2016. This has resulted in new detections of numerous invasive pests such as the polyphagous shot hole borer (PSHB); and records of known pests on new hosts such as the root pathogens *Phytophthora cinnamomi* and *Armillaria mellea*. These pests have been found, in many cases, to be negatively impacting threatened species maintained in the collections and in surrounding natural areas; and, in the case of the PSHB, a nation-wide outbreak of significant concern. The project "Monitoring tree health at sentinel sites: botanical gardens and arboreta" has provided a platform to record baseline information on pests detected across the botanical gardens and has assisted in the listing of pests under South Africa's regulations on biological invasions. The project has also contributed to the development of biosecurity best practice guidelines to help botanical gardens manage pest risks in their collections, as well as to support restoration activities emerging from these.

Proactive Planning for Seed Needs in Reforestation: Challenges and Opportunities to Strengthen the Tree-Seed Supply Chain In the Western United States

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Healthy forests are critically important for mitigating the effects of climate change, reducing biodiversity loss, and protecting our water resources. In regions where sustainable management of forest lands has been incentivized or required, wood products industries have relied on tree seed orchards and wild collection activities to meet their annual post-harvest regeneration needs. However, many regions with less productive forests and with complex terrain and/or poor civil infrastructure have been underrepresented by seed collection and banking efforts and have little or no genetic material for artificial regeneration activities. Additionally, decades of chronic underfunding combined with the worsening impacts of climate change and associated catastrophic disturbance events (e.g. wildfire) have increased the need for reforestation significantly. Proactive planning for seed needs is critical to shift from a reactive to a strategic approach to deal with the irregularity of mast events across a complex mosaic of species, populations, landscapes, and ownerships.

Seed collection, testing, and banking for reforestation is a century-old practice in the conifer-dominated forests of the Western United States. Few technological innovations and logistical solutions were made over the last half-century until recently when Silvaseed and Mast Reforestation began scaling wild seed collections across 11 Western States. This presentation will highlight the challenges impacting tree-seed availability and provide a historical perspective on seed collections before leveraging several years of operational data to demonstrate a technology-driven leap forward in addressing the seed pipeline. Key points derived from operational activities and from a recent publication will highlight opportunities for strengthening the tree-seed supply chain in an era of climate change.

Quantifying Genetic Variation in Threatened Ash Species: Insights from Ex situ Collections

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: For many species, germplasm preserved ex situ can be critical to establishing breeding and restoration resources. While ex situ collections preserve genetic diversity, there are often gaps in our understanding of the extent of diversity preserved in these collections. Thus, particularly for rare or endangered species, evaluating extant variation preserved ex situ is needed. Seed morphological traits derived from x-ray images can be used as a proxy for assessing standing genetic variance maintained in collections, distinguishing within maternal family and between population trait differences across the ranges of diverse species. For *Fraxinus* (ash) species native to North America, understanding the distribution of genetic differences across a species' range can inform the development of resources needed to ensure long-term species preservation. The Emerald Ash Borer (EAB), one of the most destructive pests ever introduced to North America, has decimated ash populations across the US and Canada. Critically endangered black ash (*Fraxinus nigra*) is a keystone species across much of its range, supporting foundational ecosystem services in the unique wetland landscapes it dominates. Given the threat of the EAB, there is a need to extend existing germplasm collections and to quantify within and between population genetic variance preserved in collections to lay the groundwork for EAB-resistance breeding and preservation. Working alongside domestic and international collaborators, we have established an ex situ collection of black ash seed that spans the US and Canada. X-ray image analysis of seed and samara morphology in our range-wide collection will be used to assess the proportion of variance in morphological traits explained by both among-population and within-family differences. Where substantial population genetic structure within populations is observed, populations can be prioritized as regions for supplemental collection to ensure genetic differences are maintained in collections. Where significant within-family variance is observed, the evolutionary potential of individual populations can be assessed. Thus, examination of morphological trait differences from ex situ collections can provide foundational data needed to characterize population genetic differences, setting the stage for future conservation and restoration efforts.

Resilience of British woodland trees: Kew's research on genetic resistance, local adaptation, diversity and seed banking

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: The government has committed to increasing tree cover to at least 16.5% of all land in England by the end of 31st December, but its tree species are threatened by an unprecedented increase in invasive pests and pathogens, and must also adapt to climate change. Royal Botanic Gardens Kew is undertaking a range of research and conservation activities aiming to enhance the resilience of UK woodland tree populations. We and our partners are seeking to understand the genetic basis of resistance of key threats (ash dieback, acute oak decline and Dutch elm disease), using a range of genomic approaches. This allows us to better understand resilience of woodland populations and develop accelerated breeding programmes to improve the capacity of tree species to cope with these threats. We are searching for signals of local adaptation in oak and birch populations using genome-environment analyses, to inform planting of the right tree in the right place in present and future climates. We are seeking to understand the implications of natural regeneration versus tree planting for genetic diversity of tree populations. Large-scale seed banking has been undertaken under the UK National Tree Seed Project, with geo-referenced mother trees across the native range of each bankable species. For birch and alder, we have germinated and genome-sequenced representative samples of these collections, to understand their diversity and local adaptation. A large new glasshouse facility is being built next to the Millennium Seed Bank, which will facilitate our research on UK trees and the propagation of material for deployment. Kew has long collaborated with Forest Research on these projects, and this partnership has recently been further strengthened through the establishment of the Centre for Forest Protection. This research is essential to the maintenance and expansion of tree cover.

Safeguarding Biodiversity and Wild Plant Genetic Resources: The Baekdudaegan Global Seed Vault

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Wild plants hold immense value in human societies, as they constitute vital components of forests that harbor biodiversity. The potential consequences of any disruption to our forest ecosystems, such as the destruction of freezers due to military actions or other compromising events, would result in the loss of seeds, wild plants, and overall biodiversity. Recognizing the significance of biodiversity preservation, particularly in relation to the well-being and future of humanity, it is imperative to establish robust backup mechanisms, even extending to secondary backup measures. Addressing this challenge, the Baekdudaegan Global Seed Vault has taken on the prestigious responsibility of safeguarding the seed collections of all wild plant species on Earth. By ensuring the existence of a secure repository, the Baekdudaegan Global Seed Vault aims to guarantee the preservation of essential plant species, which play a critical role in sustaining global biodiversity. Strategically situated at an altitude of 600m or higher, the seed vault remains impervious to sea level rise resulting from the climate crisis. Furthermore, its subterranean location shields it from external physical shocks and unauthorized access, rendering it inherently inaccessible, as it should be. The seeds housed within the Baekdudaegan Global Seed Vault are meticulously packaged in black boxes and hermetically sealed, ensuring their long-term viability. Maintained at a constant temperature of -20 degrees Celsius and relative humidity of 40 percent, the storage conditions are closely monitored on a daily basis. Consequently, the seeds are perpetually conserved under uniform conditions, providing a fail-safe measure against unforeseen catastrophes that may jeopardize the original plant populations. In summary, the Baekdudaegan Global Seed Vault serves as a pivotal initiative to secure the future of biodiversity and wild plant genetic resources. By encompassing the storage of every single seed from wild plant species worldwide, the Baekdudaegan Global Seed Vault offers an invaluable opportunity for individuals possessing wild plant seeds to contribute to the preservation of our planet.

Searching for Tolerance to Laurel Wilt Disease in Avocado Germplasm from Diverse Sources

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: Laurel wilt (LW), a deadly vascular disease caused by *Harringtonia lauricola*, affects numerous hosts in the Lauraceae. In the USA, twelve states are already battling LW, which continues to move towards major avocado-producing areas. The destructive nature of LW makes it an imminent threat to avocado production worldwide; especially, when combined with its multiple hosts and ambrosia beetle vectors. In Florida, LW has already led to the destruction of 300,000 avocado trees. If left unchecked, it could devastate the worldwide production. To date, there are no effective and cost-efficient cultural or chemical management strategies. All tested cultivars including Hass, are susceptible to the disease, but in the field, few trees have survived or have been identified as having asymptomatic infections. Using locally sourced seedling material, our group has uncovered genotypes with varying degrees of tolerance, which suggests that the host's genetic background influences the infection outcome. This study aims to identify LW-resistant/ tolerant genotypes, establish the baseline germplasm collection for future breeding programs and create a source of propagative material for the local industry. The screening uses germplasm of the following three categories: 1) surviving avocado trees; 2) varieties of Mexican or Mexican hybrid ecotype; and 3) varieties resistant or tolerant to other biotic and abiotic stressors. Screening material is sourced from germplasm collections, local growers and collaborators from different research institutions. Thus far, our team has screened 700 seedlings corresponding to 25 accessions which are part of the largest avocado germplasm collection in Mexico, "Fundación Salvador Sánchez Colín". Although most of the seedlings developed external symptoms, the disease severity varied significantly among half-siblings within each accession; less than 5% of the seedlings developed mild symptoms (<10% wilting) or no external symptoms. Two accessions, "Arbol 274B" and "Colin V-33", contained the highest number of seedlings that developed mild symptoms or remained asymptomatic. These plants are currently being propagated for subsequent replication experiments using clonal material. Portion of the non-surviving and all surviving plants will be genotyped to identify genomic regions, which potentially confer disease resistance and/or tolerance.

The need for seeds: A call to increase global seed banking efforts.

T3.23 Mini-Symposium: Resilience of Forest Biodiversity to Climate Change and Pests: Civic Engagement and Conservation in Seed Banks, Public Gardens, and Wild, Urban, and Agroforestry Landscapes

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Abstract: The 21st century is the first time in human history in which there are efforts to plant trees globally as opposed to extracting natural resources from the Earth. Seed supply is at the heart of the largest crisis factors of our time; global warming and biodiversity loss and collapse. The UN Decade on Ecosystem Restoration was proclaimed by the UN General Assemly following a call for action from over 70 countries. The UN Decade will run until 2030, which is also the deadline for the Sustainable Development Goals and timeline scientists have identified as the last chance to prevent catastrophic climate change.

Extreme climate events are already happening. Without a backup supply of seeds, nature based solutions such as reforestation and afforestation will be forced to compromise their restoration species and goals, which will impact future biodiversity.

Seed banks provide rapid response to events such as storms, floods, wildfire, which are increasing. These events destroy mother trees and lower the diversity in the field. Given that it takes on average 7-10 ten years for a tree to flower and seed, even in the best case scenarios in natural regeneration there is a risk of a permanent seed shortage in the future. Increasing fragmentation of ecosystems, pathogen and insect outbreaks also contribute to seed shortages.

In the UN Global Strategy for Plant Conservation seed banks are listed as a priority ex-situ conservation tool. It is important for land managers to collect seed now and bank it for scaling restoration, and for short term and long term storage.

Regional seed banks can provide a safety net for biodiversity and leave the next generation with the resources they will need to support healthy ecosystems.

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

Clear-cut effects on in-stream metabolic rates propagate downstream

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Clear-cutting of forests with little or no regard to riparian buffers, alters the local habitat of streams by increasing temperature, incident light, suspended sediments and resource inputs. It is well documented that such habitat changes affect local stream ecosystem processes. Here, we ask whether biotic processes can also be affected downstream of clear-cuts. We tested this in nine headwater streams that run through recent clear-cuts (1-6 years) with varying buffer widths in northern Sweden to compare biofilm and whole stream metabolic rates in their upstream, clear-cut and downstream reaches. We estimated local biofilm metabolism in all nine streams using tiles and we assessed whole stream gross primary production (GPP) and ecosystem respiration (ER) from oxygen loggers in three streams. We found that biofilm GPP indeed increased, on average, by 54 % downstream of clear-cuts in July, but that the net effect on the whole ecosystem was a decrease in ecosystem productivity due to high respiration rates. In September, the situation was different as there was instead a 50% decrease in biofilm GPP downstream of clear-cuts. Wide buffer zones (>15m) could partly mitigate these longitudinal changes, except in one stream which was dominated by fine sediments. Importantly, the magnitude of downstream propagation in biofilm GPP was related to the magnitude of responses in the clear-cut, which in turn was driven by nutrient concentrations. We show that clear-cut effects on stream ecosystem processes are not only local, but can also be propagated to downstream recipient waters if management practices within the clear-cut have not been sufficient. Using maps of registered, recent (1-6 years old) forest clear-cuts and modelled forest stream networks of Sweden, we estimated that at least 3% of all forested streams in Sweden risk having metabolic rates that are affected by upstream clear-cuts. We do not know for how long (time or space) this memory effect of forest clear-cuts on fluvial ecosystem function persists but it is likely longer than 6 years and 100m in many cases.

Consequences of Alternative Forest Management in Riparian Buffer Zones: A GIS Analysis

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: With increasing pressure from policymakers and the general public to conduct alternative forest management throughout the European Union (EU), Sweden needs to find ways to best prioritize the implementation of this alternative management. Riparian buffers are one possible location that may provide a win-win solution for meeting EU goals as well as benefiting water quality and biodiversity. Riparian buffers can protect the ecological functioning of a stream, typically by leaving a strip of unharvested trees in place around the stream, but in Sweden these buffers are often too narrow (5-7m) and are dominated by a single tree species. Implementation of alternative forest management that would promote a diversity of tree species in wide riparian buffers could benefit streams, as well as assist Sweden in meeting EU goals. To determine the amount of forest land contained within buffers under 5 m, 15 m, 30 m, and 60 m buffer width scenarios we conducted a GIS analysis of 11 study areas throughout Sweden. We also examined the current tree species composition in these potential buffer zones and analyzed the area around both natural channels and forest ditches. We found that there is a significant latitudinal gradient in species composition within the buffer zones from north to south, with total tree volume, deciduous tree volume, and spruce tree volume increasing from north to south, whereas the proportion of pine is highest in northern study regions. This latitudinal trend was not seen in terms of the proportion of forest land contained within the buffers that was productive forest land; however, there was a significant difference between the amount of productive forest land found around ditches versus streams. The percentage of the total study area's productive forest land that was contained within buffers, i.e., the amount of forest land that would be transitioned to alternative management, ranged between 3.5% and 34% for ditches, and 0.5% and 5.5% for natural channels. Converting riparian buffers to alternative forest management appears to offer great potential for maximizing protection of sensitive riparian zones, while minimizing economic losses.

Continuous cover forestry and biochar as a tool to reduce nutrient loading to watercourses

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Forest management practices on drained peatlands increase nitrogen (N), phosphorus (P) and dissolved organic carbon (DOC) export to downstream aquatic ecosystems. Increased nutrient and DOC loading cause eutrophication, hypoxia and changes in biogeochemical processes and food webs in watercourses. Furthermore, high DOC concentrations cause water brownification and problems in drinking water treatment processes. Continuous cover forestry (CCF) is proposed to be an environmentally more sustainable management option for peatland forests than the conventional even-aged clear-cutting. However, the environmental effects of CCF are poorly known.

We studied the concentrations of N, P and DOC in ground water and ditch water in clear-cut, partially harvested, i.e. CCF, and uncut drained peatland forests in Finland. We also studied the effects of harvesting intensity on DOC quality and the rate of DOC biodegradation to CO_2. The results suggest that CCF reduces the concentrations of DOC and nutrients in watercourses, decreases DOC biodegradability, and therefore the aquatic CO_2 emissions compared to clear-cutting in drained peatland forests.

One potential solution to decrease nutrient loading could be adsorption-based purification of runoff water using biochar. We have tested the use of wood biochar in runoff water purification in clear-cut forests. We studied adsorption and desorption rate, and adsorption capacity of Norway spruce and silver birch biochars. We found that biochar removes organic N, ammonium and nitrate from the water. The results also showed that the N adsorption capacity of biochar increases with an increase in the initial N concentration in the water. The adsorption process was fast, which suggests that biochar can clean water also with short water residence time in the biochar reactor. When biochar had first adsorbed N, significant desorption did not occur when biochar was again in contact with low concentration water. This suggests that biochar works well even in such conditions where there are seasonal fluctuations in water nutrient concentrations. Our results indicate that biochar can be a complementary water protection method in peatland forests.

Development of GIS-based Methods for a Climate Change adapted Forest Infrastructure

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Many experts predict that climate change will increase the likelihood of extreme weather events such as droughts and heavy rainfall. Vital forests retain water through interception or receptive soils. Prolonged droughts or insect infestations endanger trees causing higher surface runoff, which can lead to erosion and flooding of populated areas nearby.

To maintain a healthy ecosystem and allowing a sustainable forest management, forest infrastructure such as forest roads must be well functioning. However, forest roads are mostly gravel roads prone to erosion by water. Therefore, any runoff along or across forest roads may be critical and force erosion damage. Continuous road maintenance will take more efforts to keep operability for all functions. To respond to higher flows due to heavy rainfall or prolonged drought, forest infrastructure must be adapted. On the one hand water runoff must be directed to reduce potential damage on forest infrastructure. On the other hand, water should be retained in the forest ecosystem to maintain a healthy water balance.

The research project "*KlarWeg*" identifies the impacts of climate change on existing forest roads, generates and collects possible adaptation strategies and integrates them into a road management concept in order to improve the overall water balance in forests. One of its approaches is the development and testing of a GIS-based method for the localization of risk zones in case of heavy rainfall and for the detection of potentially useful areas for water retention.

Due to the accuracy of available GIS Data and the accessibility of OpenSource Software (*QGIS*), the modelling of potential flow paths through forest terrain is able to show accurate and field-validated results. Combining these modelled flow paths with data of forest roads, risk zones can be calculated, evaluated and ranked by size of the related watershed, to map out critical points in the forest infrastructure. These identified risk zones are highly vulnerable to high runoffs after e.g. a heavy rain fall and therefore to rain induced damages. Hydrological and hydraulic calculations show the effects and limits of the work, exemplified by three areas in Germany. The effects should be transferable to similar areas worldwide.

Ditch network maintenance exacerbates the export of sediments from historically drained forests after clear cut

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Nearly one million km of ditches have been dug in peatlands and wet mineral soils over the last 100 years in Sweden, primarily to improve forest growth. Many ditches have resulted in new areas of productive forests, while others have led to large-scale wetland degradation and poor downstream water quality. Understanding the consequences of traditional management of these ditches is important for improving our forestry practices, particularly how clearcutting and ditch network maintenance (DNM) affect suspended solids draining these management actions. Here, we present the results of four years of monitoring of total suspended solids (TSS) in a catchment-scale experiment at the Trollberget Experimental Area associated with the Krycklan Catchment in Northern Sweden. We measured pretreatment TSS on six catchments (November 2018 - August 2020), then successive treatments of clear-cut (CC) forest harvest on four of the six catchments (August 2020-September 2021), then DNM on two of the four clear-cut catchments (CC+DNM; September 2021-October2022).

We found that peaks in TSS concentrations occurred after both CC in August 2020 as well as DNM in September 2021, but when these single grab samples were combined with turbidity data taken at 15-minute intervals, we found that instead of just lasting a few hours as in the CC catchments, these peaks often lasted a few days in catchments that had both CC+DNM. These peaks were not outside the range of concentrations of TSS found during flood events in the reference catchment, for example in spring flood conditions. But on average, we found that catchments with both DNM and CC treatments had 430% higher turbidity than those with just CC. The turbidity measurements we recorded were over the World Health Organization's (WHO) drinking water quality standards 17% of the time during the reference period before treatments, while after CC and then CC+DNM, 90% of the measurements were over the standard. Clearly, forest management using CC and DNM impact water quality and at a minimum, DNM practices should be limited in the future if we want to ensure good water quality.

Effect of low-cost in-situ soil moisture conservation measures on soil erosion in montane Pinus roxburghii forests

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: The *Pinus roxburghii* Sarg. is a principal species of the Himalayan subtropical forests of India. It is distributed in 8690 sq km area of different Indian states. The *P. roxburghii* forest area serves as a large catchment area for two major rivers, namely, Ganga and Yamuna originated from the Himalayan mountains. Under the influence of heavy rain and moderate to steep slope terrain condition, detachment and movement of soil particles with water leads to soil erosion. Soil erosion causes loss of fertile land, and sedimentation in streams and rivers, decrease the carrying capacity of waterways. This will directly effect aquatic diversity and understorey vegetation establishment on forest land. The present study was conducted in the *P. roxburghii* forest area at Mussoorie forest division, Uttarakhand. Eight treatments (T1-Shallow ditch-I, T2-Shallow ditch–II, T3-Shallow trench, T4-Earthen bund, T5-Pine needle bund, T6-Earthen bund+ Grasses, T7-Pine needle bund+ Grasses, and T8-Control) with varying depths and lengths were applied in the field to assess the effect of low-cost in-*situ* soil moisture conservation measures (SMC) on reduction of soil losses. The recorded average annual rainfall on site was 2200 mm to 2500 mm using a tipping bucket rain gauge. Among all the treatments lowest soil sediment concentration was observed in the T5 (3436 ppm) followed by T7 (3739 ppm), T2 (3828 ppm)treatment and highest soil sediment concentration in the T8 (6817 ppm) i.e. control treatment. The T5 treatment was most effective treatment to reduce the losses of soil and it acted as a filter and stabilized soil sediments generated in runoff flow. The results indicated that utilization of dry-pine needles as SMC structure was effective to control soil erosion. Dry pine needle is readily and free-of-cost available in the extensive pine forests. The results will help in the effective management of pine needles to reduce losses of soil due to sedimentation beside reducing incidence of forest fire, improving groundwater recharge and preventing the negative effects of excess sedimentation accumulation in the natural water bodies.

Food web responses to modifying the size and configuration of riparian buffers along streams in managed forests of western Oregon, USA

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: In managed forest landscapes, the size, configuration, and extent of riparian reserves has been and continues to be an important ecological consideration. Fixed-width buffers have value as regulatory prescriptions due to their relative simplicity in application and assessment, and they have been shown to be effective in protecting stream habitats. However, they may not be the optimal configuration to protect ecological or hydrological function in streams. Alternatives such as variable retention buffers may provide greater ecological protection by allowing for more tree retention along sensitive streamside areas, with the trade-off of increased tree removal close to streams in less-sensitive sections. Despite their potential benefits the efficacy of alternative riparian prescriptions has not been widely evaluated. Using a replicated (n=6) before-after control-impact (BACI) study design, we created six experimental blocks each of which included an uncut control unit and four riparian buffer prescriptions applied to fish-bearing streams: fixed-width buffer, buffer with thinning in outer edges (Oregon current practice), variable retention, and buffer with canopy gaps. To assess potential bottom-up effects, we collected data on benthic biofilms, macroinvertebrate abundances, and the abundance and biomass of stream vertebrates (salmonid fish, sculpin, and salamanders). Preliminary data indicate a muted response in total biofilm biomass and in total macroinvertebrate abundances. When changes were present, they did not consistently align with light responses. In the first year after harvest, adult trout population responses were mixed with some sites showing slight increases and others slight decreases. However, juvenile (age 0+) trout populations increased notably across all sites in the first year after treatment, with some sites seeing two- to three-fold increases. The reference sites did not have increases in juvenile trout or in adult trout between the pre- and post-treatment surveys, suggesting that responses were attributable to the treatments. In the sites where we completed a second year of post-treatment surveys, preliminary results indicate increases in adult trout with more moderate (but still mostly positive) responses in juvenile trout. We attribute the adult trout responses in year-2 to recruitment of the previous year's strong juvenile year-class, suggesting an overall population level response at these sites.

Forest buffers along surface water bodies on forest land in Sweden - recent findings

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Sweden has about 100 000 lakes (greater than 1 ha) and a vast network of rivers, streams and ditches. Productive forest land covers 58% of the land area. Thus, environmental consideration to surface water bodies is part of every-day work in Swedish forestry. Maintaining or creating 'functional' forest buffers is one important measure for protecting surface water bodies and riparian forests. In a dialogue process on environmental consideration, the concept 'functional' forest buffers beside watercourses and lakes was defined. 'Functional' forest buffers refer to streamside forests that maintain six functions in and adjacent to surface water bodies, namely soil chemical processes, shoreline stabilization and prevention of sediment transport, food supply to aquatic organisms, shading, deadwood supply and biodiversity. When necessary, measures to improve forest buffer functionality can be taken, for example by adjusting tree-species composition of the streamside forest. More knowledge on buffer delineation and consequences of different management strategies of the streamside forest could help improve the practical implementation and functionality of forest buffers. Here, findings from some recent investigations and ongoing work on forest buffers in Sweden are summarized. In a field survey in three regions across Sweden performed in 2018, characteristics of forest buffers left beside streams, lakes and ditches during clearcutting were investigated a few years after harvesting. In two small streams in south-central Sweden, long-term effects on benthic macroinvertebrates and water chemistry of selective thinning of the streamside forest at the pre-commercial thinning stage were studied. Furthermore, six new field sites have recently been established in spruce-dominated streamside forests ready for first thinning. Current knowledge indicates that the functionality as buffers of these forests would improve with an increased share of broadleaf trees. The aim is to test how different thinning regimes affect future vegetation development. Finally, the potential to digitally delineate forest buffers is evaluated by using high-resolution Lidar data that provides information on tree cover, ground surface elevation and proportion of deciduous trees. This could aid forestry planning and implementation of forest buffers.

Forest management strategies to improve ecosystem water functions in low rainfall region

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: The Eucalyptus gender occupy large areas in Brazil in a high productivity system, reaching 7.53 million hectares of planted areas. There is a concern to maintain natural areas under protection, which may vary from one region to another depending on natural conditions, but on average these areas occupy 40% of the areas managed by the sector. These protected areas, together with good management practices, are essential to maintain important water ecosystem services, which is one of the most desired services. In an experimental area in São Paulo, Brazil, hydrological data of 2 water years (WY - 2020 and 2021) from 2 experimental catchments were sampled with a frequency of 15 minutes in a pluviometer for precipitation and in a stream-gauge instrumented with a pressure sensor to measure flow. The catchment 1 (C7,5%NV) is covered with 80% of commercial plantation conducted for a short rotation cycle aiming pulp production, it was implanted in 2017 and has 7.5% of native vegetation. The catchment 2 (C51%NV) is covered with 49% of commercial eucalyptus planting conducted in a long rotation cycle to produce sawn timber, it was implanted in 2014 and has 51% of native vegetation. The WY showed differences in annual precipitation. The second WY rained less 30% in C7,5%NV and less 22% in C51%NV. However, the relative difference in water yield between the 2 WY showed a great difference. While C7,5%NV decreased about 11%, the C51%NV had an increase of 22%. For the Base Flow Index (BFI), the C7,5%NV decreased 21%, while C51%NV decreased only 1.2%. At the time of analysis, the commercial forest in C7,5%NV was between 3 and 4 years old, which is a time of higher productivity in the cycle rotation. In C51%NV, the commercial forest was between 6 and 7 years old, which is a moment when productivity is more stable. Although a complete analysis of the cycles is yet necessary, the water yield and BFI pointed to a possible way for regions trending to lower water availability, respecting the native vegetation and planted forest proportion besides the forest development time most suitable for the natural condition.

Forest Road Engineering – Climate Change Adaption Strategies in Water Management

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Forest roads serve a variety of functions, most of them are essential for sustainable forest management. These gravel roads are susceptible to erosion by water. Therefore, rapid drainage of forest roads after precipitation events is essential to prevent damage and maintain operability of roads. While design features such as elevated cross-sectional profiles and longitudinal gradients exceeding 2% are important for surface water drainage, it is increasingly important to retain the drained water in the forests, thereby increasing the available water resources in the forest ecosystem. Given the changing global climate and associated impacts on the water regime, forest road engineering needs to be adapted in this respect.

One of the approaches to face these challenges is to analyze international standards and best practices. Due to the dependence on regional factors in forest road engineering, specific local guidelines and manuals evolved. These documents are intended to assist practitioners considering local requirements for planning, construction and maintenance of forest roads. Reviewing these documents allows for identifying meaningful road management practices of countries with climate conditions similar to conditions projected for Germany in the near future (so called “Climate Analogues”).

The proposed presentation shows the results of this meta-analysis in session T3.24, where we will give an overview of different design parameters, such as longitudinal gradients, dimension and spacing of culverts for cross-drainage of ditches, and the design of side slopes. We will also include similarities and differences in the maintenance concepts like frequency and associated technical methods. From this set of means and measures, those will be selected that will allow the best adaptation of the design and layout of forest roads to the actual needs due to climate change.

How different riparian buffer configurations affect abiotic responses in perennial headwater streams in managed forests of western Oregon, USA.

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Alternative riparian management approaches that emulate natural disturbance or enhance protection in ecologically significant locations have been proposed to improve ecological function of buffers. Riparian buffer configurations that enhance spatial heterogeneity of forest canopies may alleviate light limitation in localized sections of the stream while maintaining key shading and large wood recruitment functions. These alternative practices may create biogeochemical hotspots that can enhance in-stream primary productivity and stream food webs. We designed a large-scale, replicated field experiment (n=6) in which we applied four riparian buffer configurations in relation to an unharvested reference to manipulate spatial variability in light conditions on stream channels and then evaluate whether these treatments affected aquatic ecological function. Buffer treatments sought to establish a gradient of light conditions on the stream: 1) an unharvested reference, 2) fixed width, 3) state of Oregon current practice, 4) variable retention, 5) canopy gaps. We measured physical (large wood, substrate size, width, depth, discharge, pool area, canopy cover, light, and temperature) and chemical (nitrogen, phosphorus, dissolved organic carbon, and specific ultra-violet absorption at 254 nm; $SUVA_{254}$) responses in each of 30 streams (5 references, 25 treatments) for two years pre-harvest and two years post-harvest. Treatments enhanced light relative to reference sites, but light was not correlated with changes in canopy cover. For example, the greatest canopy cover change occurred in a variable retention treatment with minimal change in light on the stream surface. Preliminary results (n=2 per treatment) indicate large wood volume index and diameter consistently increased in fixed width buffers relative to pre-treatment and reference conditions while length consistently decreased in all treatments. Similarly, nitrate concentrations increased in fixed width and gap treatments, whereas $SUVA_{254}$ increased in variable retention and current practice treatments after harvest. Macroinvertebrates, as a biological indicator of changes in water quality, suggest variable retention treatments may have led to greatest disturbance as more chironomids, more tolerant, and less intolerant species occurred in two streams with this treatment. Post-treatment data collection is ongoing across 25 of 30 streams, and ultimately this replication will aid in understanding abiotic responses to buffer configurations across a broad geographic area.

How do ditches affect the biodiversity of Swedish forest land?

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Nearly one million kilometres of ditches have been dug across Swedish forest land over the last 100 years to improve forest production. Not much is known about how much these ditches have changed the Swedish landscape. A key concern of land managers is understanding how ditches have affected biodiversity and where management efforts should be focused: how should they manage ditches to meet different societal goals (e.g., maintain, restore, or leave a ditch alone)? Therefore, the objective of this study is to assess how ditches, dug across Sweden's history and geography, have impacted biodiversity. We used data from 9720 plots in Sweden's National Forest Inventory (NFI) to calculate Hill-Shannon diversity, a biodiversity metric that accounts for discrepancies in sample effort and size to more accurately reflect relative abundances. Our preliminary analysis revealed little overall difference in diversity between ditched and unditched forest sites. When we considered different soil types and textures, most comparisons between unditched and ditched sites remained similar. However, peatland sites with ditches appeared to have more diversity than unditched peatland sites. Bayesian mixed modelling will enable further analysis of controls on biodiversity in relation to ditching, to ultimately inform and improve ditch management across Sweden. This study is part of a larger Swedish Research Council FORMAS project: Barriers and Opportunities to Managing (BOM) Forest Ditches for Climate.

How to minimize the concentrations of methylmercury in surface water after forest harvest

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Forest harvest might mobilize mercury (Hg) retained in soils and promote the transformation of inorganic Hg to its bioaccumulative form methyl-Hg (MeHg). In this presentation we will discuss possible mitigation measures in order to minimize MeHg and total Hg (THg) in surface waters, based on catchment-scale and process-based studies.

Earlier studies reveal considerable variation in effects of forest harvest on the runoff of THg and MeHg between sites. To evaluate the site specific factors influencing forest harvest response on MeHg in water, we synthesized previous studies on forest harvest effects in the northern hemisphere and harmonized them with supplementary field measurements. We also addressed one factor that may influence the effect of forest harvest: the impacts of logging residues left on site after the harvest. The availability of labile organic matter (OM) as electron donors for Hg methylators has previously been proposed as a central factor causing higher MeHg formation in harvested forest areas. The release of labile OM compounds from decomposing logging residues may thereby promote Hg methylation, in soil or in the residues themselves. Finally, the hydrological connectivity between the locations where MeHg is produced and a ditch or stream will determine the effect of the harvest. Here, we evaluated the effect of logging tracks and other soil disturbance caused by forestry machinery to determine the hydrological connectivity and mobilization of MeHg.

We found catchments with soils sensitive to compaction and rutting, i.e. those with high wetness index, low stone and boulder content and deep organic soil layers, to be at higher risk for elevated MeHg formation in soils, but not necessarily MeHg in runoff. Instead, the combination of MeHg formation in soils and hydrological connectivity to the watercourse influenced forest harvest induced increase of MeHg in runoff. Hillslopes with lower gradients and riparian buffers had lower hydrological connectivity to surface waters. Logging residues left on site after forest harvest were found to be a source of MeHg. However, the presence of logging residues can also protect the soil from disturbances by off-road traffic and thereby prevent the potential mobilization of MeHg in ruts.

Hydrological response to Pinus forest management in sub-tropical paired catchments

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Pinus plantations represents 19,4% of planted forests in Brazil, with 1.93 million hectares for paper and corrugated cardboard packaging production according to annual report from Brazilian Tree Industry (Ibá). The WestRock Brazil company has managed a mosaic of Pinus plantations and native forests in a sub-tropical region. Besides Brazilian forestry sector is ahead in terms of sustainability, some companies go further and considers scientifically monitoring important to understand the management effects on water services. One of the most suitable methods for identifying effects of planted forests on water is the paired catchments, what involves the continuous and simultaneous monitoring of two catchments with similar edaphoclimatic conditions, one of which is submitted to forest management and the other maintains the original vegetation. As an affiliated company of Program for catchment environmental monitoring and modeling (PROMAB) from IPEF, two paired catchments have been monitored since 2009 through stream-gaging stations instrumented with pressure sensors and rain gauge registering data every 15 minutes. One of them is predominantly covered by native mixed tropical forest and the other by Pinus plantation. Both were analyzed aiming to compare hydrological indicators of water functions. The water balance has presented similar values for evapotranspiration in both catchments, which blue water varied by only 3% between them. In terms of water regulation, the Base Flow Index was similar on average, but presented differences on the first years after plantation. The Flashiness Index was already similar, but the Flow Duration Curve showed that the native catchment has lower values of maximum flows (Q10) and higher values of minimum flows (Q90). Although these general results pointed that the native catchment could be slightly more resilient, the ongoing analyses must consider the differences in the initial and final of Pinus cycle. Some differences in the first years of cycle suggest the critical moment in the forest management, but the similarity in general results can indicate that the management in Pinus catchment is fundamental to protect water and soil functions. The same similarity was observed in water quality data, what strengths the role of good practices of forest management practiced in Pinus plantation.

Incentives for improving environmental consideration in forestry - current state and need for development

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: A key element in Swedish forest policy is “freedom with responsibility”. That implies that forest owners to a large extent can chose how to manage their forests, within a legislative framework setting a minimum level of requirements. The knowledge about effects of forestry practices on water quality is considered to be rather high among forest owners and managers. Ten years ago, a dialogue process with stakeholders resulted in common strategic management objectives for good environmental consideration to a variety of features in the forest landscape, e.g. to streams and lakes. However, recent results from the annual field inventory, carried out by the Swedish Forest Agency, show that there is still a large potential for more effective and functional consideration to and management of buffer zones along streams and lakes. These results are also supported by a number of scientific studies carried out during the last few years. So far, the inventories and scientific studies have reported on environmental consideration at final felling. However, other forestry related activities are also relevant in this context, e.g. thinning, construction and maintenance of forest roads and ditch network maintenance, but the a lack of data concerning environmental consideration in practice here makes it difficult to analyse impact and estimate the effects of different measures. A changing climate, challenges concerning forest health, increased demand for products from the forest, new EU regulations as well as other factors may contribute in different ways to strengthen both policy and economic incentives for improving management and protection of forests close to water.

Metabolic processes control carbon dioxide dynamics in a boreal forest ditch affected by clear-cut forestry

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Boreal water courses are large emitters of carbon dioxide (CO_2) to the atmosphere. For forestry intensive areas of the Nordic and Baltic countries, a high share of these watercourses are man-made ditches, created to improve drainage and increase forest productivity. Previous studies have suggested that terrestrial sources of carbon sustain the CO_2 in these ditches and variability in hydrology is the main temporal control. However, few studies have explored ditch CO_2 dynamics and its associated controls in catchments being exposed to forest harvest. An altered hydrology, increased nutrient export and light availability following forest harvest are all factors that potentially can change both levels, dynamics and source controls of ditch CO_2. Here, high-frequency (30 min) CO_2 concentration dynamics together with other hydro-chemical variables were studied in a forest ditch draining a fully harvested catchment in the Trollberget Experimental Area, northern Sweden. Data were collected during the snow-free season from May to October. Ditch CO_2 concentrations displayed a clear seasonal pattern with higher CO_2 during summer than in spring and autumn. Concentrations were ranging from 1.8 to 3.5 mg C L^{-1} (median: 2.4 mg C L^{-1}, IQR = 0.5 mg C L^{-1}). Strong diel cycles in CO_2 were developed during early summer, with daily amplitudes in the CO_2 reaching up to 1.1 mg C L^{-1}. These pronounced daily cycles in CO_2 were closely related to the daily sum of shortwave radiation and water temperature. Variations in hydrology had generally a low impact on the CO_2 dynamics but did vary among seasons and between individual hydrological events. It was evident from the study that growing season CO_2 dynamics in forest ditches affected by clear-cut harvest were high and mainly controlled by light and temperature induced metabolism. These high dynamics and the associated controls need to be considered when scaling up ditch CO_2 emissions across boreal landscapes affected by forestry.

Peatland management is rocket science – holistic biogeochemical modelling as a tool for water protection

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: World has changed and peatland management has become a rocket science. This is because management pursues to simultaneous production of multiple ecosystem services, such as wood production, water protection and mitigation of and adaptation to climate change. These ecosystem services arise from the same biogeochemical origins; therefore, they also must be solved at the same time. Peatland ecosystem is characterized by a complex network of interactions and feedbacks between processes, such as hydrology, nutrient and carbon cycling, forest and vegetation growth, transport of nutrients and water in soil and in open channels. Even though forest management changes only few of the system components, the effects reflect to all the ecosystem services, also water quality, through the feedback network. The management of the complex interactions and a pursue towards the ecosystem services fundamentally changes environmental management and poses a challenge to raise the skill level within forest and environmental sciences and among the experts already working with environmental issues. It also calls for development and application of ecosystem models taking into account the process feedbacks, applying detailed onsite data and allowing to study the effect of different peatland management, such as ditch network maintenance, clear-cutting, continuous cover-forestry, fertilization and restoration on water quality, greenhouse gas balances and forest production. In this presentation we show how interactive processes reflect to water quality in peatland management.

Structure and ecological functioning of riparian buffer zones after logging

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Timber-oriented forest management has multiple impacts on non-timber ecosystem services and biodiversity. Legislation and certification schemes are implemented across countries to ensure minimum ecological standards in timber-production forests. Regulations may include sets of detailed measures to be taken during forest planning and logging operations. However, the discussion about the effects of these environmental measures to maintain biodiversity and ecosystem services is ongoing. One pivotal measure is watershed protection. Upon clearcuts, certification schemes typically demand a buffer zone to sustain the important ecotone between the water body and the forest. The width and composition of the buffer affect the ability to sustain its ecological function. Albeit the demonstrated ecological importance of the riparian buffer zon es, studies of whether its ecological functions are maintained after logging, are scarce. We aimed to fill part of this void by collecting primary field data in four areas in eastern Norway to test whether the post-logging riparian buffer zones maintained its ecological function as intended in certification schemes. All areas were subject to the Programme for the Endorsement of Forest Certification (PEFC) scheme, the world's largest forestry certification scheme. The study areas were selected in areas with recent forest management plans and aerial photos. 55 stands alongside water bodies clear-cut in 2020 - 2021 were randomly selected and field work was carried out in 2022-23. Data of buffer width, vegetation cover, multiple tree variables related to ecological structures and post-logging forest management were gathered in squared sample plots along the shoreline. We also collected data on stumps to partly reconstruct the pre-logging plots to reveal the possibilities for post-logging ecological function. Our analyses provide insight into which extent logging operations close to watersheds are in line with the scheme's intentions as well as the actual impacts of current forest management practices on the ecological function of the riparian buffer zone. This knowledge will help in the future development of forest certification schemes and forest policy and provides important information for practitioners to ensure sufficient ecological consideration in forest operations.

To ditch or not to ditch? The impact of ditching on nutrient export in a boreal catchment

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Peatland forests provide important ecosystem services including nutrient storage, intrinsically linked to the quality of surface waters downstream. However, forest management practices such as clear cut (CC) and ditch network maintenance (DNM) may affect the release of nutrients and therefore downstream water quality. Just in Sweden, there have been nearly one million km of ditches dug in peatlands over the last 100 years to improve forest growth. Therefore, it is important to understand the consequences of these historic forest management practices so that suitable measures can be devised to protect surface waters in forested peatland catchments.

To improve the understanding of nutrient losses from catchments subjected to CC and DNM we present the results from a catchment-scale experiment at the Trollberget Experimental Area where we established six experimental catchments with control sites in the adjacent Krycklan Catchment in Northern Sweden. In the outlets of the six catchments, we measured pretreatment dissolved organic nitrogen (DON), dissolved inorganic carbon (DIN) and dissolved inorganic phosphorus (DIP), then successive treatments of CC on four of the six catchments, then DNM on two of the four CC catchments.

We found that both CC and DNM increased in organic and inorganic nutrients in surface waters. Post forest harvest, median DIP, DIN and DON concentrations were higher in all four CC catchments when compared to pre-harvest. After the DNM treatment, the catchments *without* DNM (only CC) had, on average, higher concentrations ($p<0.05$) of DIP (18.1 ±2 ppb), DIN (749.5 ±42 ppb) and DON (1314.8 ± 47 ppb) in surface water than catchments *with* DNM. Furthermore, the catchments *without* DNM had the highest percent increase for DIP, DIN and DON, at least within this two year period, having an increase of 457%, 1183 % and 88%, respectively. This suggests that forest management increases nutrient leaching, but that DNM can mitigate some of the leaching associated with CC, at least in the short term. Regardless, CC and CC+DNM sites had on average, higher export of all nutrients after management than before as a result of changes in biogeochemical and hydrological conditions with possible impact of downstream water quality.

What is a good riparian buffer?

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Riparian buffers have long served as an effective tool for water protection. Within forestry, safeguarding water from potential adverse effects often involves preserving a strip of untouched forest along streams or lakes. This forested fringe aims to prevent or alleviate detrimental impacts, including increased light penetration, elevated water temperature, alterations in riparian microclimate, and sediment accumulation. While it is widely acknowledged that this practice can be successful, there remains an ongoing debate regarding the key characteristics that make a riparian buffer truly effective. In many production forests, extensive management practices have significantly modified forest structure and even altered tree species composition along stream edges, suppressing natural disturbances and fundamentally transforming riparian zone dynamics. Given these circumstances, can we assume that merely preserving such forests through non-harvesting measures will sufficiently achieve our water protection goals? In this poster presentation, I will showcase recent research on riparian buffers conducted in Sweden. I will propose innovative ideas for designing buffers that not only safeguard streams and riparian zones post-forest harvest but also exhibit long-term functionality. These buffers should incorporate a diverse tree species composition, strategic canopy gaps, and intentionally created deadwood. Moreover, they should account for hydrological, topographic, and local site conditions. By doing so, these buffers can effectively fulfill crucial ecological functions, such as preventing sediment loading, conserving biodiversity, and providing high-quality resource subsidies to organisms.

What role does logging and fish stocking play in esker biodiversity?

T3.24 Minimizing forestry impacts on water quality, aquatic biodiversity and ecosystem functions

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Abstract: Eskers are geological formation created at the end of the Ice Age that offer a wealth of sand and gravel, productive forests, high water quality and recreational resources to the Nordic countries. Esker lakes are isolated water bodies with singular characteristics: acid pH, clear water, and most of them are fishless. Such characteristics can play a decisive role regarding the species able to colonize these lakes and the predator-prey relationships. These ecosystems are submitted to a high pressure by forestry operations and fish stocking, although little is known about esker biodiversity. To increase our understanding of the biodiversity of these ecosystems, we aim to characterize the arthropod communities associated with Eastern Canadian esker lakes and assess the combined role of logging and fish stocking on their biodiversity (fish, aquatic invertebrate, and predatory insects (Odonata)). Our experimental design is composed of 18 lakes: 12 esker lakes (6 fishless and 6 stocked) and 6 lakes on the clay belt with a gradient of proximity to harvesting. Esker lakes are more acidic due to their water supply, which comes partly or totally from rainfall and/or groundwater. This is expected to influence the invertebrate species composition, given that the water body pH influences the organisms' ability to develop and reproduce. Also, we expect fishless esker lakes to be taxonomically rich in large, highly mobile, and pelagic invertebrates and teeming with large dragonflies such as *Aeshna* due to reduced predation pressure. Finally, we expect invertebrate species composition to be less affected by logging around esker lakes than clay lakes due to the maintenance of physico-chemical characteristics independent of the intensity of forest harvesting (less water runoff on sandy esker soil). This project will contribute to gain a better understanding of the invertebrate communities associated with esker lakes, and to determine the impact of anthropic disturbances (logging and fish stocking) on biodiversity to establish policies that guaranty the conservation of this singular ecosystems.

T3.25 Mitigating zoonotic and vector-borne disease risk in transformative forestry

Forests, fragmented forests, and zoonotic diseases: hazard and risk

T3.25 Mitigating zoonotic and vector-borne disease risk in transformative forestry

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Abstract: According to common definitions, “hazard” is a potential source of harm, and “risk” is the probability of experiencing harm if exposed to a hazard. Biodiversity within forests (and other natural habitats) is often considered an important hazard for infectious disease, because the diversity there includes diverse pathogens. Following this common framework, risk arises from people encroaching on the forest or other biodiverse habitat. Such a framework presents ethical difficulties for conservationists, because the very biodiversity that they seek to preserve or enhance is seen as a health threat. The ethical challenge can be resolved by calling for management of human encroachment into biodiverse habitat, to ensure that the hazard ostensibly present therein is not converted into risk. But this logical approach is misguided. Recent research demonstrates that anthropogenic fragmentation, degradation, or other disturbances of forest habitat often exacerbates hazard or directly creates hazard that did not previously exist. Hazard of infectious disease is exacerbated by disturbances because reservoir hosts and vectors (and consequently pathogen populations) are favored, whereas protective organisms are often filtered out. Consequently, a given person entering a pristine forest will, in general, have lower likelihood of infection with a zoonotic pathogen than if that person enters a fragmented or degraded forest, despite the pristine forest having higher diversity. It is important to correct misunderstandings of the effect of biodiversity and biodiversity loss on hazard and risk, because the two scenarios (biodiversity constitutes a hazard v biodiversity loss increases or creates hazard) lead to different management and policy solutions. In the former (biodiversity is the hazard), disease prevention may be accomplished simply by preventing human encroachment. In the latter (anthropogenic disturbance causes hazard), the protection of forests from destruction/degradation prevents the hazard in the first place. Managing human entry or occupation becomes a secondary issue. Examples of these scenarios will be discussed.

Managing environmental, social and economic impacts of Covid-19 Pandemic by living close-to-nature: The Case of Eastern Africa

T3.25 Mitigating zoonotic and vector-borne disease risk in transformative forestry

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Abstract: In 2020, Kenya and Tanzania participated in a regional study of the impacts of Covid-19 pandemic on the forest sector. Desktop reviews documented the impacts and implications (including risks, threats and challenges) of the pandemic. Virtual interviews were guided by a checklist of questions by which to engage representatives of national governments, civil society, local communities and forest associations, private sector, academia and research practitioners, development partners, intergovernmental, other regional organizations and relevant international organizations operating in the region. The findings revealed that regional trade in wood products was highly disrupted by the measures taken to contain the international spread of the disease. In Tanzania and Burundi, declining demand for timber products caused factories to downsize their operations. The vulnerable, indigenous people like the Batwa in Uganda and several other local communities in the region faced economic difficulties when markets for local commodities were closed and there was food insecurity during the pandemic. In Kenya, community forests were over-exploited for economic benefit by urban dwellers who found themselves jobless during the pandemic and migrated back to rural areas. These demands placed pressure on all types of forests to supply basic needs like food, energy and income. Forests also became highly-valued as sources of medicinal plants to treat Covid-related illnesses. The threat of resource over-exploitation was higher than usual because the pandemic disrupted normal forest protection operations. Urban forests also proved especially important for people's mental well-being. They offered outdoor recreation spaces at a time when government lockdowns required urban residents to remain within restricted zones for extended periods of time. These cultural and spiritual values of forests highlighted social and health benefits of living close-to-nature. The shared experiences across Eastern Africa made a strong case for greater involvement of local communities in the region in co-managing forests in the future. Forest restoration, including continuous cover forestry, can prioritize biodiversity recovery as a major disease risk mitigation tool. The findings are useful for guiding stakeholders on how forest restoration should be performed to mitigate future disease risks.

Key words: Covid-19, Eastern Africa, impacts, living close-to-nature

RODENT ABUNDANCE, DIVERSITY AND COMMUNITY STRUCTURE IN A BUBONIC PLAGUE ENDEMIC AREA, NORTHERN TANZANIA

T3.25 Mitigating zoonotic and vector-borne disease risk in transformative forestry

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Abstract: Rodent-borne diseases, including bubonic plague, remain a significant threat to public health in tropical countries. In plague-endemic areas, little information exists on factors triggering periodic bursts. The study assessed how species richness, diversity, and community structure of rodents in Mbulu District, Tanzania, are associated with plague persistence. Rodents were captured using the removal trapping technique. A total of 610 rodents belonging to 12 species were captured, with *Mastomys natalensis* being the most abundant (10.89%). Within foci, persistent plague had significantly higher abundance, species richness, and diversity compared to non-persistent localities ($p< 0.05$). Forest habitats had significantly higher species richness compared to domestic premises ($p= 0.01$). Plague persistent localities were found to be significantly positively associated with high rodent abundance (mean= 2.34, ±1.10SE, $p= 0.03$) and species richness (mean= 0.73, ±0.16SE, $p< 0.001$). Additionally, three broad rodent community structures ($R= 0.98$, $p= 0.01\%$) were found, that varied significantly between studied habitat types ($R= 1$, $p< 0.8\%$), suggesting high population interaction at fine-scale resource abundance. The high abundance and diversity of plague-susceptible rodent reservoirs are among the possible factors contributing to plague persistence in the foci. The information may be useful to develop preparedness strategies in these areas to control plague outbreaks.**Keywords:** Bubonic plague, plague persistence, rodent abundance and diversity

The impact of restoration on disease regulation: A framework for identification and management of spillover risk

T3.25 Mitigating zoonotic and vector-borne disease risk in transformative forestry

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Abstract: In recent years, the link between landscape degradation, land use and the increase in the potential for zoonotic spill-over events is becoming ever clearer. Alongside mitigating the impacts of climate change, there is a growing body of thought that by restoring landscapes, ecosystem services such as disease regulation will recover. However, there is very limited empirical evidence of the way in which landscape restoration may improve disease regulation, and the mechanisms which may underpin this are unclear. In addition, restoration can be a hugely complex process, and the extent to which restored landscapes can be equated to fully functioning, non-degraded landscapes is not known, particularly when we consider the spatial and temporal scale of restoration, the mode of restoration, and whether complete floral and faunal recovery is achieved or even desirable. Here we outline a framework for monitoring diversity recovery in restored landscapes, taking into account sustained or increased human use of the space following restoration processes. This will allow a better assessment of the success of restored landscapes in protecting against disease spillover, and identifies key moments during which monitoring can be carried out to monitor potential pathogens.

The role of forest health for human health – Disease risk from zoonotic and vector-borne pathogens

T3.25 Mitigating zoonotic and vector-borne disease risk in transformative forestry

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Abstract: Vector-borne and zoonotic diseases pose an increasing socioeconomic burden. There is mounting evidence that the structure and functioning of habitats and landscapes – including their integral biodiversity – play an important role in disease risk regulation. There are several mutually non-exclusive concepts and hypotheses that can explain this protective function of healthy environments and biodiversity. These include the dilution effect, the sanitation effect, the biodiversity and old friends hypothesis, and the microbiome rewilding hypothesis.

Forests around the globe are increasingly fragmented, resulting in smaller and more isolated forests and forest patches. This is not only consequential for biodiversity in general, but also for the prevalence and transmission of zoonotic and vector-borne pathogens. Habitat degradation induces amongst others a) a shift from species communities with specialist non-reservoirs to communities dominated by generalist reservoir species, and b) an increase in habitat edges that are favourable for vectors and reservoirs. How can the vicious cascade of habitat degradation, community changes and disease risk then be interrupted? Are nature-based solutions and rewilding the answer? Do we have enough scientific evidence to recommend or condemn certain forestry practices from a human disease risk perspective? Does climate change amplify disease risk induced via habitat degradation? What are the gaps in knowledge and how can they be overcome?

The presentation will provide an overview of current knowledge, challenges, potential pitfalls but also a roadmap for the development of a forest management strategy that increases human health via forest health. Forest types from various biomes will be addressed in the talk with experiences gained from the on-going Horizon Europe project BEPREP (beprep-project.eu/).

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

Adaptability of two European black poplar (Populus nigra L.) genetic conservation units in contrasted environments

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

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Abstract: Describing the properties of genetic conservation units (GCUs), and more generally forest genetic resources, currently relies largely on static descriptors such as genetic diversity. However, there is an urgent need to complement these with dynamic indices that can underpin forecasts of both the adaptability of forest genetic resources, as well as their resilience to future environmental threats, such as climate crisis. Here we thoroughly characterized two environmentally contrasting European black poplar GCUs (2 x 500 adult trees and 2 × 250 juveniles) using high-throughput technologies to gather the following data: (i) genomic variation (12,211 SNPs used to estimate fecundity and kinship), (ii) hard traits (i.e. adaptive traits challenging to measure) derived from Near Infrared spectroscopy (NIRS), and (iii) unmanned aerial vehicle (UAV)-derived fertility and environmental data. Using these data we used quantitative genetic models to estimate the heritability of these adaptive traits and to explore the relationship between these traits and fitness (defined as fecundity and fertility) across a range of parentage-based selection gradients. Our work highlights the challenges in obtaining the key data and in optimising ways of integrating these various datasets to predict accurately the ability of forest tree populations to adapt. Here we address these challenges by focusing on: (i) Comparing the estimations of fitness using genomic markers versus UAV data, (ii) Exploring the possibility to calibrate NIRS models for several adaptive traits, (iii) Comparing methods to properly estimate heritability by combining phenotypic and environmental variables together with relatedness variation. By exploring different approaches our ultimate objective is to optimise our ability to predict the potential of our forest tree populations to adapt to future.

Assessing drought resilience of selected European forest plots using a hydraulic process-based modelling approach

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

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Abstract: Forests play a crucial role in promoting global biological evolution and community succession and maintaining a delicate ecological balance at the global scale. The persistence and functionality of forests are highly dependent on their resilience, defined as their ability to withstand and recover from environmental disturbances. The average increase in atmospheric drought or higher vapor pressure deficit and soil drought in recent years has led to a decline in forest productivity and increased tree mortality in many areas of the world. This trend is likely to continue due to ongoing climate change. Trait-based plant hydraulic models have great potential for studying the responses of individual trees, tree cohorts, or forest stands to drought. They simulate the movement of water through the plant from roots to leaves, predict water flow and storage in different plant compartments, and can predict the risk of hydraulic failure, which is a major cause of mortality under climate change. Using the recently developed hydraulic model SurEau-Ecos and different data sources, we will assess the resilience of selected European forest plots to drought using different metrics simulated by the models, including growth and the occurrence of cavitation in the conductive tissue of trees. We will select several forest plots on which the required input parameters for hydraulic models have been measured. The forest plots belong to a set of EUFORGEN (European Forest Genetic Resources Programme) genome conservation units of European beech (*Fagus sylvatica*), Scots pine (*Pinus sylvestris*), or maritime pine (*Pinus pinaster*). We will consider the variability of tree vulnerability within a species (i.e. tree traits), and also the variability between plots in terms of hazard (i.e. climate variability) and exposure (stand density, soil properties). We anticipate that accounting for trait variability will profoundly change estimates of the risk of hydraulic failure under climate change.

Can silviculture foster genetic adaptation to climate change in naturally regenerating forests? A demo-genetic modelling approach

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

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Abstract: Management strategies to reduce forest vulnerability to climate change currently concentrate on two main principles: a silvicultural control of forest structure to reduce stress and disturbance impacts, or a control of the genetic composition by plantation to improve its capacity to respond to hazard. Considering jointly functional and genetic aspects opens new perspectives.

For naturally regenerated forests, i.e. most of the forest area around the world, we still have limited knowledge on how fast can existing forests evolve towards adaptation by natural selection and how far can silviculture interfere with natural adaptation. To address these questions, we developed an eco-evolutionary approach using a demo-genetic individual-based model that integrates forest dynamics processes, genetic diversity of tree growth and sensitivity traits, stochastic disturbance regimes and silviculture interventions.

Our results reveal that natural selection under stress can lead to a rapid positive response in terms of stand growth and survival, visible after just one generation. The higher the selection intensity, the higher the adaptive response. Reducing tree density is a strategy to reduce drought stress, which is one option to mitigate the short-term impacts of climate change. However, reducing drought stress also reduces the intensity of natural selection; and frequent, early and intensive thinnings may hamper genetic adaptation. Considering realistic levels of within-stand genetic variation of growth sensitivity to drought, we find that strategies that promote natural selection can be more effective than stress reduction strategies to enhance the forest's response to stress over long-term. As a compromise between short- and long-term benefits, we propose an evolution-oriented thinning strategy that consists in maintaining high density during the juvenile stage to maintain some level of stress exposure and facilitate natural selection, followed by classical stress reduction through thinning operations in later stages.

We conducted this simulation research for a temperate conifer species in even-aged forests, but similar approaches can be extended to other forest types.

Combining provenance trials with whole-genome analyses to identify climate resilient forest reproductive material for European white oaks

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

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Abstract: Oak trees can live for over 1000 years. Fixed in place, the climate change-mediated environmental shift that individual oak trees experience is likely to be substantial and potentially harmful. European white oaks grow from the Mediterranean coast to Southern Scandinavia, a huge environmental gradient that has fostered local adaptations that could be beneficial under future climate scenarios like drought and extreme temperature. Assisted seed translocations from forest genetic resources from drier and warmer sites, could ensure oak forest health by matching trees with their predicted future climates. However, an understanding of the geographical patterns and genomic architecture of environmental adaptation is needed as a guide. Particularly because it is unclear if the genomic basis of environmental adaptation is highly localized or even population specific in oak trees, or if it similar at a range-wide scale.

To characterize local adaptation in white oaks (*Quercus robur*, *Q. pubescens*, *Q. petraea)*, we have established three common gardens of oak seedlings (Switzerland, Turkey, Austria). Provenances were selected from both distributional and local environmental extremes (i.e. chronic soil drought vs. wet soil), and seedlings measured at traits related to phenology, productivity, and water use efficiency. Each seedling was whole-genome sequenced at low coverage to describe genomic relatedness and perform genome-wide association analyses with the assessed traits.

Quantitative genetic analyses of trait data from across the gardens shows limited differences between provenances from local environmental extremes relative to distribution extremes. This suggests environmental adaptation is predominantly visible at a large geographical scale for the three species. The genomic architecture of these adaptations is now being explored through genome-wide association studies of fitness-related traits to identify if the same genes drive the trait differences observed. This large, interdisciplinary study combines common garden experiments with genomic data to identify climate-resilient forest genetic material for the future.

Drought adaptation of Italian silver fir provenances in a climate change perspective

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

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Abstract: The resilience of Mediterranean forest ecosystems to climate change is closely linked to adaptation to drought and increasing temperatures. Intraspecific genetic diversity (i.e. tree provenances) can directly affect such adaptive responses. It is therefore essential to define guidelines for promoting conservation and sustainable management of resilient forest genetic resources.

In this study, we analyse growth dynamics of silver fir (*Abies alba*) in relation to drought, comparing morphological and physiological performances of natural populations and plantations, both currently unmanaged. Growth responses to drought has been studied deeply in three silver fir Italian provenances (western Alps, northern Apennines (local) and southern Apennines), in plantations located in the Tuscan-Emilian Apennine National Park (Italy). Drought severity was defined through the SPEI Index. Dendrochronological analyses included climate-growth relationships, drought 'resilience indices' (RRR) based on tree ring width, and water use efficiency (iWUE) estimated through carbon isotope analyses ($\delta^{13}C$) on wood samples. Finally, we used FORMIND, an individual-tree process-based model, to simulate forest dynamics under three climate scenarios (R.C.P. 2.6, 4.5 and 8.5) and compare three different climate global models (HadGEM2, NorESM1 and MPI). We used field data to parametrize the allometric and growth equations used by FORMIND to describe provenance-specific behaviour.

Our results show that plantations had a faster growth than natural populations, also showing higher resilience and recovery during severe and/or extreme drought episodes. Provenances slightly differed in mean growth rates, with higher basal area increment by the southern Apennine provenance. The southern Apennine provenance also showed significant higher recovery and resilience during moderate and extreme dry years. Modelling results confirmed these trends, even if the differences among climate scenarios and global models were rarely significant. Carbon isotope analyses highlighted physiological responses of silver fir to drought, showing a strong signal during dry years and depending on provenance.

The workflow proposed in this work couples morphological with eco-physiological analyses, allowing a comprehensive overview of tree response to drought. Our results provide new and useful

insights on the adaptive responses of silver fir under drought conditions, highlighting the potential of forest reproductive material from rear-edge populations to support future adaptation to climate change.

Ecological niche modelling for forest genetic resources mapping: key challenges and interdisciplinary solutions

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

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Abstract: Forest genetic resources (FGRs) are important for adaptive traits, functional genomics approaches, and climate-resilient forecasting. RS&GIS-based techniques, such as DOMAIN, BIOCLIM, GLM, GAM, GARP, MaxEnt-based ENM, etc., are applied to generate eco-geographic maps of FGRs. Under all these approaches, MaxEnt uses present-only data, bio-climatic variables, satellite GIS-layers to develop species' current occurrence, habitat suitability maps, niche future scenarios, molecular marker-based diversity patterns, population genetics spatial data representation, etc.

The MaxEnt model uses large amounts of datasets at a given time, often leading to issues related to handling intricate data, the risk of generalization, and difficulties in terms of interpretation, besides demands for large storage capacity and efficient computer processing systems. Two important considerations are the huge geospatial dataset (which requires ground validation) and the use of open-access satellite imagery (LANDSAT, SENTINEL, etc.) in modelling exercises. High resolution needs more time as compared to low resolution, but the former would be easier to generate LULC and forest types maps, biodiversity maps, etc. The power of MaxEnt prediction accuracy is statistically governed by the input data. While working on 50 FGRs of the state of Uttarakhand (India), MaxEnt was applied to 37 wide-distribution species based on a minimum of 10 geo-coordinates available for species presence data. Accordingly, Class-I (>80 geo-coordinates), Class-II (35-80 geo-coordinates), and Class-III (10-<35 geo-coordinates) included 11, 12, and 14 species, respectively. The area of estimated range in the case of 37 prioritized FGR species ranged from as low as 15.54 km^2 (*Tsuga dumosa*) to 832.4 km^2 (*Quercus semecarpifolia*), representing 0.03% to 1.56% of the geographical area, and 0.06% to 3.43% of the forest cover of the state. Species *viz*., *Bombax ceiba*, *Rhododendron arboreum*, *Taxus wallichiana*, *Myrica esculenta*, *Ougeinia oojeinensis*, *Betula utilis*, *Oroxylum indicum*, and *Terminalia chebula* had a relatively higher extent of distribution range, amounting to 716.9 km^2, 617.48 km^2, 545.86 km^2, 477.26 km^2, 384.73 km^2, 305.16 km^2, 286.51 km^2, and 262.89 km^2, respectively. We concluded that the MaxEnt logistic output is solely based on the prevalence assumption given environmental suitability rather than an actual extensive and intensive field-level assessment and estimation.

The genetic consequences of population marginality: a case study in maritime pine

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

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Abstract: Geographical marginal populations are located at the edge of the species' range and fragmented into sparse isolates, often in non-optimal environments. Because of their location, marginal populations may harbour highly specific alleles for local adaptation, thus potentially constituting valuable genetic resources for biological conservation. However, we lack evidence of the extent to which marginal populations are affected by particular genetic processes related to their typically small size, such as genetic drift or the purge/accumulation of genetic load. In this study, we used *Pinus pinaster* Ait., a widely distributed and economically important conifer characterized by a fragmented range, as a model species to better understand the genetic processes at play in marginal populations, as well as to test some of the main predictions of the Central-Peripheral Hypothesis (CPH). Based on 81 populations (1,431 individuals) and 10,185 Single Nucleotide Polymophisms, we estimated population genetic indicators potentially related to ecological resilience (genetic diversity, genetic differentiation and inbreeding) and population vulnerability to climate and adaptability (genetic load and genetic offset), and correlated them with eight geographical marginality indices computed following Picard et al. (2022). Our study showed some significant correlations between marginality indices and genetic indicators. Indeed, we observed a trend towards decreasing genetic diversity and increasing genetic differentiation with geographic population marginality, which is consistent with the range-wide patterns of genetic diversity and differentiation described for this species, and which supports the CPH. However, we did not find a significant relationship between inbreeding, genetic load or genetic offset and population marginality. Overall, our results suggest that marginal populations keep similar levels of genetic variation and adaptive capability as central populations, and thus may still be a valuable source of pre-adapted alleles to atypical environmental conditions in *Pinus pinaster*.

The role of intra-specific genetic diversity in forest productivity, mortality and resilience

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

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Abstract: The research on species mixtures has shown how species diversity has an overall positive effect on productivity, as well as on the resistance and resilience of forest stands, especially when the complementary between species is high. In this work, we investigate whether these benefits occur also in genotypes mixtures. To this aim, we transfer the methodologies commonly used when analyzing species mixtures to study the impacts of mixing provenances on forest growth. We present models for the study of genetic diversity effect on growth, analyzed in a broad set of provenance plots, for *Pinus sylvestris, Pinus pinaster*, *Picea abies* and *Abies alba*, in Spain and Germany. With the help of a moving window design, that selects the immediate vicinity of every tree, we calculated relevant tree and stand characteristics, together with the diversity of provenances and mean genetic distance inside of each moving circle. With this data we have fitted generalized linear models with growth and stand characteristics, accounting for the site as a random effect.

A higher number of provenances has shown a positive and significant effect in the structural diversity (coefficient of variation of diameter at breast height - dbh). Our results have also shown a positive impact in the height growth, but not on diameter growth, potentially indicating a higher competition for light, at least noticeable in the young development phase of *Pinus sylvestris.* Although this may change with age, silviculture guidelines and management recommendations could be drawn up for young stands. Moreover, we will analyze logistic models on mortality in young and old stands. Yearly growth based on cored data from all sites will be used for detecting dry years, and to calculate resilience accordingly. With linear modelling we will study the effect of genetic diversity on the stand structure to resilience of each site. Finally, general management recommendations to improve stand resilience and sustainable use will be developed.

When dendroecology meets genomics: Adaptive genetic variation to drought in white spruce indicates a potential for increasing forest resilience

T3.26 Multi-disciplinary approaches to the modelling of FGR resilience: there's more than genetics to Forest Genetic Resources

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Abstract: Rapidly warming climate and increasing instability is affecting water availability for conifer species at mid-latitudes, thus urging the need for assessing their adaptive capacity to better predict forest vulnerability and resilience under drier climates. In this study, we first used a dendroecological approach to determine the level of climate sensitivity of white spruce (*Picea glauca*) trees grown in a long-term provenance-progeny trial. We detected a clear signal of local genetic adaptation to drought, with provenances originating from drier locations showing a higher resilience than those from wetter locations. The study of carbon and oxygen isotopes in wood rings revealed different water use strategies even within white spruce populations, in response to extreme drought conditions. We also dissected the genomic features underlying drought adaptation in white spruce, combining gene-environment associations (GEAs), genotype-phenotype associations (GPAs) and transcriptomics. We identified a set of 285 genes significantly associated with climatic factors or key phenotypic traits, of which 110 genes were differentially expressed under drought stress in controlled greenhouse conditions. Our multidisciplinary approach has provided new insights into the nature and relative importance of the physiological mechanisms underlying drought resistance in conifers. These findings represents an important step towards characterizing the genomic basis of drought resistance in these species.

T3.27 New forests with greater resilience: the importance of forest genetic resources in forest landscape restoration

Gene flow and seed production in fragmented landscapes

T3.27 New forests with greater resilience: the importance of forest genetic resources in forest landscape restoration

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Abstract: The primary objective of forest restoration and conservation is to facilitate the adaptation of forests to climate change, enhance the biodiversity of forest ecosystems, and address the consequences of climate change-driven large-scale disturbances. In recent years we have seen an increase in initiatives, such as the EU Green Deal, which plans to plant 3 billion additional trees in Europe. However, newly established forests require high tree species diversity and genetic diversity to meet ecosystem services and carbon storage. Therefore, these initiatives require large amounts of quality seeds and seedlings of various species, albeit many of the species are currently occurring in fragmented populations with unknown genetic composition. Seed procurement is regulated internationally by the OECD, the EU, and within individual countries' legislature – all to various extents, often entailing recommendations on the size and density of seed stands and harvested trees. Most EU recommendations were developed in the 1990s and put into regulation in 2002 without considering climate change.

Moreover, since then, scientific knowledge of gene flow and genetic diversity has increased exponentially, mainly due to the availability of better genetic markers and analysis tools. Challenges to seed production have continued to grow. As a result, the quality of seeds used for afforestation and restoration is declining. Tree population fragmentation and its impact on seed production is an aspect that can be addressed through specific conservation and restoration strategies to mitigate its adverse effects on seed production. However, despite extensive research on fragmentation genetics and seed quality, it is surprising that the link between these two subjects has hardly been explored. Our research aims to consolidate existing knowledge on the relationship between fragmentation, genetic diversity, gene flow, and seed quality in the context of declining seed production and the need for forest ecosystem restoration. Moreover, our work aims to identify gaps in communicating the latest scientific knowledge to policymakers and seed source regulations.

Genomic information as decision support for use of stone pine in Mediterranean agroforestry landscapes

T3.27 New forests with greater resilience: the importance of forest genetic resources in forest landscape restoration

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Abstract: The emblematic umbrella-shaped Mediterranean stone pine *Pinus pinea* L. has been widely used for coastal land reclamation and restoration of degraded oak coppices and scrublands, and its forests render an emblematic nonwood forest product: Mediterranean pine nuts, the highly priced edible seed kernels of the species. In the last fifty years, stone pine has increased its area in more than 70%; since 19th century, its expansion by plantations has been threefold.

Under the drier and warmer conditions predicted for the near future in Southern Europe, the use of this resilient multipurpose tree might become even more relevant as tool for diversifying complex forest and agricultural landscapes. Its role as nut tree in agroforestry is relevant for the forest-farmland and forest-urban transition zone, where it can both help to restore open tree cover on marginal farmland, as well as structure abandoned zones of encroaching woodlands by creating open gaps or bands without understorey, essentially also as support for wildfire control.

In the last decades, outstanding cone producing plus trees have been selected in Spain and Portugal. Grafting allowed replication in common garden trials, aiming at the selection of best clones for orchard plantations. Aiming to assess accurately forest genetic resources (FGR) and their use in stone pine conservation, improvement and deployment, a recent genomic tool for the species (5,671 SNP markers) has allowed the verification of identity preserved of more than a hundred clones, some already registered as base materials for producing graft scions, others still under evaluation. Clonal identification and hence feasibility of identity checks for traceability and certification is more accurate with SNPs than the previous tool based on microsatellite markers. The SNPs have also allowed screening genetic differences among Iberian populations, defining gene pools in relation with breeding and FGR conservation programs. Combined with quantitative genetics from field trials, these results set the base for a knowledge-based deployment of the species.

Keywords: *Pinus pinea*, pine nuts, clonal identification, breeding, SNP array

Management and conservation of valuable forest genetic resources of Quercus petraea: an example from a national park in Austria

T3.27 New forests with greater resilience: the importance of forest genetic resources in forest landscape restoration

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Abstract: The increasing demand for climate-adapted seeds and planting material poses a challenge due to the limited availability, particularly for tree species such as oaks. National parks, known for their large-standing diversity and a wide range of habitats, can serve as valuable sources for identifying "elite phenotypes" suitable for both the conservation strategies and initiation of tree breeding valuable for tree management.

We aimed to identify and secure valuable forest genetic resources of the National Park Thayatal in Austria by selecting drought-tolerant "elite" phenotypes and autochthonous genotypes of high neutral genetic diversity. For this purpose, we selected 404 mature trees of *Quercus petraea* (Matt.) Liebl. from eight populations growing on medium to arid sites in eight populations. Genetic markers were applied to estimate autochthony, genetic structure, and genetic diversity indices. Further, we assessed their age and characterised them for possible drought tolerance using wood core analysis and water use efficiency (WUE) analysis. In the summer of 2023, potentially drought-tolerant tree progeny will undergo high-throughput plant phenotyping (HTTP) and transcriptomics to assess their reaction to drought.

The trees ranged in age from 40 to 240 years. The DNA analyses indicate a high genetic diversity in the studied mature trees, exhibiting a plastid haplotype 17a, autochthonous for this area. Nevertheless, the genetic structure estimated by ten nuSSRs revealed a pronounced structure in the dataset. A total of 85 elite potentially drought-tolerant trees were found based on their response (resistance, recovery ability, hardiness, and relative resistance) to three historical drought events (1992-1994, 1947, 1917). Based on the isotopic analysis of δ13C of latewood in wet (1987) and dry (1994) years, it was found that the estimated WUE did not display any significant differences among the groupings of trees (drought tolerant, or not drought tolerant) for the four responses.

We discuss the studied oaks towards their conservation and sustainable use for establishing seed stands and orchards to enhance seed production, genetic monitoring initiatives, and the integration of other omics approaches such as phenomics and transcriptomics for deep analyses of drought tolerance of selected phenotypes.

Sustaining gains made towards achieving the Bonn Challenge target for Ghana

T3.27 New forests with greater resilience: the importance of forest genetic resources in forest landscape restoration

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Abstract: Following the launch of the Bonn Challenge in 2011, many countries made pledges to bring several millions of degraded lands under restoration. Ghana is making much effort to achieve its commitment of bringing 2 million degraded lands under restoration in 2030. Many forest landscape restoration initiatives/ projects are ongoing across the country, but given the complexity of implementing such projects, there is the need to determine the success factors and identify the key challenges and barriers in order not to derail progress towards the 2030 target. Data and information was collected using a mixed method approach including desk study and case studies through stakeholder consultations with local communities and other relevant stakeholders. The findings showed that most restoration projects have contributed to increasing tree cover in degraded areas, enhancing water protection and carbon sequestration, and improving women's access and ownership to land and tree tenure, supporting smallholder communities to diversify their income sources and contributing to behavioral changes towards resource extraction. Some factors that have contributed to these project benefits include the existence of relevant policies and strong institutional frameworks supporting restoration actions. Despite these successes, major technical and governance challenges remain. Key among them includes the unavailability of high quality seeds and seedlings in sufficient quantities that would their survival and establishment in the field. Access to high quality germplasm should be prioritized at the planning stage of restoration projects. Ensuring that the diversity and quality of germplasm is sustained will require capacity building and training for local communities and private who engage in the supply of seedlings and there is for relevant government agencies to map trees that are potential seed sources in reserved and conservation areas and protect them from illegal logging and mining.

The choice of post-fire restoration strategies affects functional trait diversity of early successional communities and future forest resilience

T3.27 New forests with greater resilience: the importance of forest genetic resources in forest landscape restoration

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Abstract: Under the ongoing climate change, forest disturbances are increasing in Germany. Restoration and reforestation actions in those areas are further challenged by extreme weather conditions such as recurrent drought and heat waves.Regaining resilient and productive forest stands after disturbance is a key goal. Resilient forest stands can be characterized by specific functional traits of the plant community such as drought tolerance or resprouting capacity. Such traits can be brought in by planting of specific (non-native) target tree species. However, artificial plantings require active restorations as extensive soil preparation. Active restoration strategies expose the disturbed soils further to extreme conditions for a longer time. Contrary to active restoration of functional trait diversity; passive restoration promotes natural adaptation of the regenerating forest ecosystem over a long time span. To date, knowledge on the combination of restoration strategies and it´s impact on early and later stage functional trait diversity is scarce. In order to increase the knowledge base on restoration and functional trait diversity we investigated early stage succession three years after a forest fire in Brandenburg, Germany. We studied early successional plant communities after fire, that underwent passive, purely active (full clearing), and combined restoration actions. Using plant trait data of encountered herbaceous and tree species from TRY database we identified differences in functional trait diversities along the gradient from active to passive restoration. Areas under passive and a mix of active and passive restoration showed a community of short-lived herbaceous species which can be potentially used for topsoil regeneration and the protection for recently introduced target tree species. In unburnt areas and areas of full active restoration, we found a highly competitive vegetation layer, indicating a highly dynamic and unstable environment. Based on the field investigations and secondary data analyses we conclude that a mix of restoration measures can be useful in creating favourable environments for target tree establishment while shaping the functional trait community towards a more resilient forest .

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

A review of connectivity studies in European forests: target species, scales and methods.

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: Habitat connectivity plays a crucial role in mitigating the negative impacts of habitat isolation and promoting species migration. It is widely acknowledged as vital for preserving biodiversity at various levels, from genes to communities. Consequently, connectivity has gained significant attention in conservation plans and policies. However, due to the diverse range of approaches and concepts surrounding connectivity, its assessment and evaluation can sometimes be inconsistent and uneven. Measuring ecological connectivity is not yet a standardised process, and the systemization of measurements and comparability of connectivity results remains challenging. Our review focused on studies conducted in the past 20 years that analysed forest connectivity in Europe. We classified the measuring methods into 15 categories and examined their relationship with the study's main goals, study area scale, and selected focal taxa. Among the 142 articles reviewed, more than 1,000 different focal species were studied, with birds and mammals being the most commonly researched groups, and amphibians the least. Notably, 90% of the epiphyte studies included temporal connectivity, suggesting a potential vulnerability of this subgroup to habitat temporal continuity. The majority of studies were carried out at a regional scale and in mixed landscapes (forest plus two or more other landscape classes), and most of them had the intention of a connectivity assessment without further conservation goals stated. Less than a quarter of the studies compared different measuring methods. A trend towards methods assessing functional versus structural connectivity has emerged over the years, however, there are still relationships between the selected methods and other factors (such as focal taxa and scale) that require further examination. Based on our findings, we propose future directions to explore these relationships and develop standardized methods for assessing forest connectivity. By addressing these gaps, we can enhance our understanding of connectivity patterns and effectively incorporate connectivity considerations into conservation strategies.

Assessing the Socio-Ecological Effectiveness of Forest Management Institutions in Bangladesh- A Case Study from a North Eastern Forest Ecosystem

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: There are many studies done on biodiversity in tropical forest ecosystems. However, researches on the management institutions regarding the biodiversity conservation are rare. The present study focuses on this issue. Since, Bangladesh is burdened with highly populated country which affects forest ecosystems. This is why, researches on forest management issue is essential in this forest ecosystem. North-eastern forest ecosystems are not in exception. Therefore, it was conducted in north-eastern forest ecosystems in Bangladesh. Traditional (reserve forest) and co-managed (reserve forest with co-management) forest areas had been selected for the field study. GIS technologies are used for the plot selection in the field. Systematic sampling technique and circular plots had been used to collect the data required for this study. Biodiversity parameters: species richness, abundance, basal area, canopy cover, regeneration, disturbances had been collected to analyze the ecological effectiveness of the management techniques. The data were analyzed using R-statistical program to compare the ecological effectiveness of different management institutions in the study area. Ecological parameters were found higher in co-managed areas than the traditionally managed areas. However, social parameters show mixed and ambiguous results. This study opens the avenue for the further assessment on the role of management institutions for biodiversity conservation as well as for the management of forest areas of Bangladesh.

Keywords: management institutions, co-management, traditional management, biodiversity, livelihoods.

Assisted dispersal as a tool to promote the recovery of biodiversity in newly afforested agricultural soils.

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: With climate and land use changes adding pressure to the dwindling populations of forest specialists in Northern Europe, the establishment of new populations in forest plantations can be a successful strategy to ensure their preservation on the long term.

New forests are often planted on agricultural soils, however, isolated in a matrix of unsuitable anthropic landscape, with little access to source populations. Furthermore, the planted areas bear a legacy of their former land use, which could constrain the development of late-successional communities.

Our study explores the efficacy of assisted dispersal as a tool to restore plant and soil microbiome in recently afforested agricultural land: in 2015, $2m^2$ soil turfs were transplanted from an old forest to young tree plantations in Denmark. A full factorial setup was used, with 10- and 20-years old forests of beech and oak, in sand and clayey soils. Further, assisted dispersal of *Anemonoides nemorosa* (L)Holub rhizomes and of a 0,3 mm sieved soil layer were carried out in separate $1m^2$ quadrats. Soil was sampled at the time of establishment, and vegetation was surveyed annually. The establishment success of anemones and the other transplanted species was monitored, along with changes in the flora in nearby areas unaffected by the transplant.

In 2022, new soil samples were taken and soil E-DNA was extracted in the transplants and the donor site. The plant communities and the microbiome will be analysed, in order to unravel the belowground outcomes of the transplant, and how these interlace with the patterns seen in the ground vegetation. The experimental setup will also allow a comparison of different conditions at the moment of transplant: differences in development due to tree age, species, and soil texture will be addressed.

This study will shed light on the efficacy of assisted dispersal as a tool to promote biodiversity in afforested agricultural soils, adding a new perspective on the persistence of the microbiome almost 10 years after inoculation, establishment of forest communities across different taxa, and under different environments conditions.

Biodiversity and forest management abandonment in boreal and temperate forests: a meta-analysis reveals time since abandonment and climate interact

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: Growing evidence suggests that forest management practices are threatening the long-term conservation of a number of animal, fungi, and plant species worldwide. Although unmanaged forests are considered important for biodiversity, forest management continues to affect these vital habitats. We systematically reviewed the scientific literature to gain insight into the effects of forest management abandonment on biodiversity. We calculated log response ratio effect sizes to perform a meta-analysis on species richness between still managed (MAN) and no longer managed (NLM) forests, throughout the world's boreal and temperate forest ecosystems. Our statistical approach included improvements relative to a rigorous treatment of pseudo-replication, an objective choice of taxonomic resolution, and new forms of residual heterogeneity. Plant species richness was significantly lower in NLM than in MAN stands, while fungi richness was higher in NLM sites. We, in addition, tested the effect of time since abandonment of management (TSA), and climatic variables, on the biodiversity difference between NLM and MAN forests. These results underline the slow but real and context-dependent recovery capacity of certain taxa after management abandonment. Our findings support the call for more coordinated and contextualized policies aiming to set aside forest zones in production forest systems for worldwide conservation purposes.

Bryophyte-Seedling Associations in Nothofagus Sub-Antarctic Forests: Insights into Ecological Relations and Regeneration Dynamics

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: Bryophytes, including mosses, liverworts, and hornworts, play a crucial role in the dynamics of native forests by contributing to fundamental ecological processes such as tree regeneration. This study aimed to investigate the association between bryophytes and *Nothofagus* seedlings in sub-Antarctic forests and determine if the substrates on which bryophytes grow influence this association. The research was conducted in contrasting landscapes (coastal and mountain) of Tierra del Fuego, Argentina, to better understand the ecological relations in the natural regeneration processes. The hypothesis proposed that bryophytes serve as a substrate for seed germination and initial growth in pure and mixed forests of *N. pumilio* and *N. betuloides*, leading to widespread associations between tree seedlings and bryophytes in all landscapes. The study involved establishing 60 transects in each forest and landscape location, evaluating bryophyte cover using the point intercept method, and assessing substrate types such as bare soil, decaying wood, and litter cover. The relative interaction index (RII) was adapted to analyze the competition or facilitation between bryophytes and tree seedlings by comparing their respective cover percentages. Twenty-seven bryophyte species (15 mosses and 12 liverworts) were identified, with nine mosses and eight liverworts associated with tree seedlings. The results revealed that *N. pumilio* seedlings were less abundant in bryophytes than other substrates, indicating an inhibitory effect on their germination and growth. In contrast, *N. betuloides* seedlings, in both pure and mixed forests, exhibited higher abundance on bryophyte substrates, particularly in mosses in the mountain landscape. These findings suggest that bryophytes play a facilitating role in the germination and initial growth phases of *N. betuloides* seedlings. The conservation of bryophyte communities is crucial for the natural regeneration of *N. betuloides*, as it promotes the continuity of this forest type in both pure and mixed structures.

Co-management Approach: An Innovative Governance to Promote Sustainable Management of the Sundarbans Mangrove Forests of Bangladesh

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: The Sundarbans is the largest single tract of mangrove forest in the world which is located in the southwest corner of Bangladesh. This is a unique ecosystem which is a great breeding and nursing ground for a great biodiversity. It supports the livelihood of about 3.5 million coastal dwellers and also protect the coastal belt area and inland area from various natural calamities. Historically, the management of the Sundarbans was controlled by the Bangladesh Forest Department following top-down approach without the involvement of local communities. Such fence and fining-based blue-print approach was not effective to protect the forest which caused Sundarbans to be deforested severely in the recent past. Therefore, local multi-stakeholder-based bottom-up co-management approach was introduced in the Sundarbans in 2006 to facilitate its biodiversity conservation. Various co-management organizations (CMOs) were introduced under the co-management approach where the local community people could actively involve in various activities related to the management and welfare of the Sundarbans including the decision-making process. The objective of the study was to assess the performance of CMOs to facilitate sustainable management of the Sundarbans. The qualitative study followed face-to-face interview to collect data from a total of 40 respondents using snowball sampling technique. The study showed that the co-management approach improved governance of the Sundarbans through the active participation of local community people and their interactions with the officials via the platform of CMOs. It facilitated accountability and transparency to some extent through following some formal and informal rules and regulations. It also improved the power structure of the management by fostering local empowerment process particularly the women. Moreover, people were able to learn from their interactions with and within the CMOs as well as interventions improved environmental awareness and promoted social learning. The respondents considered good governance as the most important factor for achieving the goal of sustainable management and biodiversity conservation of the Sundarbans. However, the governance was also facing various challenges resulted barriers to the sustainable management of the Sundarbans. Respondents recommended greater patronization form the government with effective participatory monitoring and evaluation system to improve sustainable management of the Sundarbans.

Deadwood as key element for bryophyte diversity in interaction with macroclimatic variables in managed and unmanaged temperate lowland forests

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: Setting aside strict forest reserves is one of the conservation measures promoted to preserve a proportion of the biodiversity threatened by forestry. However, there is a lack of knowledge concerning the respective roles of management abandonment, forest stand structural attributes and climatic or topographic variables in determining biodiversity in temperate forests. To address this issue, we conducted the first national-scale study in France to compare the biodiversity of managed versus unmanaged forests. Focusing here on bryophytes – all species and forest specialists –, we analyzed the data from 132 plots in ten lowland forests throughout France comprising both managed and unmanaged stands. Our aim was to disentangle the relationships between bryophyte richness and (i) management abandonment per se, (ii) associated forest structure variables such as deadwood volume and (iii) macroclimatic variables known as important for bryophytes (temperature, precipitations, relative humidity, solar radiation and vapor pressure deficit). For each studied combination of variables (single, additive or interactive models), we compared hierarchical Bayesian models of several types: linear with fixed slope, linear with random slope – one slope per forest –, quadratic, sigmoid or threshold models. The main drivers of bryophyte richness were deadwood variables, in managed as well as in unmanaged stands. We observed a sigmoid relationship of the total deadwood volume for the overall richness and threshold effect of the large and very large deadwood volume for the forest specialist richness. Combination of deadwood and macroclimatic variables were the best predictors of bryophyte richness, following non-linear relationships: higher solar radiation reinforced the positive effects of large deadwood on forest-specialist bryophyte richness; higher mean annual temperature counteracted the positive effects of total deadwood amounts on total bryophyte species richness. We conclude that high amounts of deadwood in managed as well as unmanaged forests are key elements for bryophyte richness and that ongoing climate changes may modulate their effectiveness as conservation structures.

Effect of different silvicultural treatments on the understory of temperate oak forests: the Pilis Forestry Systems Experiment

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: Forest management has a major impact on the understorey vegetation. We compared understorey variables across different experimental silvicultural treatments in a temperate oak-hornbeam forest in Central Hungary. Five treatment types were used in six replicates representing rotation and selection silvicultural systems: control (C), clear-cutting (CC), gap-cutting (G), preparation (partial) cutting (P), and retention tree group (R). The response of several community variables of the understorey was investigated to the treatments in the first 6 years after their implementation.

We found a large temporal and spatial variability over the study period. In all cases, the interventions led to an initial increase in species richness, often followed by a decline later, as the regeneration layer started to close. At the end of the study, R had the highest average species richness, comprising a heterogeneous group of perennial forb species. The interventions all resulted in a rapid increase in total herb layer cover, mainly in favour of graminoid and perennial species. The extent of the cover increase depended primarily on the intensity of the intervention, reflecting the amount of additional light received (CC > G > P > R > C). Turnover values, i.e. the rate of compositional change, also decreased in the same order. The effect of game exclosure was especially pronounced in CC and G, where game browsing slowed downed the regeneration outside the fences. The most significant changes in almost all variables were in the CC. It had the highest number of indicator species, many of them annual, ruderal, and invasive. G preserved the forest character of the vegetation dominated by light-flexible species. R and P preserved successfully the forest characteristics of the understorey.

Increasing the share of continuous cover forestry methods is crucial to preserve the forest herb layer at the landscape scale. Rotation forestry with large cutting areas is not recommended or should be kept at low landscape rates, as these areas are highly exposed to disturbance-related and invasive species. Leaving retention tree groups can be crucial to the survival of numerous forest species.

Forest degradation assessment in the Andean-Amazon region based on species composition approach

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: The montane forest ecosystems in the Andean-Amazon region are being degraded by anthropogenic disturbances such as logging and fire. Forest degradation not only reduces carbon stocks, but also promotes the decline of other ecosystem functions through changes in forest structure and biodiversity. However, changes in biodiversity are more difficult to be captured in broad-scale assessments compared to changes in biomass and carbon stocks. This study aimed to understand forest degradation status in montane forests in the Andean-Amazon region and to provide information that will contribute to planning of forest conservation, sustainable forest management, and restoration in the forest-agricultural landscape. We investigated the variation in forest structure and tree community composition with the different extent of anthropogenic disturbance by ground-based surveys, then evaluated forest degradation status at a regional scale by remote-sensing approaches including satellite imagery and UAV photography. Our study areas were Huanipaca district in Apurimac and Yanatile district in Cusco, Peru. Huanipaca is located in an Andean mountainous region, while Yanatile is in a high Amazon region. We set up circular plots with 20 m radius, and conducted field surveys including tree size measurement and species identification. For the regional scale assessment, we developed statistical models that relate dissimilarity in species composition among sites and band data from satellite imagery (Landsat 8 and Sentinel-2). The model including normalized burn ratio (NBR) as an explanatory variable reasonably accounted for forest degradation status based on dissimilarity in species composition among sites. By using this model, we obtained maps of forest degradation status in the regions. The maps produced were able to detect less degraded forest areas that we observed by the ground-based survey. Such areas can be extracted as priority sites for conservation. Our results suggest that species composition can be a key indicator for evaluating forest degradation status. In this presentation, we also introduce the application of the 3-dimensional forest structure data obtained by UAV-SfM to extract structural features to represent forest degradation status for the model accuracy improvement.

Forest Management Practice Influences Bird Diversity in the Mid-Hills of Nepal

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Abstract: Forest management practice plays a critical role in conserving biodiversity. However, there are few studies on how forest management practice affects bird communities. Here, we compare the effectiveness of the Panchase Protection Forest (PPF; protected forest with government administration) and the Tibrekot Community Forest (TCF; community forest with community forest users' group administration) in hosting bird diversity in the mid-hills of Nepal. We examined 96 point count stations during summer and winter in 2019 and recorded 160 species of birds with three globally threatened vultures (red-headed vulture *Sarcogyps calvus*, slender-billed vulture *Gyps tenuirostris*, and white-rumped vulture *Gyps bengalensis*). Forest management practice, season, and elevation all influenced the richness and abundance of birds. The diversity, richness, and abundance of birds and the most common feeding guilds (insectivore, omnivore, and carnivore) were higher in TCF than in PPF; however, globally threatened species were only recorded in PPF. We also recorded a higher bird species turnover (beta diversity) in TCF than in PPF. Our study indicates that community-managed forests can also provide quality habitats like those of protected forests managed by the government and provide refuge to various bird species and guilds. However, we recommend more comparative studies in other tropical and sub-tropical areas to understand how different forest management practices influence bird diversity.

Global long-term impacts of forest management on biodiversity

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Abstract: Forest managed for wood production could play an important role in biodiversity conservation outside protected areas; yet current global annual extraction of 3.9 billion m^3 roundwood and woodfuel results in a rapid decline and degradation of forests and its biodiversity. Previous studies show that sustainable forest management mitigates harmful impacts on biodiversity on the short term. Yet, little is known about long-term recovery times, nor about the ecosystem properties that explain management impacts on biodiversity, such as vegetation structure and composition. Through an expansion of three meta-analysis-based global databases (i.e., PREDICTS, GLOBIO and an unpublished database) with data on forest management (178 studies, 399,304 observations), time since management impact (113 studies, 209,129 observations) and vegetation structure and composition (3-38 studies, 47,098-162,138 observations), we aim to better understand ecological principles underlying impacts of forest management on animal biodiversity expressed as mean species abundance (MSA). In line with previous studies, we show that reduced-impact logging and selective logging have the least impact on biodiversity (MSA: 0.7, variance weighted average), and perennial tree crop plantations the highest (0.4). We find indications that management-specific vegetation structures partially produce this order, where high tree density and foliage cover negatively affect MSA, while the opposite is true for tree species richness, understory height and basal area. Each management type changes forest vegetation in their specific way, producing management-specific biodiversity impacts over time. Effects of selective cutting on MSA remain stable over 50 years, displaying no sign of recovery. MSA in clear cutting systems is relatively high in the years following cutting, after which it declines and stabilizes between 30 to 70 years. We find similar patterns for perennial tree crop and plantation systems; yet, we for these systems observe a slight MSA recovery between 50 and 80-100 years after establishment. Interestingly, agroforestry systems display a gradual MSA increase between 0 and 30 years following establishment before stabilizing. Overall, our results highlight the need to consider long-term effects of forest management systems on biodiversity to prevent under- or overestimations of their impacts.

Impact of active coppice management on microclimate and understorey vegetation in a Mediterranean oak forest

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Abstract: Understorey diversity contributes to forest functionality and services. Thermophilization processes caused by global warming have been detected especially in regions with warm macroclimates, such as the Mediterranean one. Coppice-with-standards is still one of the most common types of management in this region, aimed at the production of renewable energy (firewood). The modification of forest structure caused by coppicing could limit the capacity of forest canopy to offer microclimatic refuges for the herb communities. Hence, it is crucial to assess the sustainability of this traditional management under the current climatic stressors. We contributed to this topic by analyzing shifts in temperature, understorey diversity (taxonomic, phylogenetic, functional), and productivity in an ancient forest of central Italy with *Quercus cerris* and *Q. petraea*. Here coppice-with-standards and high forest are next to each other under homogeneous site conditions for long time. To this purpose, in 2021 we installed air and soil temperature dataloggers in three high forest and three coppice-with-standards sites. Following a nested sampling design, forest structural variables, light availability, and soil pH were determined before surveying understory vegetation in four 5 x 5 m randomly selected quadrats in each of the six sites. Understory aboveground productivity was determined in two 0.5 x 0.5 m subplots per quadrat. Functional traits associated with the acquisition and conservation of resources (vegetative traits) and reproductive efficiency were collected from the TRY database. Regarding microclimate, the mean offset values between forest and open areas in daily maximum temperatures were significantly larger in the high forest than in coppice stands during all seasons. Our results supported that coppicing promotes understorey species richness, although this is due to the presence of mostly generalist species. Interestingly, coppicing led to clustering in phylogenetic structure and differed significantly from high forest in functional diversity for some traits, highlighting the presence of ongoing acclimation processes. In light of these results, we emphasize the need to take into account different facets of plant diversity, to reach a more holistic understanding of the effects of coppicing on deciduous oak woodlands of the Mediterranean region, on plant diversity, and temperature buffering capacity of the forest.

Impact of Community Based Forest Management on floristic composition and structure of dry Miombo woodlands

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Abstract: Forest decentralization has promoted sustainable woody biomass harvesting in several Tanzanian forest reserves. However, the impacts of this management approach on species composition and structure changes remain largely unknown, yet people's preference for certain species, especially for fuelwood, is well documented. This study assessed the effect of community-based forest governance on the availability of preferred fuelwood species and changes in the overall status of the 6000 ha Gangalamtumba village-land forest reserve over the past ten years. A comparative analysis of forest attributes was carried out by re-measuring 33 permanent (but non-conspicuous) 0.126 ha nested sample plots. Through 81 household interviews, we link the floristic findings to preferred and extracted fuelwood quantities. Insignificant changes were observed in the overall basal area and species composition and structure of highly preferred fuelwood species, including *Brachystegia spiciformis,* Combretum sp*., Brachystegia boehmii, Dichrostachys cinerea, Senegalia nigrescens* and *Codyla densiflora.* Nevertheless*,* significant changes were observed in the abundance of tree species and in certain diameter classes. However, this observation appeared the result of natural processes rather than harvesting activities . Therefore, the study suggests that decentralization has served to conserve the growing stock down to the species level, especially where the most preferred and used species are also the most dominant species within the ecosystem. As the demand for wood is likely to grow we recommend a further expansion and institutional development of decentralized forest governance in Tanzania.

Impacts of Livestock Practices on Forest Degradation and Resilience in Northern Patagonia

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Abstract: Livestock grazing has been recognized as a significant driver of ecological change in *Nothofagus* forests and their understory plant communities. The impacts of grazing can result in alterations in vegetation composition and structure, leading to potential shifts in ecosystem dynamics and resilience. Understanding the factors influencing these state changes and irreversible modifications is essential for assessing ecosystem resilience and facilitating effective ecosystem recovery strategies. In this study, conducted in the northern Patagonia region of Chile, the objective was to explore the factors influencing state changes and irreversible modifications within *Nothofagus* forests subjected to livestock grazing. Comprehensive field assessments were carried out to achieve this, including forest structure inventories, understory censuses, microsite characteristics evaluation, and herbivore presence assessment. The collected data were then subjected to thorough analyses using uni- and multivariate statistical methods. These analyses aimed to examine the impact of grazing on forest dynamics, assess potential stocking rates, and elucidate the interactions between livestock and herbaceous plants. The findings of this study revealed that livestock interactions with herbaceous plants, both directly through grazing and indirectly through trampling and nutrient cycling, can have significant consequences for the structure and composition of the vegetation. Canopy openings caused by grazing can affect light availability and create microhabitats favouring certain plant species. Some plant species may experience increased cover and biomass, while others may suffer from reduced competitiveness or displacement. Intensive pastoral pressure can also lead to shifts in plant community composition, altering the abundance and distribution of different species and potentially facilitating the invasion of undesirable plant species. These changes in vegetation characteristics have broader implications for trophic interactions, nutrient cycling, and overall ecosystem functioning. This study provides valuable insights into the impacts of livestock grazing on *Nothofagus* forests. It highlights the need for proactive management approaches integrating ecological knowledge and adaptive strategies to achieve sustainable land use practices and promote biodiversity conservation in these ecologically significant areas.

Landscape scale mixtures of intensively and unmanaged forests increase biodiversity - Empirical effects of the Triad zoning

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Abstract: For three decades, the concept of Triad zoning has been proposed to balance the social, ecological, and economic demands at the landscape scale by providing intensively, extensively, and un- managed forests. However, the assumed effect on biodiversity was rarely tested against empirical data.

We used the Europe-wide multi-taxon database compiled by the Bottoms-Up Platform to quantify, for the first time, the effects of Triad components' forest landscape composition on regional (multi) biodiversity. We defined Triad components according to the silvicultural system applied; INT: clearcutting with and without tree species change and coppice, EXT: shelterwood and selection cutting, UNM: natural development. To ensure comparable environmental conditions and avoid regional bias, we searched the database, comprising 88 sites across Europe, for sites of the more or less eutrophic, (sub-) montane beech forest natural vegetation type, keeping only sites with at least two Triad components and three taxa represented, arriving at a well-balanced dataset of 222 plots from 9 sites from Czechia, France, Germany and Italy.

To analyse the effect of Triad components on biodiversity, the composition of forest landscapes was varied in steps of 10% using 1,000 resamplings of up to 20 plots per step (66 unique landscape compositions), quantifying regional (gamma) diversity.

Biodiversity of five taxa responded significantly but differently to forest landscape composition (R^2 from 0.243 to 0.748). Regional diversity of bryophytes, lichens and deadwood fungi was highest for pure UNM landscapes, while birds and deadwood beetles profited from adding INT to UNM. Vascular plants regional diversity was promoted by INT with minor contribution of UNM. Multi-biodiversity culminated in landscapes composed of 70% UNM and 30% INT (95.1%), dropping drastically towards pure EXT and INT (73.3 %) landscapes, suggesting complementarity between unmanaged and intensively managed forests, at least for some taxa.

The relative contribution of INT, EXT and UNM to multi-biodiversity may change according to the

forest natural vegetation type, and further investigations are needed with this respect. Our results emphasize the value of multi-taxa biodiversity monitoring and call for widespread use of standardized sampling methods.

Large scale restoration using semi circular bunds and retention ditches ("Fanya juu" and "Fanya Chini") in East African rangelands

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Abstract: The need for large-scale restoration initiatives in Sub-Saharan Africa is urgent. Land degradation, deforestation, and climate change pose significant challenges to ecosystems, biodiversity, and livelihoods. Restoration efforts are crucial to reverse these trends, enhance resilience, and promote sustainable development in the region. Large-scale restoration efforts in East African rangelands have increasingly employed innovative techniques such as semi-circular bunds and retention ditches, commonly known as "Fanya juu" and "Fanya chini" respectively. These techniques, championed by organizations like Justdiggit, aim to restore degraded landscapes, improve water infiltration, and enhance vegetation cover. The success of these methods lies in their ability to harness the natural processes of water flow and soil erosion to rejuvenate the ecosystem. The implementation of semi-circular bunds and retention ditches offers several benefits. Firstly, it helps combat soil erosion by reducing the velocity of water runoff, preventing gully formation, and retaining sediment on-site. This leads to improved soil structure and reduced sedimentation in downstream water bodies, positively impacting water quality. Secondly, the increased water infiltration and retention result in enhanced soil moisture levels, supporting vegetation growth. This allows the restoration of grasslands, shrubs, and trees, which in turn promotes biodiversity conservation and provides fodder for livestock. Large-scale restoration using "Fanya juu" and "Fanya chini" techniques is not only ecologically beneficial but also contributes to the socio-economic well-being of local communities. Restoration of vegetation cover improves forage availability, allowing pastoralists to sustain healthier livestock populations. The restored landscapes also provide opportunities for diversification, such as agroforestry and beekeeping, creating additional income streams. Moreover, by involving local communities in the restoration process, these projects foster community engagement, ownership, and empowerment, resulting in long-term sustainability. In conclusion, large-scale restoration efforts utilizing semi-circular bunds and retention ditches in East African rangelands present a promising approach to combat land degradation, improve water management, and restore ecosystems. These techniques harness natural processes to restore vegetation cover, enhance biodiversity, and provide socio-economic benefits to local communities. By combining ecological restoration with community engagement, these projects hold great potential for achieving sustainable landscapes and resilient livelihoods in East Africa.

Long-term response of saproxylic beetles to ecological restoration

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Abstract: The aim of this study is to assess the effect of time since restoration on substrate availability, assemblage composition and species richness of beetles. We used a unique large-scale long–term field experiment conducted in northern Sweden. Dead wood inventories and window trapping of beetles was conducted in 18 stands, six of each treatment (burned, gap-cutting, including dead wood creation, and control) during tree year: 2010 (baseline), 2012 (one year after treatment) and 2019 (eight years after treatment). The total volume of dead wood was approximately 10 m^3/ha prior to restoration but in 2019 it increased to 50 and 20 m^3/ha in burned and gap-cut stand, respectively. Beetle assemblage composition differed between burned stands and controls all years, except 2010, the pre-treatment year. However, the initial dominance of fire dependent and fire favoured beetles in burned stands 2012 decreased over time and by 2019 few individuals from these group could be found. Instead, other species, secondary favoured by fire, dominated the catch in burned sites. Assemblages in gap-cut stand differed significantly from control stands in 2012 but not in 2019. Thus, we found partial support for our prediction that assemblages would become more similar to controls with time. However, the species response to restoration differed between feeding guilds, e.g., fungivores exhibited a different response than predators and potential explanation for this will be discussed. In summary, prescribed burning had a strong and long-lasting effect of substrate availability/diversity and on beetle assemblage composition. But there was a fast turnover of species following burning and in 2019 species that apparently are secondary fire favoured, a group for which we have limited knowledge, dominated the catch. This implies that prescribed burning will have long lasting effects on saproxylic communities but short lasting effects on early successional fire specialists. Gap-cutting had much subtle effects on both dead wood availability and beetle assemblages than burning. Most of the species present prior to gap cutting, was also present post restoration but complemented by some more light demanding species, suggesting that this restoration method is less detrimental to species associated with old forests and forest continuity.

Microclimatic changes induced by experimental gap openings in a sessile oak–hornbeam forest: the Pilis Gap Experiment

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Abstract: Forest management integrating nature conservation aspects into timber production focuses increasingly on small-scale interventions. However, the ecological consequences of gap cuttings remain ambiguous in oak-dominated forests. In the Pilis Gap Experiment, we analyze how combinations of different gap shapes (circular and elongated), and gap sizes (150 m^2 and 300 m^2) affect the microclimate and biota of a mature sessile oak-hornbeam forest in Hungary.

We first report the changes in direct and diffuse light, soil moisture, daily air and soil temperatures, and relative air humidity in the experimental cuttings in the vegetation season directly following their implementation. Diffuse light had a central maximum and a concentric pattern. Direct light was distributed along a north-south gradient, with maxima in northern gap parts. Soil moisture was determined by gap shape: it increased significantly in the centre of circular gaps, with multiple local maxima in the southern-central parts of large circular gaps. Its pattern was negatively related to direct light, and larger spatial variability was present in circular than in elongated gaps. The daily mean air temperatures at 1.3 m increased in all, especially in large gaps. Soil and ground-level temperatures remained largely unchanged, reflecting light and soil moisture conditions affecting evaporative cooling. Relative humidity remained unaltered. Even though the opening of experimental gaps changed microclimatic conditions immediately, effect sizes remained moderate. Gap size and gap shape were both important determinants of microclimate responses: gap size markedly affected irradiation increase, gap shape determined soil moisture surplus, while soil and air temperatures, and air humidity depended on both components of the gap design.

We conclude that 150-300 m^2 sized management-created gaps can essentially maintain forest microclimate while theoretically providing enough light for oak regeneration; and that the manipulation of gap shape and gap size within this range are effective tools of adaptive management.

Motivating better husbandry of Forested Ecosystems

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: Many countries require landholders to observe a "duty of care" for conservation of their land, often requiring adherence to explicit guidelines, sometimes supported by up-front grants with long-tailed obligations, all of which are problematic. These approaches may be coupled with other arrangements that hamper land management at the landscape scale, needed to support biodiversity. In contrast, many European countries have a long tradition of hunting game species, and revenues from hunting rights provide a powerful incentive to manage forests for wildlife and biodiversity values. This review highlights some of the unintended consequences of the "duty of care" approach, and canvasses alternatives and incentives that may foster more effective and innovative management of both private and public forested lands. An effective alternative is to make annual payments for attaining selected conservation outcomes. Efficient ways to implement such payments will be reviewed and discussed.

Natural forest transformation: an analysis of changes over the last century in the Świętokrzyski National Park in Poland

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: The forests of the Świętokrzyski National Park in southern Poland are an example of changes in the species composition of forest stands occurring mainly spontaneously. The main forest-forming species in this area was the European silver fir (*Abies alba*) with an admixture of the European beech (*Fagus sylvatica*). Both species appear to be beneficiaries of the climatic changes occurring in this part of Europe: an increase in mean temperature with a slight decrease in precipitation in upland and mountainous areas. This study aimed to analyse the changes occurring in the species composition of the Świętokrzyski National Park's forest stands from 1925 to 2014. In this area and in the assumed time horizon, data from long-term studies of permanent sample plots characterising changes in most of the park area were not available. We used 299 random sample points distributed evenly over the study area and descriptions of the stands where the points were located during the inventory period. Inventory data from the years used were: 1925, 1954, 1971, 1997, and 2014. Data from the forest management plans were compiled into a database and processed to determine the biodiversity and role of species in each stand layer. The share of each species in all forest layers and their regeneration was used to determine their forest-forming role. The forest-forming role of the two species studied was linked to the forest habitat type, moisture variant, forest type, and forest condition. Spatial analyses were based on a digital elevation model, from which derived layers were calculated and their values were related to forest-forming role. The widespread and persistent dominance of fir in the forest ecosystems of the study area was confirmed. In the case of beech, a correlation between forest-forming strength and altitude was observed. Up to a level of 480 m above sea level, this strength increases and then decreases at higher elevations. Changes in the occurrence of other tree species important in the lower layers of the stands were analysed. This may be significant for further transformation of the forests of the study area.

Species colonization-extinction dynamics in understory vegetation communities in response to forest and climate conditions

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: Modifications of forest ecosystems due to climate change, conjointly with forest harvesting, are shaping boreal forest biodiversity. Long-term composition of understory vegetation communities results from the dynamics of each species. Climate conditions as well as the structure and composition of the overstory vegetation, modified by forest management, influence the species dynamics. Moreover, the ability of an understory vegetation species to colonize and occupy a plot also depends on its functional traits that influence growth, reproduction, and survival. Functional traits in understory vegetation community thus reflect species responses to the environment. In order to understand large-scale and long-term changes in understory vegetation communities, we take into account the dynamics of individual species, i.e. their colonization and extinction. In this sense, our first objective is (i) to increase understanding of effects of stand structure and climate conditions on the dynamics of understory vegetation. We then (ii) investigate the effects of different forest management actions on understory vegetation. We used hierarchical modelling of species communities to analyze changes in the rates of colonization and extinction of each understory plant species depending on stand structure and climate conditions. For this purpose, we used vegetation-monitoring data from permanent plots in the Swedish National Forest Inventory from 1993 to 2021. We use presence-absence surveys conducted every 5 years of 268 plant species. Finally, to study the interactions between species in understory plant communities, we investigated the effects of species presence and cover of 71 species on colonization-extinction rates. We hypothesize that stand structure will directly affect understory vegetation, especially through changes in available light. Younger, less dense stands would have more light-favored species and, on the contrary, older, denser stands would have more shade-favored species. We therefore expect changes in colonization and extinction according to the species and its associated functional traits, and thus modifications of understory vegetation communities. Furthermore, we expect that forest management actions will lead to larger short-term direct and indirect effects on understory vegetation communities, while climate change will lead to longer-term changes.

Transformation of non-native Sitka spruce stands to Continuous Cover Forestry (CCF): enhancing biodiversity value of managed forests in Ireland.

T3.28 Opportunities to promote biodiversity recovery and protection through innovative forest management approaches

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Abstract: The majority of Irish forests are even-aged plantations of non-native conifers, managed under the clearfelling silviculture system. However, current national forest policy promotes the transition to Continuous Cover Forestry (CCF), which has been shown to have multiple environmental benefits in comparison to clearfell-replant silviculture. Transformation to CCF typically relies on promoting natural regeneration to restock felled trees. In cases where natural regeneration is unsuccessful or management aims to introduce broadleaf trees to conifer plantations, underplanting represents a viable method to introduce the greater tree species richness in forests. The aim of this study is to assess the relationship between canopy openness in stands of Sitka spruce and the survival, growth, and health of underplanted broadleaf trees. In addition, the occurrence of natural regeneration and changes in vegetation communities following transformation to CCF are also being monitored.

Sitka spruce plantations that have had selective CCF thinning interventions are being used for this study. Broadleaves (*Quercus petraea* and *Fagus sylvatica*) were planted with in gaps of varying canopy openness (2%- 42%). Mortality, height and photosynthetic efficiency of underplanted seedlings are being monitored to directly assess the impact of light intensity on tree survival and productivity. Determining canopy openness that maximises tree health, natural regeneration, and understorey vegetation diversity will offer valuable insights into how CCF can enhance the biodiversity value and resilience in managed forests in the face of climate change.

Vegetation changes due to prevalent mammalian herbivores foraging in native forests in Chiliean Austral Macrozone

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Abstract: The native forests in the Chilean Austral Macrozone are a valuable natural resource, providing significant economic benefits for the local communities. However, these forests are facing numerous challenges due to the pressures exerted by mammalian herbivores, including domestic livestock and wild native or exotic herbivores. The primary objective was to assess how prevalent domestic and wild mammalian herbivores impact understory vegetation by engaging in differential foraging across native forest gradients in the Chilean Austral Macrozone. To achieve this objective, gathering information on biotic and abiotic factors that contribute to forest degradation or change within the Macrozone was essential. Several specific objectives were identified: (i) Determine understory vegetation biomass, distinguishing between palatable and non-palatable, and native and exotic species. (ii) Identify potential factors, both biotic and abiotic, that influence the composition of vascular plant communities by analyzing the herbivore pressures exerted by prevalent species across the studied forest gradients. (iii) Evaluate the nutrient content, such as dry matter, of dominant vascular plant species, and identify indicator species that can be used to assess forage nutritional quality for prevalent herbivores within the studied forests. Data was collected from stands located in ranches and national reserves in the Aysén and Magallanes regions. Various forest use scenarios were considered, such as livestock grazing during summer and winter, and different densities of mixed herbivore species or herbivore exclusion. The study examined factors such as stand variability characteristics (microsites), edaphic conditions, and the level of anthropization within the landscape and climate patterns. The existing herbivore pressure on the native forests necessitates adopting more sustainable strategies to prevent irreversible degradation in the long run. Overgrazing has already caused changes in vegetation cover and distribution of native plant species, inadvertently resulting in undesired new ecosystems that lead to economic losses for local ranchers. The findings from this study will contribute to the development of conservation strategies by providing insights into effective, sustainable development practices in the Chilean Austral Macrozone.

T3.29 Reforestation Under Drought Conditions

Alternatives to Herbicides for Reforestation Under Drought Conditions in the Pacific Northwest U.S.

T3.29 Reforestation Under Drought Conditions

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Abstract: Sustainable forest management of Douglas-fir represents an essential component of the environmental, economic, and social well-being of the state of Washington and the U.S. However, forests in the Pacific Northwest are challenged by annual summer droughts, with evidence of decreased survival of Douglas-fir seedlings after intense summer seasons. This scenario could become more severe in the context of climate change as soil water is often the main limiting resource for the early growth of planted Douglas-fir. Forest vegetation management (VM) has become an important component of reforestation programs, improving seedling survival and growth by reducing competitor abundance and increasing soil water availability. There are several strategies for VM, including chemical, mechanical, and manual alternatives; however, there is little information on the comparative effects of these methods and their relationship with the environment. Alternative methods to controlling vegetation are limited and many may not be feasible to employ across the total acres harvested annually across the region. Recently, members of the public have raised concerns over the use of herbicides in forestry, especially the use of glyphosate. Thus, this research evaluates the effectiveness of different herbicide and non-herbicide VM strategies. Eight VM treatments were evaluated at five sites in Washington State. These treatments included no-action control, pre and post planting herbicide applications with and without glyphosate, mechanical harvest residue management, and manual hand weeding during the first growing season or the first two growing seasons. We analyzed seedling survival, growth and physiology (including stomatal conductance and predawn and midday water potential), soil moisture availability, as well as early-seral vegetation abundance and diversity during two growing seasons after planting (the project will continue for three more years). This research aims to provide a better understanding of the effect of multiple VM alternatives on seedling growth conditions. Our goal is to inform public opinion and reforestation managers about the effectiveness of chemical and non-chemical VM alternatives for reforestation under water-limited conditions.

Can a biodegradable paper donut help to reforest pine Mediterranean species under harsh environments?

T3.29 Reforestation Under Drought Conditions

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Abstract: Creating more resilient and productive landscapes is a key goal of most reforestation projects. However, the attainment of these targets is not straightforward under harsh environments, as outplanted seedlings need to survive to complete successful establishment. This study assesses how the outplanting success of two pine species in the Mediterranean continental region can be improved by using a biodegradable paper donut. The so called Cocoon is a circle made from recycled cartons with a hole in its center that serves as water reservoir for the seedling during their fist summer after planting. For this purpose, in April 2019, we set up two experimental plots in each of two sites (Segovia and Valladolid) that show different environmetal conditons. Five hundred (500) one-year old *Pinus pinaster* and 500 *Pinus pinea seedlings* were planted in each site to test the efficiency of the Cocoons in the short- (after first summer) and in the long-term (after 4 years). Treatments were species (*Pinus pinaster* and *Pinus pinea*) and presence/abscence of Cocoons (control vs cocoon). During the first summer, the highest mortality rates were recorded in July and August for both sites and treatments. In October 2019, after the first summer, mean survival rates in Valladolid site were 62.8% in P. pinea and 67.8% in *P. pinaster*, with slightly higher survival rates in seedlings grown with the Cocoon. The positive effect of the Cocoon was higher in Segovia site, where survival rates were as high as 85,6% in *P. pinaster* and 92,8% in *P.pinea* in sedlings grown with Cocoon, decreasing to 28,4% and 55,6%, respectively, in control plants. The positive effect of Cocoon is corroborated, mainly in Segovia site, where the climate and edaphic conditions are not optimal for reforestation purposes. However, four years after outplanting (summer 2023), the effect of the Cocoon is expected to be reduced, as once the seedlings are installed and have been able to develop an adequate root system they will not be so dependent on addtitional water input.

Drip irrigation in the context of forest regeneration in areas with dieback from drought and other causes

T3.29 Reforestation Under Drought Conditions

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Abstract: The Upper Rhine region is one of the most heat-stressed and driest regions in Germany. Therefore, the inter- and transdisciplinary project '*WaldlabOR'* focuses on this area as a model region to study forest transformations. In the context of the sub-project '*Adaptation strategies for the conservation of forest ecosystem services in climate change hot-spots'*, an experiment is conducted on the influence of irrigation to regenerate forests in areas with dieback from drought and other causes. The experiment takes place at three sites in the Upper Rhine region and focuses on four tree species to identify long-term adapted tree species for extremely dry and hot sites: *Tilia cordata, Quercus rubra, Quercus petraea* and *Acer platanoides.* The irrigation technology is being developed in close cooperation with NETAFIM, one of the world's leading irrigation companies. The technology will be based on drip irrigation in tree clusters. Using a fully factorial design in the experiment, we compare non-irrigated and irrigated tree clusters. The effectiveness and efficiency of the irrigation technology will be quantified through different variables such as mortality, growth, root quality and soil moisture. Here, we present the experimental design along the chosen technology, climatic projections for the area and calculations of water requirements. The project aims to have model character for regions with similar problems now or arising in the future. Concrete solutions and action approaches for forest management will be developed in an innovative inter- and transdisciplinary approach.

Effects of stem decapitation, water-deficit stress, and pot size on the growth, morpho-anatomy, and physiology of Pterocarpus indicus seedlings

T3.29 Reforestation Under Drought Conditions

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Abstract: Predicting how transplanted seedlings survive in planting sites necessitates an understanding of how multiple stresses interact and affect seedling growth, morpho-anatomy, and physiology. Here, we analyzed the interacting effects of stem decapitation, water-deficit stress, and pot size on the growth, morpho-anatomical, and physiological traits of *Pterocarpus indicus*seedlings. Significant changes in root collar diameter (RCD), biomass allocation, number of leaflets (NL), mean leaf area, guard cell size, stomatal aperture size, phloem cap fiber (PCF) thickness, xylem vessel density (XVD), relative leaf water content (RWC), stomatal conductance (g_{sw}), transpiration rate (E), fluorescence quantum yield, transpiration (E), photosynthesis (P_N), and electron transport rate (ETR) of decapitated and undecapitated *P. indicus* seedlings in different pot sizes (Small, Medium, Large) and watering regimes (every 2, 7, and 14 days) were analyzed. The decapitation × water-deficit stress × and pot size interaction did not affect growth and morpho-anatomical variables, but they did on most physiological aspects of the seedlings. Decapitated seedlings watered every 14 days and planted in either medium or large pots have lower g_{sw}, P_N, E, and RWC. However, significant effects of pot size × watering interaction on RCD and stem, fine root, and coarse root biomass allocations were also detected in decapitated seedlings. While the RCD of large-potted and water-stressed (every 14 days) seedlings decreased, allocations to stem and fine and coarse roots significantly increased. Moreover, we found significant effects of decapitation × watering reactions on the NL, PCF, ETR, and XVD. The NL and PCF significantly decreased, while the ETR and XVD significantly increased in decapitated and water-stressed seedlings. Overall, the decapitation-watering interaction can cause significant stress to *P. indicus* seedlings; however, it can be alleviated by utilizing medium and/or big pots during initial growth in the nursery. This could be a viable nursery practice for boosting seedling survival in actual planting areas. Real-scale field experiments are recommended to elucidate the responses of the seedlings to interacting multiple stresses.

Enhancing Reforestation Success through Hydrogels in Mountainous Forests: Investigating Drought Stress Mitigation and Ecological Implications

T3.29 Reforestation Under Drought Conditions

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Abstract: Alpine forests are already experiencing the impacts of climate change, and these effects are expected to intensify in the future with more frequent and severe disturbances. To enhance forest ecosystem resilience and adapt to human-induced climate change, optimizing forest management practices is crucial. Artificial regeneration, particularly on marginal sites with challenging growth conditions, requires a detailed understanding of native and non-native forest reproductive materials and planting methods to ensure successful tree establishment.

One significant challenge for reforestation is the increasing occurrence of longer and more frequent spring and summer droughts, which pose a threat to seedling survival. This study focuses on evaluating the effectiveness of hydrogels as a solution to mitigate drought stress and promote sustainable reforestation. By enhancing soil water storage capacity, hydrogels have the potential to improve soil moisture retention and seedling survival after disturbances or during forest conversion. The study considers various factors such as tree species, geology, exposure, accompanying vegetation, reforestation method, and planting period, while also conducting a cost-and-benefit analysis.

The research employs both and large-scale in-situ experiments in alpine forest landscapes and ex-situ experiments to investigate the interaction between hydrogels and tree seedlings. In an ex-situ rhizobox experiment, soil and ecophysiological methods, including stable isotopes, are utilized to examine the extent to which spruce and oak seedlings use water stored in hydrogels during drought stress periods. The different treatments affect above- and below-ground growth, plant nutrition (including ectomycorrhizae), and the hydraulic system of the plants.

The findings of this study provide scientific insights and practical knowledge to enable forestry professionals to effectively address the challenges of climate change and enhance the resilience of tree seedlings in reforestation efforts, particularly in the context of increasingly frequent drought events.

Exploring Assisted Tree Regeneration to Support Sustainable Forest and Woodland Management in Oshikoto and Kavango Regions, Namibia

T3.29 Reforestation Under Drought Conditions

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Abstract: Forests, woodlands, and trees play a key role in African economies, including a dry country such as Namibia, supporting the livelihoods of many people in rural and urban areas. They provide a range of goods and services, including timber, food, medicines, construction and fencing material, habitats, and energy. Moreover, woodlands play a significant role in ecosystem functioning especially in biodiversity, water, and nutrient cycling. However, Namibia's dry forests and woodlands are facing many threats such as climate change, deforestation for agriculture, natural disturbances such as uncontrolled fires and droughts, and poverty-driven unsustainable harvesting. Additionally, the natural regeneration of indigenous trees is often hampered by the browsing of seedlings, seed predation, and competition. To address these issues, this study aims to investigate methods to support assisted tree regeneration and seedling establishment in nurseries as a strategy for sustainable forest and woodland management. The research will be conducted in two vegetation types: the mountain savanna and karstveld at Ongava Research Centre, and the forest-savanna and woodland at Mashare Agricultural Development Institute. The study will assess seed germination and vegetative regeneration through stem cuttings and assess bio-inoculants' impact on seedling growth. The study will gather comprehensive data on the germination success, vegetative regeneration success, and impact of bio-inoculants on seedling growth across different soil mediums, and seeding depths. The findings will contribute to developing tree nursery protocols, promoting sustainable forest management, and reducing pressure on heavily used tree species while assisting reforestation and afforestation efforts. The results will be shared with stakeholders and local communities to encourage active regeneration. Ultimately, this research seeks to advance knowledge in assisted tree regeneration and its potential contributions to sustainable forest and woodland management.

Keywords: Assisted tree regeneration, Sustainable Forest management, climate change, vegetative propagation, bio-inoculant, nursery protocol

Important effects of soil water legacy on tree growth of plantations under contrasting climatic seasonality of the semiarid regions

T3.29 Reforestation Under Drought Conditions

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Abstract: Wood growth, as one of the major components in vegetation carbon storage, is commonly described as a linear function of carbon assimilation in existing vegetation models. However, recent evidence suggests that wood growth is highly responsive to climate, particularly to soil water availability. Insufficient soil water poses a significant challenge for afforestation in semiarid regions, limiting the survival and carbon sequestration potential of plantations. Therefore, comprehending the relationship between soil water availability and tree growth is essential for evaluating the effectiveness of afforestation efforts under climate change. Using high temporal-resolution dendrometer measurements, we investigated the relationship between tree stem growth and the seasonal dynamics of soil water in plantations located in two semiarid regions characterized by different climate seasonality. Our results suggested that the daily growth rate of trees in semiarid areas is primarily influenced by the availability of soil water and the atmospheric vapor pressure deficit, resulting in discontinuous growth patterns throughout the growing season. In cold-dry regions (northern China), *Larix principis* utilizes the residual spring snowmelt in the soil to complete its growth before the peak rainfall period. In warm-dry regions (southern Israel), *Pinus halepensis* sustains its growth by tapping into the water stored in the soil after the peak rainfall period. Despite variations in climate patterns and dominant tree species, our results indicate a consistent conclusion that trees in semiarid areas can effectively harness the legacy of soil water to maximize their annual growth. This finding highlights the adaptive strategies of tree plantations in semiarid regions, efficiently utilizing the local soil water resources to maintain carbon sequestration.

Increasing green cover and carbon accumulation through afforestation of salt affected areas in drylands of India

T3.29 Reforestation Under Drought Conditions

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Abstract: As part of its intended nationally determined contribution (INDC) to the Paris climate agreement 2015, India has committed to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030. One of the strategies worked out towards this is to afforest about 2.98 million ha of salty wastelands in Rajasthan, Gujarat, Haryana and Punjab states of India.

Trials were conducted on barren lithic, calcid, coarse sandy to loamy sand salt affected soil in Jodhpur (Rajasthan) and silty black highly saline soil in little Rann of kachchh (Gujarat). The approach was to grow salt tolerant species & use soil amendments. The indigenous multipurpose halophytic tree *Salvadora persica* maintained 66.7 to 85.2 % survival even after ten years. Gypsum + 9g N treatment gave 85.2 % survival and 12.0 & 5.67 kg tree^{-1} of fresh & dry biomass in arid sandy soils in Rajasthan while on black soil in Gujarat, wheat husk (WH)+FYM+urea treatment gave 90% survival and 7.17 & 3.71 kg tree^{-1} Green & dry biomass. *A. bivenosa* was more suitable with WH+FYM treatment on black soil.

Acacia ampliceps (Australian tree) recorded 76 % survival on gypsum treated deep alkali soils (60 to 75 cm depth) and yielded twofold biomass (12.0 & 5.35 tree^{-1} to 5.43 & 2.14 kg tree^{-1} fresh & dry biomass for gypsum treated and 8.1 & 5.35 kg tree^{-1} to 3.9 & 1.56 kg tree^{-1} fresh & dry biomass for untreated trees on deeper and shallow soils) at five years of age. Natural regeneration of *S. persica* was also observed on sandy soil in Rajasthan, especially under *Prosopis juliflora.* Overall, significant improvement in site conditions improved and growth of indigenous vegetation was observed.

Intensive silviculture enhances carbon sequestration and natural forest regrowth in restoration plantations in Brazil

T3.29 Reforestation Under Drought Conditions

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Abstract: Brazil has committed with the Bonn Challenge to restore 12 million hectares of degraded lands by 2030. This pledge is particularly important because Amazon and Atlantic Forest biomes have lost 22% and 74% of their original cover, respectively. Therefore, the country has a huge task for the following years.

A significant part of these hectares to be restored are degraded pastures in tropical regions, covered by aggressive non-native C4 grasses, making these landscapes very difficult to restore by natural forest regrowth. Under these conditions, the strategy is to plant native tree species using the best silvicultural practices to ensure survival and high productivity. Unfortunately, this is not a viable option for landowners who try to restore forest ecosystems. With the undesirable competition with grasses, the resource-use rate (light, water, and nutrients) for the trees is low, leading to high mortality and marginal growth. The objective of this study is to assess the effect of intensive silviculture, similar to commercial plantations of *Eucalyptus*, applied to mixed-species plantations for restoration purposes.

To assess the effects of silvicultural practices to increase survival, growth, and carbon sequestration in forest restoration plantations, we integrated data up to 20 years from 3 experimental sites in different locations testing variations in planting spacing, soil preparation, competing vegetation control and fertilization.

Intensive silvicultural practices on early stages of these restored areas, until canopy closure, were critical for the success of the planting project, with intensive competing vegetation control acting as the main important factor for increasing survival and growth. Carbon sequestration in aboveground biomass under intensive silviculture can reach up to 4 $Mg.ha^{-1}.year^{-1}$, compared to ~1 $Mg.ha^{-1}.year^{-1}$ under low silviculture. Under intensive silviculture, canopy closure occurred at 3.5 to 4 years after planting, leading to competing vegetation control (mainly non-native C4 grasses) by shading which enabled natural regeneration of tree species. The canopy closure under low silviculture takes 10 years or more and the grasses limit natural forest regrowth. This network of trials will be monitored for the following years to evaluate the long-term effects of intensive silviculture in restoration plantations in Brazil.

Leaf morpho-physiological traits of Populus sibirica and Ulmus pumila in different irrigation regimes and fertilizer types

T3.29 Reforestation Under Drought Conditions

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Abstract: Climate change can intensify soil dryness and nutrient deficiency, and this calls for an environmentally sustainable forest and groundwater resource restoration. Massive afforestation, however, may deplete groundwater supply due to increased evapotranspiration, resulting in a more severe water scarcity. Thus, we investigated the effects of different watering regimes and fertilizer types on the morpho-physiological traits of *Populus sibirica* (Horth ex Tausch) and *Ulmus pumila* (L.). The leaf area (LA), specific leaf area (SLA), chlorophyll concentration, stomatal conductance (g_s), chlorophyll fluorescence, and predawn and midday leaf water potential were measured across treatments. During the first growing season, the LA of *P. sibirica* was higher in the 4-8 L h^{-1} without fertilizer, but it was lower in the 4 L h^{-1} + COMP during the second growing season. The 2 L h^{-1} without fertilizer and 2 L h^{-1} + NPK had larger LA compared with CON for the first and second growing seasons, respectively, for *U. pumila. P. sibirica* seedlings at 4 L h^{-1} without fertilizer had the highest SLA for 2021 and at 2 L h^{-1} + NPK for 2022, whereas CONT and 4 L h^{-1} had the highest SLA than the other treatments for 2021 and 2022 growing seasons, respectively, for *U. pumila.* The chlorophyll concentration of *P. sibirica* seedlings in the first year was generally higher in CONT, while the 2 L h^{-1} without any fertilizer yielded a significantly higher chlorophyll concentration of *U. pumila.* CONT and 2 L h^{-1}+NPK-treated *P. sibirica* seedlings had a significantly greater g_s during the first year and second year, respectively. The CONT with NPK/COMP generally had a higher g_s compared with the other treatments in both experimental periods for *U. pumila.* The predawn and midday leaf water potentials of *P. sibirica* and *U. pumila* were generally the lowest in CONT, followed by 2 L h^{-1}+NPK/COMP during the first growing season, but a different pattern was observed during the second growing season. Overall, the morpho-physiological traits of the two species were affected by watering and fertilizer treatments, and the magnitude of the effects varied depending on growing season, amount of irrigation, and fertilizer type.

Local and traditional knowledge restoration techniques of savannah landscapes for climate change adaptation, Burkina Faso.

T3.29 Reforestation Under Drought Conditions

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Abstract: Land degradation is occurring in almost all terrestrial biomes and agro-ecologies, in both low- and high-income countries. Thus, the populations have developed traditional techniques (Zaî system, stone cordons, half-moons, etc.) to better manage water for agriculture in the face of its degraded lands. We refer to the literature review on local techniques and traditional methods of water and soil conservation, using cultural mapping which integrate Geographic Information Systems and social data. This article aims to map its different techniques, assess the impacts, the involvement of gender with social aspects and policies. The studies were carried out at the beginning of the rainy season in Zitenga. We therefore retain local and traditional water and soil conservation techniques that contribute to local and national economies, sequester significant amounts of carbon, strengthen food and clean water supplies and safeguard biodiversity. Local and traditional water and soil conservation techniques is strongly connected to sustainable development and contributes directly to UN Sustainable Development Goals 1, 2, 6, 13, 14 and 15, through: creating jobs and sustainable value chains; enhancing food security and dietary diversity; increasing water availability; supplying wood energy for cooking; mitigating the effects of climate change and enhancing the resilience of ecological and social systems. It can also contribute to Goal 16 by increasing the availability of natural resources. A policy brief is in perspective for taking into account indigenous and local knowledge in water and soil conservation policies.

Morphophysiological Responses of High and Low Elevation Douglas-fir Seedlings to Drought-Preconditioning in Idaho, United States of America

T3.29 Reforestation Under Drought Conditions

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Abstract: Climate projections anticipate that changes in precipitation will vary regionally, with some regions likely seeing higher moisture and others experiencing a decrease in precipitation. These alterations present challenges for reforestation in regions such as Northern Idaho, where droughts have become more frequent and intense, as exemplified by the 2021 drought, highlighting the need for drought-hardy seedlings. With climate change expected to exacerbate drought and extreme cold events, producing tree seedlings resistant to these conditions becomes crucial. Nonetheless, there is a dearth of applied research that guides nursery practices for producing drought-hardy seedlings for reforestation sites. Knowing the elements that affect the drought hardiness of Douglas-fir seedlings can produce more robust seedlings that endure harsh climatic conditions. This study aimed to enhance the production of drought-hardy seedlings for reforestation in drought-prone regions. We conducted an experiment in a greenhouse, using container seedlings derived from seeds collected at high (6100 ft) and low (2050 ft) elevations in the northern Idaho Rocky Mountains. We investigated the effects of drought durations (two and three months) and intensities (Control, Moderate and extreme) on Douglas-fir seedlings physiology, morphology, root growth potential, and cold hardiness.

We found a significant effect (p 0.0001) of drought intensities and durations on predawn and midday water potential, resulting in a decrease in water potential in both provenances. High-elevation seedlings exhibited a root collar diameter that was 0.181 mm smaller and a height that was 2.29 cm shorter than low-elevation seedlings. Moreover, the high elevation provenance demonstrated increased root growth potential, with a 1.11 cm increase in root length. The control treatment exhibited higher root growth, while the extreme drought displayed reduced growth. The Injury index was affected by freezing temperatures and the treatments but not by seedling provenance. In comparison to other treatments, seedlings subjected to extreme and moderate droughts exhibited enhanced cold hardiness.

This study emphasizes the drought resistance of seedlings and the beneficial effect of drought preconditioning on their cold hardiness, which are essential to their survival and growth in natural forest ecosystems. These findings have practical implications for forest seedling nursery practices and reforestation efforts in drought-prone regions.

Population demographic characteristics Saxaul (Haloxylon ammodendron C.A.Mey.) Bunge forests in Mongolia

T3.29 Reforestation Under Drought Conditions

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Abstract: Desertification affects all parts of the ecosystem of arid regions and becomes the main reason for soil erosion, shortage of biological diversity, loss of productivity, loss of soil nutrition, and water shortage. The Saxaul forest (*Haloxylon ammodendron* (C.A.Mey.) Bunge ex Fenzl) covers 1650 km from west to east and 360 km from north to south in the southern part of Mongolia. In order to determine age group and survival, we involved 21 populations in 16 soums of 6 provinces (Khovd, Gobi-Altai, Uvurkhangai, Bayankhongor, Umnugobi, and Dornogobi) in Mongolia. We established a sample field of 30x30 m size and measured the height, diameter, and crown of all the tree trunks. The total number of the trees on the sample field is 2141 trees, the average height of the trees is 72.27±1.33 cm (max 480 cm; min 3.5 cm), the diameter is 3.6 cm (max 40.0 cm; min 0.1 cm), and crown diameter 86.85±1.55 cm (max 464.5 cm; min 3.0 cm), respectively. Tree height in the Saxaul forest population occupies 33.27% in the 40 cm class, 36.54% in the up to 80 cm, and 15.28% in the up to 120 cm class; the number of trees decreases and the percentage of the population reduces as the height class increases. As for the diameter class of the trees, it occupies 30.8% in up to 1cm class, 39.65% in up to 3cm, and 13.96% in up to 6 cm class. We calculated the survival by the tree ages: the percentage of loss is high for the cultivated and small trees but the loss reduces for the young trees and the survival has been stabilized. Therefore, it shows the necessity to plan the work of protecting the Saxaul forests.

Screening for drought tolerance of two high-value conifers in British Columbia, Canada

T3.29 Reforestation Under Drought Conditions

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Abstract: Western redcedar (Thuja plicata) and Douglas-fir (Pseudotsuga menziesii) are important commercial tree species used extensively in reforestation programs in western North-America where they provide a wide range of economic, social and ecological benefits. In addition, western redcedar is of particular importance to Indigenous cultures. Both species have benefitted from dedicated tree breeding programs established several decades ago. Ongoing concerns about climate change and the increased impact of more frequent and more intense drought events have led to renewed interest to identify seed sources that will be successful for reforestation under dry conditions. Two large scale studies, one for each species, were established to screen a large number of full-sib families for drought tolerance. Multidisciplinary research teams evaluated the performance of these families under drought conditions from a wide range of research angles: i) growth and survival; ii) biomass allocation and morphological characteristics; iii) physiological response and gene-expression; iv) nutrient translocation and soil characteristics. Authors present and discuss the main takeaways and lessons learned over the course of these studies, with particular emphasis on reforestation-drought interactions. Results will contribute to identifying seed sources with superior performance under drought conditions.

The application of nitric oxide-releasing chitosan nanoparticles as a nature-based solution to improve drought tolerance of neotropical tree seedlings

T3.29 Reforestation Under Drought Conditions

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Abstract: Approved in the 2019-2020 BiodivClim call from BiodivERsA, the RESTORE (natuRe-basEd SoluTions for imprOving REforestation) project aims at developing innovative biotechnological strategies to induce drought tolerance in tree seedlings used for reforestation purposes. Among the developed biotechnological tools, we are testing the inoculation with associative microorganisms isolated from forest sites and the application of nanoparticles synthesized from natural polymers as eco-friendly carrier systems for plant growth regulators. In this talk, we will focus mainly on nitric oxide (NO)-releasing nanoparticles, that have been shown to enhance the protective effects of this signaling molecule in plants submitted to abiotic stresses. We will show the results of a study that evaluated the effects of NO-releasing nanoparticles on drought-stressed *Cecropia pachystachya* Trécul seedlings, a pioneer neotropical tree largely used in reforestation efforts. S-nitrosoglutathione (GSNO) was encapsulated into chitosan nanoparticles, which protected this natural NO donor from premature degradation and extended its half-life. When applied to the substrate, nanoencapsulated GSNO delayed the appearance of wilting symptoms in seedlings exposed to moderate and severe drought conditions, yielding higher leaf water potential and relative water content compared to the other treatments (control, free GSNO and nanoparticles without NO). Gas exchange analyses showed that GSNO-loaded chitosan nanoparticles increased the stomatal conductance of drought-stressed plants, which allowed the maintenance of high CO_2 assimilation rates. This effect was mainly restricted to early morning, when the high air relative humidity prevents excessive loss of water. Moreover, nanoencapsulated GSNO had a positive effect on biomass accumulation in plants submitted to moderate drought. Overall, these results suggest that GSNO-loaded chitosan nanoparticles enhance the tolerance of *C. pachystachya* seedlings to moderate and severe water deficit. Experiments in the field and with other tree species are in progress to ratify if this nanoformulation could be applied as a strategy to produce tree seedlings more tolerant to drought stress, thus increasing the success of reforestation programs in a scenario of climate change.

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The influence of retention forestry on reforestation success following dieback of Norway spruce stands

T3.29 Reforestation Under Drought Conditions

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Abstract: The extremely dry and hot period between 2018 and 2020 caused massive bark beetle infestations and extensive dieback of Norway spruce stands in many European regions. Frequently, the lack of advance regeneration with tree species suitable for future climatic conditions necessitates artificial regeneration. Yet, owing to the increasingly extreme climatic conditions following complete salvaging of dead stands, the success rate of planting has often been very poor. Here, we aimed at investigating whether the retention of dead trees and other structural elements could mitigate microclimatic conditions for tree seedlings and thus improve their survival and growth.

For this purpose, we established a landscape-scale replicated experiment in the southern Black Forest to compare four treatments differing in retention levels/salvaging intensity: (1) complete removal of all dead trees, (2) retention of high stumps (2 m height) and slash piles, (3) partial harvest of two thirds of dead trees, and (4) no harvest. In all treatments we planted saplings of sessile oak, Norway maple and Douglas fir. To study the influence of different retention levels, we measure solar radiation, wind speed, temperature, precipitation, soil moisture and soil temperature as well as plant growth and mortality, photosynthetic rates, chlorophyll fluorescence, water potential, nutrient content and carbon allocation within the seedlings that were planted between autumn 2021 and spring 2022.

Following the hot and dry summer 2022, 17 % of the seedlings had died until the end of August. Mortality was higher for individuals planted next to stumps and high stumps compared to standing dead trees. Microclimatic conditions were most extreme for saplings planted on the southern side of dead trees and stumps with temperatures of up to 30° C even in October and fluctuations of up to 20° C within one day. At the northern side of trees and stumps and in circles of crown material, it was 10° C cooler on average. Data on growth performance of seedlings will be complemented with physiological analyses and measurements will be continued in 2023. Results of this project will contribute to the development of efficient and appropriate regeneration approaches following dieback of forest stands.

Tree diversity reduces uncertainty in sapling survival under drought

T3.29 Reforestation Under Drought Conditions

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Abstract: Current forest research recognizes the importance of tree diversity to foster resilience to climate extremes, such as drought. So far little attention has been given as to how tree diversity can generally reduce uncertainty in survival of young planted trees. We conducted a global analysis on sapling survival from 34 tree diversity experiments (363 167 trees, 168 species, 3744 plots, 7 biomes) to answer two questions: 1) Does drought and tree diversity alter the mean and variation in plot-level tree survival, with less uncertainty in survival as diversity increases? and 2) Do trait syndromes associated with drought resistance associate with higher species survival under non-drought conditions? First, we found a general reduction in variability of plot-level survival because mortality risk differs among species and is spread across them in more diverse stands (a "stock option effect"). This reduction in survival uncertainty was enhanced as drought severity increased, meaning that more diverse stands were less variable in survival compared to monocultures of the same species with increasing drought severity. Second, we found that xylem resistance to cavitation (P50) was a predictor of higher species survival independently of the drought conditions encountered by the species in this study. In addition, lower P50 (stronger drought resistance) was coordinated with traits of the leaf economic spectrum that are indicative of a conservative resource use, which may have contributed to higher survival. These results highlight: 1) The effectiveness of tree diversity as insurance for sapling survival under drought, and 2) stronger drought resistance confers to higher species survival in drought and non-drought conditions. From a management perspective, we advocate the mixing of tree species to reduce uncertainty in survival of planted trees and the addition of drought resistant species with conservative growth strategy in mixtures to increase survival of young planted forests.

What is the impact of repeated droughts on young trees and how do we inform future drought-resilient planting?

T3.29 Reforestation Under Drought Conditions

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Abstract: Precipitation patterns are shifting, changing our climate towards more frequent and intense climatological drought events. As a result, newly established forests will be exposed to higher and repeated water deficits, increasing their vulnerability. Although the impact of a single drought event on growth is well understood, it is still unknown what exposure to repeated droughts has on the recovery post-event and when recovery is inhibited on such a scale that becomes catastrophic, leading to mortality. In this study, we present the first results of a potted drought manipulation experiment, in which we expose six species (three commercial conifers and three broadleaves) in two drought severities (30% and 60% reduction in water input) and three duration (two, three and four weeks). We assess several leaf-level and soil traits to quantify the impact and recovery on photosynthesis and water uptake. We ask if there is full recovery to post-drought conditions or if there is acclimation to drought. Finally, using our knowledge, we present a new classification method of drought tolerance that will provide evidence-based guidance to underpin future planting with drought-resilient species.

T3.30 Research advances towards sustainability for the high-value Meliaceae

Boron fertilization on the growth of Khaya grandifoliola C. DC. seedlings in sandy and clay texture soils

T3.30 Research advances towards sustainability for the high-value Meliaceae

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Abstract: Planted forests have been widely used as an alternative to guarantee the preservation of native forests around the world. African mahogany (*Khaya grandifoliola* C. DC.) is a tree of African origin belonging to the botanical family Meliaceae. It has noble wood of great economic potential for internal and external trade and can be used in the furniture industry, shipbuilding, civil construction, panels, and laminates, among other uses. In Brazil, commercial plantations of the species have expanded, and studies are essential to obtain greater productivity and better adaptation of the species in the country. The objective of this work was to analyze the effect of the application of boron (B) sources and doses in clayey and sandy soils on the growth of *K. grandifoliola* seedlings. Two types of soil (clayey and sandy), two sources of boron with different solubilities, and four different doses were evaluated. The boron sources selected were: a) application of low solubility boron fertilizer (borogran®, 10% B); and b) application of high solubility boron fertilizer (granubor®, 15% B). The doses of each boron source tested were: a) 2.5 kg ha^{-1} of B; b) 5.0 kg ha-1 of B; c) 7.5 kg ha^{-1} of B; and d) 10.0 kg ha^{-1} of B. In the control treatment, there is no external source of B. The experiment was carried out in a 2 x 2 x 4 factorial, with four replications in a randomized block design, with the control as treatment additional. Every 30 days, during a period of 150 days, the height, diameter, and height/diameter ratio of the seedlings were measured. Regression equations for seedlings behavior in different treatments were estimated and data from the last evaluation were compared using Tukey's test at a 5% significance level. The results obtained allow to infer that the application of a high solubility boron source (borogran®) at a dose of 5kg.ha^{-1} in clayey soil enabled greater growth of *K. grandifoliola* seedlings. For sandy soils, the dose of 7.5 kg ha^{-1} of boron from the source (borogran®) is recommended.

Construction of core collection and phenotypic evaluation of Toona sinensis

T3.30 Research advances towards sustainability for the high-value Meliaceae

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Abstract: *Toona sinensis*, commonly called Chinese toon, is regarded as a valuable mahogany belonging to the genus of *Toona* in the Meliaceae. The young leaves of *T. sinensis* are edible woody vegetables that are deeply loved by the masses. In addition, the old leaves are important raw materials for silage feed and medicinal ingredients, with great economic value.The wood grain of *T. sinensis* is interlocked and the structure is fine, with a hard and slightly heavy texture that is easy to process. The longitudinal section is smooth and slightly glossy, with a uniform and consistent color. It is suitable for use as a material for beams, columns, doors, windows and other uses.

T. sinensis is widely distributed in eastern and southeastern Asia. An efficient mechanism for preserving and utilizing of germplasm resources is crucial for speeding up the process of genetic improvement of *T. sinensis*. We have collected a total of 1040 germplasm resources of *T. sinensis* from China, Britain and New Zealand. Using a total of 27,040 markers, we have analyzed the genetic diversity, genetic structure and core collection of these resources. Additionally, a comprehensive evaluation method for phenotypes of *T. sinensis* was established by principal component analysis (PCA) and the technique for order preference by similarity to ideal solution (TOPSIS). Our analysis included three main results: Firstly, the breeding population, consisting of a total of 1040 individuals, contains a diverse genetic pool and can be divided into two genetic clusters. Secondly, the best core collection was obtained from the alternative population, consisting of a total of 208 individuals and comprising 20% of the breeding population. It was screened out based on Core Hunter 3 software with the average entry-to-nearest-entry (E-NE) algorithm. Finally, a comprehensive evaluation method was established based on eight selected agronomic traits of the core collection. This method allowed us to screen out the best individual plants of the core collection, including N0237, N0972 and N0409. Overall, our research findings will enable better preservation and utilization of *T. sinensis* germplasm resources and result in faster improvement of *T. sinensis* varieties.

Early growth characteristics of native trees under mono and mixed plantation conditions: High potentials for Meliaceae and Combretaceae species

T3.30 Research advances towards sustainability for the high-value Meliaceae

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Abstract: In Africa, tropical forests have become highly degraded and are losing their productive and protective functions. There is an urgent need for an increase in tree plantation establishment to boost product supply and reduce pressure on natural forests. Pure and mixed indigenous plantations of high-value timber species from Meliaceae, Combretaceae, and other native species are being promoted as preferred sources of hardwood timber supply, carbon sequestration, and biodiversity conservation. However, limited information is available on the early growth characteristics, structural and management requirements of such plantations. This research is investigating the potential of plantation development of pure and mixed stands of species in the Meliaceae (*Khaya* spps), Combretaceae (*Terminalia*) and Malvaceae (Mansonia, Triplochiton) families. Pure and mixed species plots (50m by 50m) were established for *Mansonia altissima*, *Khaya ivorensis*, *Khaya superba*, *Khaya grandifoliola, Terminalia superba* and *Triplochiton scleroxylon* species, using 2m by 2m and 3m by 3m espacements. The survival rate, early growth characteristics, challenges, and prospects of plantation development were monitored. After 18 months, 68% survival was observed among species, while mean height and stem collar girth were 79.0±0.82cm and 5.6±0.08cm, respectively. High mortality occurred among the seedlings of *Mansonia altissima* and *Triplochiton scleroxylon*, particularly during the dry season. Factors such as increasing cost of site maintenance, pest attack, extended dry spells, insect attack, competition from weed and understorey vegetation; limited stand development, while silvicultural treatments such as spot and line weeding, site cleaning as well as mulching, promoted seedling establishment. High growth performance and early formation of canopy were observed for *Khaya senegalensis*, *Khaya ivorensis*, *Khaya grandifoliola and Terminalia superba*, under monoculture and mixed plantation conditions. The choice of species is critical to the successful establishment of native tree plantations. However, intensive monitoring and effective silvicultural management are essential for the successful establishment of indigenous tree plantations for productive and protective forestry.

Effects of fertilization on growth and physiological characteristics of Toona ciliata var. pubescens

T3.30 Research advances towards sustainability for the high-value Meliaceae

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Abstract: In order to explore the response of the precious tree species *Toona ciliate* var. *pubescens* to different amounts of fertilizers.In this paper, the young forest of *T. ciliate* var. *pubescens* was taken as the research object.A random block d young forest of *T. ciliate* var. *pubescens* , and three fertilization levels (high, medium and low) were set, including nitrogen fertilizer (N), phosphorus fertilizer (P), compound fertilizer (CF) and slow release fertilizer (SRF).The results show that: (1) fertilization could promote the height and DBH growth, and the effect of nitrogen fertilizer and compound fertilizer wasmore obvious.The average tree height, average DBH and average volume of 4-year old with nitrogen fertilizer increased by 15.0%, 21.9% and 67.5% compared with CK, respectively, and the annual average growth of DBH under low nitrogen (N1) treatment was the highest (2.99 cm).Compared with CK, the average tree height, average DBH and average volume of compound fertilizer were increased by 16.7%, 19.2% and 54.3%, respectively.High slow-release fertilizer (SRF3) and low phosphorus (P1) had the largest annual increases in tree height and DBH (1.96m and 2.33cm) in the 4th year, respectively.(2) Fertilization significantly increased chlorophyll content and non-structural carbohydrate content in leaves of *T. ciliate* var. *pubescens*, nitrogen fertilizer significantly promoted the synthesis of soluble sugar and phosphate fertilizer significantly promoted the synthesis of starch.(3)Low nitrogen (N1) and phosphate fertilizer promote the content of N and P, respectively, and P fertilizer, compound fertilizer and nitrogen fertilizer significantly increased K content in leaves.The principal component analysis showed that the effect of fertilizer to promote growth was nitrogen fertilizer > compound fertilizer > phosphorus fertilizer > slow-release fertilizer > control . Among them, low nitrogen (N1), i.e. 100 $g \cdot plant^{-1} \cdot year^{-1}$, had the highest comprehensive evaluation value.Comprehensive fertilization cost and benefit, nitrogen fertilizer or compound fertilizer can effectively promote the growth and development of *T. ciliate* var. *pubescens* young forest . It is recommended to apply 100 g nitrogen fertilizer per plant per year in young forest stage.The results can provide a reference for the forest nutrient management in the early stage of afforestation.

Electrical Resistance Tomograph (ERT): An innovative technique in estimation of heartwood content in standing trees of Swietenia macrophylla King

T3.30 Research advances towards sustainability for the high-value Meliaceae

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Abstract: *Swietenia macrophylla* King, also known as big-leaf mahogany, is a large deciduous tropical tree species native to Central and South America. *S. macrophylla* frequently reaching heights of over 20-30 m and diameter at breast height (DBH) of more than 1-1.5 m with an umbrella-shaped crown. *S. macrophylla* have been reported to grow in large plantations and also widely used for avenue planting in South India. Tree is gaining importance as a promising tree species for industrial plantations as well as for reforestation and afforestation. The ability to predict the growth and yield potential of *S. macrophylla* plantations is of considerable importance for planning plantation programmes. However, relatively very little reliable periodic stand measurement data are available. Added to this, information on heartwood development and estimation is totally lacking. Keeping this in view, tree tronic tomograms like Electrical Resistance Tomograph (ERT) was applied as a non-destructive method for advanced aiding for tree inspection to understand heartwood development and estimate in standing trees to predict the yield. In this study, we tested the validity of electrical resistance tomograph (ERT) to estimate heartwood diameter in big leaf mahogany by collecting core samples from fifty trees. The study revealed that the resistivity pattern in mahogany trees consisting of high resistivity in the inner part of the stem with lower resistivities on the outside. On an average resistance pattern of mahogany trees varies from 200 ohms to 943 ohms. The demarcation of SW-HW boundary was based on the distinct colour differentiation from blue (low resistance) to red (high resistance). A comparison between ERT and actual heartwood diameter shows a slope of the linear regression close to unity (0.90) with a narrow spread of values ($R^2 = 0.90$). Finally, by this study Electrical Resistance Tomography proved to be a significant predictor of heartwood diameter in standing trees of mahogany trees.

Keywords: Mahogany, Electrical Resistivity Tomography, Heartwood, Resistance pattern, Core sample

In situ genetic conservation: Mahogany and Spanish cedar in the Yucatan Peninsula as a possible test case

T3.30 Research advances towards sustainability for the high-value Meliaceae

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Abstract: As deforestation continues, more tree species become endangered, along with their genetic variation. Approaches to genetic resource conservation include *ex situ* plantings (away from the sites of origin) and in situ forest stands. We explore the viability of *in situ* conservation, using big-leaf mahogany (*Swietenia macrophylla*) and Spanish cedar (*Cedrela odorata*) in the Yucatan, Mexico, as a test case.

Various *ex situ* plantings have been made of germplasm for both Spanish cedar and big-leaf mahogany in the Yucatan peninsula, but these plantings are susceptible to maintenance problems, fire, hurricanes, disease, and local development. Other options must be considered. Most forest land in the Yucatan peninsula (and in all of Mexico) is held by communities (ejidos). *In situ* conservation of designated seed trees in community forest reserves might be a more practical solution. Stands can be replicated in different ejidos, reducing overall vulnerability to loss.

Several factors in Mexico may facilitate *in situ* conservation. 1) Mexican forest law and regulations create a legal framework for both *in situ* and *ex situ* conservation. 2) At least some of these forest ejidos have reserves set aside within their property. Forest inventories in ejidos also provide information on the presence of these species in different locations. 3) There may be sufficient interest in ejido communities to maintain their forests. We will explore how these factors may enhance the viability of *in situ* conservation for these species in the Yucatan, and present a draft plan for consideration. We also consider how this case may apply to species under threat in other places.

T3.31 The impact of introgressive hybridization on adaptive capacity of forest trees in the Anthropocene

Consequences of diversity in the white oak syngameon for functional variation, adaptation and symbiont biodiversity

T3.31 The impact of introgressive hybridization on adaptive capacity of forest trees in the Anthropocene

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Abstract: Organisms exist as part of dynamic, flexible, and evolving ecosystems, with multiple interacting levels of biodiversity. Genetic and functional variation in one species influences and is influenced by variation in sympatric species, often at different trophic levels. This complexity is magnified by introgression, which moves adaptive alleles among phylogenetic lineages, shaping community assembly and species interactions. This talk presents a project investigating a suite of closely coordinated studies on two continents, jointly funded by US and Chinese research teams with complementary skills in phylogenomics, ecophysiology, fungal and insect taxonomy and ecology, to investigate the genomic, functional, and phylogenetic diversity of oak trees and the ectomycorrhizae, endophytic (leaf) fungi, and gall wasps that associate with them. The project objectives are:

Objective 1. Reconstruct the genomic mosaic of differentiation and introgression in the white oak syngameon across the range of focal oak species and co-occurring white oak species and characterize geographic patterns of (i) leaf functional and phenotypic variation in oaks and (ii) the functional and phylogenetic diversity of mycorrhizal fungi, leaf endophytic fungi, and gall wasps associated with focal oak species.

Objective 2. Evaluate the effects of genetic diversity and differentiation among populations within focal host species, across a climatic gradient, on (i) oaks' relative fitness and functional traits, and (ii) phylogenetic and functional diversity of their fungal and insect communities.

Objective 3. Assess the effects of forest community phylogenetic diversity on the phylogenetic and functional diversity of oak fungal and insect communities.

In this presentation, we will present preliminary findings from the eastern North American white oak syngameon centered around *Quercus macrocarpa* (bur oak) based on genome-wide SNP data. We

present estimates of introgression between *Q. macrocarpa* and several widespread sympatric white oaks, including *Q. alba*, *Q. bicolor*, *Q. muehlenbergii*, and *Q. stellata*. In addition, we will present preliminary findings on the relationship between leaf endophytic fungal communities and oak genetic and phylogenetic diversity.

EXPLORING CYTONUCLEAR INTERACTIONS AND THEIR PHENOTYPIC OUTCOMES IN A POPLAR HYBRID ZONE

T3.31 The impact of introgressive hybridization on adaptive capacity of forest trees in the Anthropocene

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Abstract: The interaction between nuclear and cytoplasmic genomes, which includes chloroplast and mitochondrial genomes, is crucial for maintaining essential functions in plant species. The maintenance of these functions largely depends on the coevolution of cytoplasmic genes with co-functioning nuclear genes, including mitochondrial-nuclear (mt-N) and chloroplast-nuclear genes (cp-N). Thus, cytonuclear interactions, or the interplay between mt-N/cp-N genes with cytoplasmic genes, have likely coevolved at the species level. However, when interspecific hybridization occurs, it can affect the co-evolved cytonuclear interactions and have consequences for phenotypic trait variation, which is important for adaptation. *Populus* trees are an excellent model for studying cytonuclear interactions because they have weak reproductive barriers and extensive hybridization in nature. In this study, we utilized whole genome resequencing data of 576 *Populus* trees from a hybrid zone between *Populus trichocarpa* and *P. balsamifera*, spanning seven latitudinal transects. We used genotypes sourced from across the hybrid zone transplanted to three replicated common garden environments to investigate the contribution of cytonuclear interactions to phenotypic variability in novel environments. We estimated admixture proportions from nuclear data and assigned chloroplast identity using phylogenetic analyses. Initially, we examined the impact of climate on changes in ancestry for nuclear genes, cp-N genes, and chloroplast genes across the hybrid zone. Preliminary analysis of clinal variation showed similar patterns across the gene groups, but different centers and widths of clines, suggesting that fine-scale selection might influence cytonuclear interactions in the hybrid zone. Through our common garden experiments, we evaluated the role of cytonuclear interactions in phenotypic traits relevant to adaptation. Our findings indicate that chlorophyll content is influenced by varying cytonuclear interactions. These results highlight the importance of thoroughly evaluating the role of cytonuclear interactions in hybridizing species to understand how these interactions can affect phenotypic outcomes, which are crucial for predicting fitness in novel environments.

Ficus Hybridization and Enhancing Adaptive Capacity of Tropical Forests

T3.31 The impact of introgressive hybridization on adaptive capacity of forest trees in the Anthropocene

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Abstract: Tropical rainforests are the most ecologically diverse and complex terrestrial ecosystems, and their preservation and adaptation to rapid environmental change in the Anthropocene is crucial for the health and development of both natural ecosystems and human societies. *Ficus* plants is one of the largest genera of woody plants, with over 800 species distributed throughout the tropics. *Ficus* plants maintain highly specialized pollination relationships with their specific fig wasp pollinators through their unique enclosed inflorescences (figs) and species-specific figs volatiles. This supports thousands of pollinating and non-pollinating fig wasps, arthropods, and over a thousand species of vertebrate frugivorous animals, making the *Ficus* plants become a keystone group in many tropical rainforests. Understanding the mechanisms behind the formation, maintenance, and future adaptation of the extremely high species diversity and complex ecological relationships of the *Ficus* plants is importance for the stability and adaptation of tropical rainforest ecosystems in the Anthropocene.

Here, I will introduce the latest research progress on the fig-fig wasp co-diversification via plant-pollinator coevolution and plant hybridization. By revealing the patterns and mechanisms of introgressive hybridization of *Ficus* plants, as well as their impact on the speciation and key trait evolution of both fig trees and fig wasps, I propose a concept of "species community with a shared future", in which sympatric species responding to the environment changing as a whole system via the ecological networks and genetic exchange networks among them, and this may supply an overall package protection strategy to enhance the adaptive capacity in community level.

Genetic consequences of hybridization between oak species

T3.31 The impact of introgressive hybridization on adaptive capacity of forest trees in the Anthropocene

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Abstract: Hybridization is common between modern oak species and presumably occurred among their ancestral lineages. To investigate the deep history and genetic consequence of hybridization in oak species, we used phylogenomic analyses of nuclear and plastid genomes to detect signatures of hybridization across the Fagaceae. We showed that introgression resulted from historical hybridization events between ancestral species representing three oak sections, *Ponticae*, *Quercus* and *Virentes*. Identity-by-descent (IBD) analyses based on whole-genome SNP data clearly detected a large number of shared haplotypes between these sections. These shared haplotypes apparently originated during hybridization, and most of them are significantly longer than expected under neutrality. These results suggested that shared haplotypes were maintained by natural selection, providing convincing evidence for the persistence of adaptive introgression. Current hybridization also may provide an additional genetic pathway for species to repeatedly adapt to similar environments via molecular parallelism. To test this hypothesis, we studied a pair of sympatrically distributed East Asian oak species, *Q. variabilis* and *Q. acutissima*. Population genomic analyses revealed an east-west divergence within *Q. variabilis*, and detected a ~270kb region showing a strong signal of selection. This region contains 20 genes, including 10 members of ethylene-responsive factor (ERF) family, which are involved in the response to abiotic stress. To investigate the origin of advantageous variation in this region within *Q. variabilis*, we first performed forward simulations to reject models of selection acting on *de novo* mutations or standing variation. Next, a battery of tests including phylogenetic analysis, efficient local ancestry inference, and gene flow analysis revealed multiple lines of evidence supporting beneficial alleles in this region originated through introgression from *Q. acutissima* into *Q. variabilis*. Finally, we found that the same ~270 kb region was under selection in *Q. acutissima*, suggesting that adaptive introgression has contributed to molecular parallelism in repeated climate adaptation in oaks. These studies underscore the importance of hybridization in the evolution of oak species across time scales.

Genomic evidence for extensive introgression among oaks and assessment of mal-adaptation

T3.31 The impact of introgressive hybridization on adaptive capacity of forest trees in the Anthropocene

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Abstract: The two native species of oak in Britain, (Quercus robur L and Q. petraea (Matt) Liebl.) are resilient keystone species, supporting over 2000 macro species, and are a major feature of the British landscape, economic history and culture. Many observations suggest Q. petraea is found mostly in the north and west and Q. robur in the south and east, with slightly different environmental preferences, although the species are often sympatric and can hybridise. Hybrids are hard to identify based on morphology.

Here, we report whole genome re-sequenced data from 418 oak trees sampled at 60 sites across England, Wales and Scotland. These sites were previously part of a long-term forest condition survey. We used genomic methods to allocate trees to species, and identify hybrids and introgression. We found large numbers of hybrids and extensive of introgression of Q. robur alleles into Q. petraea genomes. None of our sampled individuals from Scotland were pure Q. robur. Within each species we found little genomic population structure.

To seek evidence for genetic adaptation to local environments, we used latent factor mixed methods models to identify associations between allele frequencies and nineteenth century climate parameters. We used genetic offset methods to assess potential future mal-adaptation within a changing climate.

The resilience of UK oaks may be partly due to dynamic exchange of alleles between two species with slightly different niches. Adaptation to future climates may involve co-planting of the two species and changes to a “local is best” seed sourcing policy

Interspecific hybridization of tropical rainforest trees in Southeast Asia

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Abstract: Interspecific hybridization is occasionally common in tropical rainforest family, Dipterocarpaceae. Previous studies have shown that there is a species possibly derived through hybridization, suggesting the importance of hybridization in species divergence. We studied the possibility of hybridization between closely related species in *Shorea*, the largest genus in Dipterocarpaceae and found that interspecific hybridization is not uncommon in a small isolated tropical rainforest in Singapore. In the forest, *Shorea curtisii* is the most abundant species, while ecologically divergent species such as *S. leprosula* and *S. parvifolia* also occur at lower densities. Field observations and DNA analysis revealed that hybridization between *S. curtisii* and *S. leprosula* is relatively common, while the hybridization between other species is less so. Phenological observation in 2009 indicated that the flowering times of *S. curtisii* and *S. leprosula* were nearly identical, and that the hybrid trees were fertile, implying that the strength of pre-zygotic isolation is weak between these species. To test whether the hybrids are maladaptive, we monitored growth of seedlings in nature and found that survivorship and growth of the hybrid seedlings are equivalent or even higher than the "pure" species. This implies that post-zygotic isolation is not complete and successive introgression may enhance the consolidation of distinct gene pools of two species. We also found the hybrid individuals from other coastal hill dipterocarp forests, or hill dipterocarp forests with human disturbance where two species coexist, indicating the hybrids may be considerably widespread. Other than *Shorea*, hybrids are also present between ecologically distinct species of *Dyera* (Apocynaceae). The hybrids of Swamp Jelutung (*D. polyphylla*) with Hill Jelutung (*D. costulata*) are occur at the damaged peatlands. Together these results suggest that hybridization and introgression are likely to occur in Southeast Asian tropical rainforest species, mediated by damage from natural and human disturbances.

Introgressive hybridization is a major source of diversification and helps maintain adaptive capacity

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Abstract: The Anthropocene is driving rapid environmental change in many different ways, both local and global. The rate of change is substantially greater than most living organisms on Earth have experienced for many millions of years. The emerging environments of the future will also be novel combinations of abiotic and biotic conditions, suggesting that overall fitness of currently existing diversity will decline during the Anthropocene. How will organisms, particularly those with great longevity, generate functional diversity in order to adapt in the future? The creation of novel and adaptive functional traits through endogenous mutation seems unlikely to be sufficient, given its slow pace. Introgressive hybridization has played an important role in the diversification of many lineages, plant and animal and seems to be particularly associated with deep major bifurcations and innovations in the Tree of Life. This introgression process may be the best source of functional diversity available, particularly for trees and other long-lived organisms. Here, I explore the role that introgressive hybridization plays in a syngameon, given different scenarios of environmental change, in the maintenance of functional diversity. Statistical modeling suggests that the syngameon is particularly stable as advantageous traits can diffuse through the network rapidly corresponding to its fitness. The interconnectedness of the species creates a wide range of phenotypes more quickly than pairwise or isolated species. I would argue that an important step in anticipating the upcoming biodiversity bottleneck would be to enhance introgressive hybridization among interfertile species. Diversify first and allow natural selection to choose the winners from a much broader and deeper candidate pool of phenotypes. I discuss potential experiments that could be installed to examine the underlying nature of introgressive hybridization and generate novel phenotypes for trialing.

Phenotypic and genomic studies of two California sympatric oak species show compelling evidence of adaptive hybridization and introgression

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Abstract: Oaks are notoriously promiscuous, but why. Introgression has rarely jeopardized the species identities across this diverse genus despite their frequent hybridization with other oaks and pervasive, yet not indiscriminate, ancient interspecific gene exchange. These observations beg the question whether hybridization is just the outcome of weak reproductive isolating mechanisms among species that allow limited exchange of neutral genetic variation. Alternatively, does it allow the introduction of beneficial genetic variants that enhance the fitness of hybrids and subsequent backcrossed generations? In this talk, we will examine hybridization and introgression between two distantly related oak species found sympatrically in southern California USA across a range of environments—the California endemic shrub oak, *Quercus berberidifolia*, and the non-endemic tree oak, *Quercus engelmannii*. This study system is ideal because strong interspecific phenotypic differences make putative hybrids easy to identify and a long divergence time of 35-40 million years makes it less problematic to detect interspecific DNA sequences. To test the adaptive introgression hypothesis, we will describe evidence from four studies. First, as proof of ongoing hybridization, we will describe phenotypic and genetic analyses of putatively “pure” and “hybrid” individuals to identify their species’ assignment and degree of admixture. Second, we will analyze transcriptomes to show that drought-associated functional genes are enriched in hybrid individuals. Third, we will use single nucleotide polymorphisms (SNPs) from reduced library sequences to test whether historical gene flow is asymmetrically favoring gene flow from the endemic into non-endemic oak, as one might predict if the endemic oak is more adapted to California Mediterranean-type climate than the non-endemic species. Finally, we will provide direct evidence in support of the adaptive introgression hypothesis using whole genome sequence data for 33 *Q. berberidifolia* and 31 *Q. engelmannii* individuals. Within the genomes of *Q. engelmannii* individuals, we find 24 unique introgressed regions containing 32 well-annotated functional genes, including several genes associated with biotic stress and pathogen resistance. We conclude that *Q. engelmannii*, the non-endemic oak, has benefitted historically from selective introgression from the endemic shrub oak and that the presence of on-going hybridization may be key to its ability to adapt to future climate conditions.

Predicting fitness under future climates across Populus trees from a natural hybrid zone

T3.31 The impact of introgressive hybridization on adaptive capacity of forest trees in the Anthropocene

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Abstract: If tree populations are unable to adapt to changing climates, migrate to suitable climates, or survive changes through phenotypic plasticity, they will become extirpated without human intervention. Populations may be able to adapt to new climates relatively rapidly when standing genetic variation that increases fitness under new environments is already present. One mechanism that can introduce new genetic variation is interspecific hybridization. Forest trees often form natural hybrid zones and experience adaptive introgression, in which beneficial genetic variants are introduced from one species to another. In fact, hybrid individuals may have higher fitness in novel environments compared to their parental species, which are adapted to a particular environmental niche. These natural hybrid zones can be used to understand the fitness effects of hybridization and to inform management of tree populations under climate change. We have established 15 common gardens with *Populus* genotypes collected from multiple latitudinal transects spanning the natural hybrid zone of *Populus trichocarpa* and *P. balsamifera*. Replicated genotypes were planted into each common garden site, enabling us to model the relationship between climate and phenotype and identify the climate under which each genotype accumulated the greatest growth, a proxy for fitness in forest trees. We test which genotypes have the highest overall growth and which grow well across a wide range of environments. Populations may experience a trade-off between the maximum rate of growth and the ability to grow well across a wide range of environments, i.e. between generalist and specialist strategies. We predict that "specialist" genotypes that are strongly locally adapted and able to outcompete foreign genotypes in a home environment will have lower fitness in non-home environments when compared to "generalist" genotypes, which are well-adapted to a wider range of environments. Furthermore, we predict that *Populus* hybrids will exhibit a more "generalist" strategy than parental genotypes due to their novel genomic architecture, and thus will be pre-adapted to the novel environments expected under climate change. Our results can be used to determine the best strategies for planting *Populus* into restored or managed stands while taking into account future climate and the uncertainties in its prediction.

Sequential hybridization facilitated ecological transitions in the Southwestern pinyon pine syngameon

T3.31 The impact of introgressive hybridization on adaptive capacity of forest trees in the Anthropocene

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Abstract: The evolutionary importance and prevalence of multispecies interbreeding networks, or syngameons, have been increasingly reported in natural systems. However, the formation, structure, and maintenance of syngameons have received little attention. Through gene flow, syngameons can increase genetic diversity, facilitate the colonization of new environments, and contribute to hybrid speciation. In this study, we evaluated the history, patterns, and consequences of hybridization in a pinyon pine syngameon using morphological and genomic data to assess genetic structure, demographic history, and geographic and climatic data to determine niche differentiation. We demonstrated that *Pinus edulis*, a dominant species in the Southwestern US and a barometer of climate change, is a core participant in the syngameon, involved in the formation of two drought-adapted hybrid lineages including the parapatric and taxonomically controversial *fallax*-type and the allopatric *P. californiarum*. This is the first study documenting sequential hybridization events in natural systems, in which a novel independent lineage resulting from gene flow (*P. californiarum*) hybridized with one of its parents to create a second novel lineage (*fallax*-type). Overall, we found that species remain morphologically and genetically distinct at range cores, maintaining species boundaries while undergoing extensive gene flow in areas of sympatry at range peripheries. The recognition of *P. californiarum* as a species has conservation implications as it has a narrow and scattered distribution divided by the US-Mexican border. Our study shows that sequential hybridization may have caused relatively rapid speciation and facilitated the colonization of different niches, resulting in the rapid formation of two new lineages. Participation in the syngameon may allow adaptive traits to be introgressed across species barriers and provide the changes needed to survive future climate scenarios.

Unraveling the effects of introgression on local adaptation in red spruce (Picea rubens Sarg.): Genetic rescue and shaping of adaptive traits

T3.31 The impact of introgressive hybridization on adaptive capacity of forest trees in the Anthropocene

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Abstract: Introgression, the transfer of genetic material between species through hybridization, can significantly influence the patterns of local adaptation in forest trees. Introgression can act as a type of "genetic rescue" for ecologically important species by introducing adaptive genetic variance for selection to act upon. Red spruce (*Picea rubens* Sarg.), a climate-sensitive coniferous tree with a distribution along the eastern coast of North America, is known to hybridize with its sister species, black spruce (*Picea mariana*). Red spruce suffers from very low genetic diversity and N_e; thus we aimed to unravel the possible contribution of introgression on local adaptation in red spruce by utilizing large-scale genomic data and phenotypic traits.

Traditionally, testing for local adaptation has relied on reciprocal transplant experiments involving a pair of "home" and "away" populations planted in both sources' environments. However, this approach becomes complicated when investigating more than two populations and fails to consider the complexities arising from demographic history and population structure. To overcome these limitations, we employ a novel version of the Q_{ST}-F_{ST} test called Q_{PC} analysis, wherein genomic data is used to infer population structure and genomic relatedness to estimate additive genetic variance in phenotypic traits. We used Q_{PC} to test for local adaptation in trait means and their plasticities, using measurements of growth, phenology, and physiology on >5,000 trees in three common gardens established along a latitudinal gradient across the species range.

The results indicate that while some traits such as phenology show local adaptation along a latitudinal climate gradient, most of the selection on adaptive growth, phenology, and physiological traits was driven by introgression between red and black spruce. The influx of genetic variance from black spruce introgression resulted in admixed genotypes with early flushing buds, increased water use efficiency (WUE), height growth and biomass production. These results suggest that for genetically depauperate species like red spruce, past introgression served as a major source of genetic variation that selection acted upon to shape locally adaptive traits. These admixed genotypes hold the potential for improving the chances of successful establishment and long-term survival of red spruce in current and new ecological niches.

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

A long term study reveals that restoration guided by an umbrella species, the white –backed woodpecker, does not reach target levels.

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract:

1. Maintaining structural and functional elements of ecosystems are essential in order to preserve biodiversity and ecosystem function. As a means of streamlining conservation work, the umbrella species concept was developed. In Sweden, the putative umbrella species the white-backed woodpecker has guided conservation and restoration of deciduous forests for two decades.
2. Here, we evaluate the decadal effects of restoration aimed at the white-backed woodpecker on biological diversity patterns of saproxylic beetles. We compare stands that were restored ten to twenty years ago to non-restored stands and historical white-backed woodpecker habitats acting as restoration target stands.
3. Deciduous deadwood volumes were greater in restored stands than non-restored stands but less than restoration target stands. Deadwood in restored stands was also concentrated to later decay stages whereas target stand deadwood was more evenly spread across decay stages.
4. We found that restored stands show similar levels of species richness and abundance of most groups of saproxylic beetles to that of non-restored stands while not reaching the same levels as the restoration target stands. Species assemblages were different in restored stands compared to non-restored stands but also compared to restoration target stands. Indicator species in restored stands were mainly generalist species whereas indicator species in target stands where deciduous specialists.
5. *Synthesis and applications:* We conclude that now, after one to two decades, initial restoration effects found in a previous study are mostly gone, and restoration has not managed to mimic diversity patterns found in restoration target habitats. We stress that continuous restoration is needed by either revisiting the same stands or restoring adjacent stands in the surrounding landscape every ten to twenty years. Our results stress the importance of identifying a target level when assessing restoration outcome.

Age is not paramount for ground cover vegetation in ageing hemiboreal Scots pine and Norway spruce stands

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Intensifying forest management and reduction of rotation period necessitates intensive conservation strategies, such as the triad concept, under which connectivity of biodiversity hot-spots and reserves is facilitated by specific extensive management. Mostly, biological value of a stand has been associated to stand age, although stand properties, which are often intercorrelated with age, might be of the primary importance. Hence, disentangling of the effects of age and structure on biological diversity of a stand is a precondition for the specific management of the ecological network and connectivity of intensively managed forest landscape. The relationships between ground cover vegetation (vascular, woody, bryophyte), which is a principal component and often used as indicator of biodiversity, and stand properties were assessed in pre-harvesting/harvesting age and two-times older old-growth coniferous stand in the eastern Baltic region (Latvia). Stands corresponding to mesotrophic site conditions, dominated by Scots pine and Norway spruce were surveyed. Both stand groups showed generally similar ground cover flora, with 18–23 species per stand. Though ground cover vegetation showed higher variability in the old growth stands, which favoured species with lower occurrence. The principal gradients of ground cover vegetation were related to light, site fertility and structural components such as standing stock and canopy composition (degree of deciduous, particularly *Betula* spp.). Considering the explicit contrasts, stand age did not affect ground cover vegetation, implying principal effects of stand structure, which are manageable properties. The relationship between ground cover vegetation and stand structure implies that currently applied rotation period of ca. 70–110 appears efficient for ground cover vegetation to reach a stable stage. Accordingly, conservative management strategy regarding rotation period while facilitating compositional and structural diversity of stands appears efficient for areas crucial for connectivity under the intensive triad conservation concept, aiding sustainability and multifunctionality of forests.

Can tree-related microhabitats solve the trade-offs between beetle biodiversity conservation and timber production in managed forests?

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: The Mediterranean forests are known as among the richest biodiverse forest ecosystems due to their environmental heterogeneity. Human pressure and climate change are the main threats to these ecosystems compromising their functions. For this reason, ensuring the multifunctionality of forests is the greatest challenge for forest managers. Although the establishment of protected areas helps to halt the loss of biodiversity, the release of certain structures, such as tree-related microhabitats (TreMs), habitat trees, and deadwood, in regularly managed forests could help to preserve many species of vertebrates and invertebrates, such as birds, amphibian or insects, and despite human action. Knowing and analysing the relationships between these structures and different taxa is essential to balance seemingly conflicting ecosystem services and to integrate biodiversity conservation and timber production, also in managed forests. This study aims to analyse the existing relationships between beetles, especially saproxylic beetles, and TreMs in a managed forest, to understand how and how much these structures impact beetle communities. The study was conducted in a regularly managed pure beech forest in the Apennine mountains of central Italy. The influence of environmental factors, forest structure, and biodiversity-related parameters on the abundance and richness of beetles and saproxylic beetles was assessed. Results, showed the key role of TreMs as predictors of beetle abundance and richness, demonstrating for the first time the one-to-one association between individual TreMs types and saproxylic specimens. The study emphasises the importance of TreMs as proxies for the maintenance and enhancement of beetle biodiversity. Furthermore, the relationships observed can guide silvicultural interventions, allowing foresters to better choose the habitat trees to release, to promote biodiversity without renouncing timber production.

Characteristics of tree microhabitats in commercially managed forests in Lithuania

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Tree related microhabitats (TrM) are recognized as important substrates and structures for biodiversity in forests. The aim of study was to evaluate microhabitats in intensively managed forests, provide protection recommendations and long term biodiversity monitoring. In total we surveyed 132 study plots (500m^2) and evaluated 3.4 thou. trees in 11 regions of Lithuania. We aimed to analyse TrM in pedunculate oak, Scotch pine, Norway spruce, Birches, black alder, Eurasian aspen, Norway maple and linden stands.

On average we observed 6.27 TrM in one study plot. Higher density observed in black alder (15.7 TrM/plot) and oak, aspen, linden stands (5.9-7.7 TrM/plot). Birch stands had less (4.9 TrM/plot), however coniferous stands (1.7-2.4 TrM/plot) the least density. Most of the trees with TrM contained one (18.8%), two and more microhabitats had 4.4% of trees. The diameter of tree had significant effect of TrM appearance (χ^2=284; p<0.00001). When the diameter of tree was 30cm, probability of TrM occurrence was 0.2. However, the probabilities reach 0.5 and 0.8 with the increase of diameter up to 55cm and 85cm. On average, the diameter of the trees with one TrM was 35cm, two – 50cm, three – 58cm, four – 75cm, five – 85cm, six – 88 cm.

We found TrM on 23.3% mature for felling trees. Highest proportion were evaluated on pedunculate oak (51.1%), dominated crown deadwood (31.2TrM/100tree) and epiphytes (15.04TrM/100 tree); Norway maples (43.2%) - epiphytes (30.53 TrM/100 tree) and cavities (CV-10.31 TrM/100 tree); and black alder (43.4%) - root buttress cavities (31.76 TrM/100 tree). Less TrM were on Eurasian aspen (26.8%), mostly often observed epiphytes (19.08 TrM/100 tree); birch (21.2%) - stem deformations (10.1 TrM/100 tree); and linden (15.4%) - epiphytes (7.02 TrM/100 tree). However, Norway spruce and Scotch pine related with least proportion of TrM (respectively – 8.0 and 8.6%), dominated stem deformations (3.33 TrM/100 tree), injuries and wounds (2.85 TrM/100 tree); as well as bark (1.77 TrM/100 tree) and injuries and wounds (3.28 TrM/100 tree) respectively.

Trees with two and more TrM should be protected during felling's. Mostly valuable trunk cavities, old bark loss, coarse bark, large dead branches, epiphytes should be prioritized. Diversity of TrM should be sustained during management.

Does retention forestry help conserve biodiversity in the boreal forest?

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Retention harvesting has become a prominent practice under the paradigm of ecosystem-based, or disturbance-based, forest management. A central aim is to conserve biodiversity, or to facilitate recovery of biodiversity towards that of unmanaged forests. The EMEND (Ecosystem Management Emulating Natural Disturbance) project, located in north-western Alberta, Canada, includes five levels of dispersed green-tree retention (clearcut, 10%, 20%, 50%, 75% retention) plus unharvested reference stands replicated in four different boreal mixedwood forest types (deciduous (broadleaf)-dominated (DDOM), deciduous-dominated with conifer understory (DDOMU), mixed deciduous-coniferous (MIX), conifer-dominated (CDOM)). There were three replicate, 10 ha, compartments per forest type per treatment. The experiment was established in 1998 and abundance and composition of various biotic groups has been monitored regularly in permanent sample plots ever since. We used generalized additive mixed models (GAMMs) to characterized the temporal pattern of community similarity (Chao-Jaccard Index) between post-harvest stands and unharvested reference stands for up to 17 years post-harvest, for: songbirds, bryophytes, carabid beetles, spiders (Linyphiidae, Lycosidae, and other spiders, separately), Staphylinid beetles, and vascular understory plants. We compared this to the average similarity among reference compartments sampled in a given year and defined “recovery” as the time period at which the lower confidence interval of that similarity intersected with the recovery curve (GAMM smoother). We found that recovery trajectories varied among biotic groups and forest types. Still, many biotic groups had recovered within 12 – 17 years post-harvest, even in clearcuts; that is, their compositional similarity to unharvested reference forest was equivalent to that between unharvested reference compartments. There were notable exceptions: bryophytes, carabid beetles and Linyphiidae and other spiders, and understory vascular plants showed poorer resistance or resilience following harvesting than did other biotic groups. Further, recovery tended to be poorer / slower in forests with a conifer component (CDOM, MX, DDOMU) than for the deciduous-dominated forest type. There was some evidence that higher levels of retention harvesting better conserved biodiversity or facilitated faster post-harvest recovery than did clear-cutting, but a longer time period is needed for further clarity on any such effects.

ECONOMIC VALUATION OF PRIORITY AREAS FOR THE CONSERVATION OF PLANT DIVERSITY IN A CLOUD FOREST IN CENTRAL MEXICO

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Biodiversity is a natural resource that can be evaluated under a monetary metric to establish a framework for environmental management. The cloud forest shelters a high species richness and is one of the most threatened systems. The objective of this study was to estimate the use and non-use values of the flora diversity in priority areas for conservation in a cloud forest and map its value. To estimate the use value, we obtained information about useful plants and their market prices or wasted time in their recollection. The choice experiment method was used to calculate the non-used values of species richness, biomass, and accessibility. To project spatially these values, we classified the area covered by cloud forest and qualified its conservation condition. We proposed an Index of Importance for Biological Conservation (InICoB), based on quantitative indicators of the composition and structure of the vegetation such as life forms, the presence of endemic, climax, native, and protected species, diversity, structural complexity, and complementarity that can be applied to any plant community and are easy to interpret. The use value was higher in areas with preserved cloud forest because it contains a greater number of species, more used resources, and a greater density of large trees, which contribute significantly to the economic value. The non-use value of species diversity was the highest, and people showed a greater concern for the conservation of biodiversity. However, the value of plant diversity also depends on its accessibility. Closer sites with soft slopes, although having medium biological quality, have a high total value. We projected these values on a spatial scale, and the classification carried out with the InICoB adequately evaluated the different environmental units. Knowing spatially the total economic value of ecosystems is a valuable tool in land use planning and decision-making.

Effect of retention forestry on biodiversity conservation in planted forests in Hokkaido, Japan

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Natural forests in Hokkaido, northern Japan, are dominated by mixed stands of evergreen coniferous and deciduous broad-leaved trees. The forest floor is typically covered with dwarf bamboo, *Sasa* spp., which prevents natural tree regeneration, in turn, resulting in the degradation of natural forests by selective cutting. Since the 2000s, most timber has been harvested from planted forests with even-aged coniferous stands. Therefore, retention forestry is considered an effective approach to conserving biodiversity in Hokkaido. This study conducted a retention forestry experiment in planted forests with native conifer species, *Abies sachalinensis*, to determine the effectiveness of conserving biodiversity. We established aggregated retention (60 × 60 m was retained), dispersed retention (10, 50, and 100 broad-leaved trees/ha were retained), clear-cut, and unharvested sites during the 2014–2016 period and monitored understory plants, birds, and ground beetles. Planted forests provided habitats for numerous understory plants before logging compared to the adjacent broad-leaved forests, where the forest floor was dominated by *Sasa* spp. The forest floor was disturbed by logging, site preparation, and weeding to grow the planted seedlings. Disturbed sites were invaded by ruderal plants, whereas undisturbed areas in aggregated retention sites provided refuge for forest understory plants. Forest species of ground beetles were least abundant in clear-cut sites, but their abundance increased with the level of dispersed tree retention; aggregated retention sites also functioned as refuges for ground beetles. A low level of dispersed retention mitigated the negative impacts of logging on forest bird abundance, whereas aggregated retention did not have similar effects. Overall, effective retention methods that depend on the target organisms and a combination of aggregated and dispersed retention are desirable.

Enhancing Biodiversity Conservation through Multi-Taxon Approaches: Insights from Longitudinal Studies

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Biodiversity loss, mass extinction, and ecosystem collapse are central concerns in contemporary literature on biodiversity conservation. While numerous studies focus on the impacts of land-use and land-use changes on individual organism groups, there is a growing need to extend conclusions to broader biodiversity and ecosystem levels. Over the past few decades, our research team has conducted several studies revealing distinct responses among organism groups to environmental changes. Our findings emphasize the potential risks associated with solely examining a single organism group, as it may overlook substantial inter-taxon variations and lead to contrasting conclusions regarding the effects of environmental changes on biodiversity aspects.

For instance, our investigations demonstrate that commercial thinning operations favor many lichen species while negatively impacting numerous bird species when understory spruce is removed. Additionally, we have observed that moss species richness on stumps is higher when the stumps are lower, whereas lichen species richness exhibits an inverse relationship. Had we solely focused on one organism group in each study, our conclusions would have varied significantly depending on the selected group.

While single-taxonomic group studies undeniably contribute valuable insights to conservation biology, the urgency to acquire knowledge as a foundation for biodiversity protection necessitates a broader approach. Therefore, we propose that researchers incorporate multiple organism groups in their studies to capture a more comprehensive representation of biological diversity. By adopting this multi-taxon perspective, we can enhance our understanding of complex ecological interactions and make informed recommendations to safeguard biodiversity in a time-constrained context.

Forest disturbance, biodiversity and ecosystem functioning

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Disturbance is a fundamental driver of forest dynamics, aboveground and belowground ecosystem processes, and plant, animal and microbial biodiversity. In this presentation I will focus on fire, because it is arguably the most important forest disturbance globally, because forest management has a major impact on fire return intervals and severity, and because fire regimes in much of the world are being altered by human-induced climate change. First, I will discuss the mechanistic basis by which fire affects ecosystem functioning both above and below ground over contrasting time scales ranging from years to millenia. Second, I will draw on work we have been carrying out on a group of lake islands in northern Sweden over the past 30 years that collectively represent a 5000 year post-fire chronosequence, to better understand how fire history and time since fire impacts on aboveground and belowground biodiversity and ecosystem processes that drive carbon sequestration. Finally I will compare this chronosequence with other long term forested chronosequences around the world to make the case that disturbances are an essential component of forests and are needed to rejuvenate forest ecosystems and maintain their long term functioning. Key conclusions from this presentation will emphasize the role of disturbance regimes in regulating processes that drive carbon sequestration and biodiversity in forested ecosystems in the long term, and the relevance of this to forest conservation and management.

From nature reserve to mosaic management: retention forestry as land sharing to conserve birds in plantation landscape

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Meeting wood demands with increasing human population and consumption is a pressing conservation issue, and is often framed as a choice between land sparing and land sharing. Although most empirical studies comparing the efficacy of land sparing and sharing supported land sparing, land sharing may be more efficient if its performance is tested by rigorous experimental design and habitat structures providing crucial resources for various species—keystone structures—are clearly involved. Landscape planning how to integrate land sparing and sharing is also an important but open question.

We launched a manipulative experiment to retain naturally regenerated broad-leaved trees when harvesting conifer plantations in central Hokkaido, northern Japan. We surveyed birds in harvested treatments, unharvested plantation controls and natural forest references one-year before the harvest and for three consecutive post-harvest years. Results showed that retaining some broad-leaved trees increased total abundance of forest birds over the harvest rotation cycle (i.e., before and after harvesting). Retaining a small amount of broad-leaved trees (20-30 broad-leaved trees per ha) may be a cost-effective on-site conservation approach for the management of conifer plantations.

We conducted a simulation experiment to inform retention forestry applied to tree plantations in the landscape. Landscape comprised natural habitat, unimproved matrix and improved matrix, which are equivalent to natural forests, intensively managed plantations, and extensively managed plantations (plantations with retained trees), respectively. We examined matrix effects on regional populations across a gradient of habitat loss and fragmentation by integrating demographic processes and movement modeling based on circuit theory. Results showed that matrix improvement aimed at increasing movement survival will likely bring large conservation benefits. Buffering and connecting habitat remnants with improved matrix could provide benefits as long as movement survival is increased. Simultaneous implementation of habitat management and matrix improvement would yield synergistic conservation benefits.

We propose that retaining native regenerating trees in plantations can be a useful option, and can be incorporated into management systems using certification schemes and best management practices. The approach of retention forestry as land sharing can be integrated with land sparing to efficiently reconcile wood production and biodiversity conservation in the landscape.

Habitats complexity and biodiversity indicators in beech forests with different management systems in the Italian Apennines

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Forest management is a primary driver of habitats complexity and may impact or enhance forest biodiversity based on the applied management practices. In this study we compared biodiversity indicators in high beech (*Fagus sylvatica* L.) forests in the Tuscan Apennines (central Italy) managed with different sylvicultural systems.
The work was carried out in five study areas: three even-aged stands of about 10, 60, and 100 years old managed with the uniform shelterwood system, one uneven-aged stand managed with the single tree selection systems, and one unmanaged stand (old-growth forest). In each area, field works were carried out in a plot of 2500 m^2 (50 x 50 m). In each plot, we collected data to derive biodiversity indicators related to stand structure, deadwood, tree-related microhabitats, beetles and birds. For each area, we analyzed the stand structural attributes, deadwood characteristics and microhabitats occurrence, evaluating their role on the abundance, distribution and diversification of saproxylic and non saproxylic beetles and bird fauna.
Our results show that silvicultural practices have led to a simplification of the forest complexity in managed sites compared to the old-growth site, both in terms of structural heterogeneity, amount of deadwood, relative diversity of microhabitats and abundance of beetles and birds. However, in the managed stands, despite being affected by anthropic disturbance, species included in the Italian Red List were 36% of whole beetle communities. Furthermore, two species were in the Habitats Directive: *Morimus asper* (Cerambycidae) and *Lucanus cervus* (Lucanidae). In the old-growth stand, the discovery of the black woodpecker (*Dryocopus martius*) and crested tit (*Lophophanes cristatus*) was of particular ecological value.
Our findings provide a better knowledge of the influence of forest management on biodiversity, providing a contribution to develop management practices useful to combine forest production and biodiversity conservation in montane beech forests.
The study was carried out within the LIFE SySTEMiC project - LIFE18ENV/IT/000124.

How "close-to-nature" are forest disturbance regimes in managed forests in Germany?

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Close-to-nature forestry is considered our best option to address the societal demands towards forests while simultaneously safeguarding forest biodiversity and ecosystem functioning. However, close-to-nature forestry in Central Europe has largely focused on stand-level processes while ignoring landscape-scale phenomena such as disturbances. What hinders a current modulation of management after natural disturbance regimes is a lack of quantitative information on disturbances under unmanaged conditions.

At the same time, forest disturbances will amplify in the future under climate change. A central premise of management is that disturbances can be reduced through risk management, yet whether and to what degree unmanaged forests differ in their natural disturbance impacts from managed forests remains unclear.

To tackle this knowledge gap, we investigate disturbance regimes for managed and corresponding unmanaged forests across Germany. We integrate a Landsat derived forest disturbance map, tracking the disturbances of the last decades, with climate and environmental data and compare them between managed and unmanaged forests across different ecoregions.

In order to account for diversity in forest types, management practices and climates, we structurally match Germany-wide unmanaged forest sites (management ceased at least 35 years ago), with multiple comparable managed forest sites. The matching includes site condition (including climate), elevation and forest type to isolate the effect of management.

We ask two questions: (i) are the canopy openings in managed forests within the recent range of natural variability derived from unmanaged forests, and (ii) are natural disturbance impacts higher in managed or unmanaged forests?

The findings bear significant implications for biodiversity conservation, as they explore whether forest management impacts the frequency and size of canopy openings, thereby influencing forest biodiversity in a crucial manner. Furthermore, assessing disturbance impacts in relationship to different management addresses the question of potential co-benefits between climate-adapted forest management and biodiversity conservation.

Influence of green retention trees to growth of pine plantation and environmental factors in hemiboreal forests, Lithuania

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Green retention trees in pine forests are important for maintaining biodiversity. Retention trees provide shade, shelter, and food for wildlife, and can create a diverse habitat for birds, mammals, and other species. Green retention trees create a microclimate which can also affect the growth of planted seedlings. The aim of this research was to determine the effect of green retention trees on pine plantation growth and environmental factors: soil pH, temperature, humidity, and light conditions. The study was carried out in the south-eastern part of Lithuania in the plantations of pine trees, growing in the clear-cutting areas next to green retention trees. In pine stands in dry, poor sites, where clear cutting was carried out and green retention trees were retained, 50 transects were set up. Parameters of green retention trees were measured; pine plantation growth and growth conditions were assessed. The number of pine saplings was recorded; sapling height and the length of apical shoot were measured. Soil pH, moisture, and temperature were measured with portable "PNT 3000" and "WET" devices, while the light index - with "Hemi View Canopy System". The findings of the research revealed that green retention trees affected the density, height, and length of the apical shoot of nearby growing pine plantations. The impact on soil temperature, moisture, pH, and light was also found.

Influences of stand tending on forest microclimate and woodlice populations in temperate forest ecosystems

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Climate change impacts the health of forests through hotter droughts, resulting in increased tree mortality and decreasing growth trends. To preserve forest ecosystems, climate-smart forest management has been proposed as a drought alleviation strategy, with stand tending, more specifically thinning intensity, as a potential tool. However, the possible negative effects of thinning on forest microclimate and forest-related biodiversity are often overlooked. Thinning reduces canopy cover, a key driver of the microclimate and climate buffering capacity of a forest. With climate change, the microclimate becomes increasingly important for the survival of forest-related biodiversity. Forest-related species are highly dependent on local microclimate conditions, which are preserved by a closed canopy. Woodlice, for example, require relatively high levels of humidity and often serve as microclimate indicators. Therefore, this study aims to investigate the relationships between thinning intensity, forest microclimate and woodlice populations in pedunculate oak (*Quercus robur* L.) and beech (*Fagus sylvatica* L.) dominated forests in the Brabantse Wouden, Belgium. In this study, we hypothesize that increasing thinning intensity reduces the forest's temperature and humidity buffering capacity due to more open stand conditions, leading to shifts in woodlice communities towards drought-tolerant species. To address these research questions, TMS4-loggers monitored the forest microclimate (temperature and soil moisture) while woodlice populations were caught using pitfall traps during the summer of 2022, characterized by intense droughts. Preliminary results show that when macroclimate temperatures rise, so do microclimate temperatures, but at a slower rate, meaning that higher macroclimate temperatures result in a stronger temperature buffering capacity. Contrary to the scientific consensus, forest stand characteristics and thinning intensity did not seem to significantly affect the temperature buffering capacity. Maximum surface temperatures were found to influence the weighted drought tolerance of woodlice communities with higher temperatures favoring more drought-tolerant species. These findings shed light on the complex relationship between forest management practices and forest microclimate, providing insights to support informed climate-smart forest management strategies. It emphasizes that forest managers, when deciding on the intensity of their stand interventions, should not only consider tree growth but also other ecosystem functions, such as the role of microclimate in maintaining forest biodiversity.

Repeated clear-cutting of boreal forests - a tipping point for forest biodiversity?

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Boreal forests are important carbon sinks and host a diverse array of species that provide important ecosystem functions. Boreal forests have a long history of intensive forestry, in which even-aged management with clear-cutting has been the dominating harvesting practice for the past 50-80 years. A a second cycle of clear-cutting is emerging, and there is an urgent need to review the effects of repeated clear-cutting events on biodiversity. Clear-cutting has led to reduced numbers of old and large trees, reduced volumes of dead wood of varied decay stages and diameters, and altered physical and chemical compositions of soils. The old-growth boreal forest has been fragmented and considerably reduced. We reviewed short- and long-term (≥50 yrs) effects of clear-cutting on boreal forest biodiversity in four key substrates: living trees, dead wood, ground vegetation and soil. We assessed landscape-level changes (habitat fragmentation and edge effects) on this biodiversity. There is evidence for long-term community changes after clear-cutting for several taxa: epiphytic lichens; saproxylic fungi, bryophytes and insects; epigeic bryophytes; soil snails, bacteria, and ectomycorrhizal fungi. Still, for the majority of taxa, long-term effects of clear-cutting are not well understood. On the landscape level, reduced connectivity to old-growth forests has negative effects on several species of fungi, lichens, bryophytes and insects, notably among red-listed species. Repeated cycles of clear-cutting might pose even stronger pressures on the boreal forest biodiversity due to continued fragmentation of old-growth forests and accumulation of extinction debts. Boreal forest ecosystems have undergone drastic changes over the past century and we fear the breadth of today's forestry practices could push the biodiversity across a tipping point.

Safe operating boundaries for boreal forest harvesting

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: All human societies and economies are bounded by the limitations of the planet Earth. This scientific fact implies that ecological boundaries set by the biosphere are fixed and not negotiable. Forest ecosystems have a specific capacity to provide ecosystem services and sustain biodiversity, determined by their current state, future environmental conditions (e.g. climate), and future management. Not overshooting this capacity, i.e., keeping the use of forest resources within their ecological boundaries, requires that forest management is conducted in ways and harvesting is kept at levels that allow maintenance of natural capital. A major challenge is to maintain a constant high flow of wood biomass for bioeconomy purposes within ecological boundaries. To this end, management that emulates natural disturbances, such as continuous cover forestry, are potentially useful. In this study, we aimed at defining a safe operating boundary for boreal forest use. We applied forest growth simulation and optimization tools to select management regimes that effectively halt the decline in biodiversity, and eventually allows forest ecosystems to achieve a favourable conservation status at a targeted time. This analysis is carried out in heath forest types using large forest dataset representing central and south boreal regions in Finland. We used the criteria defined in the assessment of threatened habitat types in Finland and defined favourable conservation status being a state where forest habitat types will be removed from the red-list. The results show that if the society wants to keep forest use within the safe boundaries, harvesting levels should be considerably below the maximum economically sustainable roundwood removals. The safe harvesting level and optimal management regimes vary among forest habitat types. However, in addition to forest protection, continuous cover forestry turned out an effective management regime in production forests in mitigating negative forestry effects on biodiversity. These results challenge the society to find sustainable socio-ecological ways of using forest resources.

Species diversity and spatial heterogeneity jointly drive the aboveground biomass in temperate and tropical forests

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: The important roles of biodiversity in maintaining ecosystem functioning and stability have been confirmed by a large number of studies. However, most previous biodiversity and ecosystem functioning (BEF) studies have generally been limited to very small spatial grains. Thus, knowledge regarding the biodiversity-ecosystem functioning relationships across spatial scales is lacking. Moreover, the multiscale nature of biodiversity, and specifically β diversity (i.e., spatial heterogeneity in species composition) was still largely missing in BEF studies. Here, using the vegetation and functional trait data collected from four 6-ha forest dynamics plots (FDPs) in temperate and tropical forests in China, we examine the scale-dependent relationships between tree diversity and the aboveground biomass (AGB), as well as the roles of species spatial heterogeneity in determining the AGB. In tropical forest, effect of species richness on AGB decreased with spatial grains, while functional dominance played a dominant role at larger spatial grains. In temperate forest, on the contrary, positive relationship between species richness and AGB occurred at all spatial grains, while roles of functional dominance decreased with spatial grains. β diversity was positively correlated with AGB, but weaker than α diversity in determining AGB. AGB was positively correlated with turnover but negatively correlated with nestedness component. Overall, complementarity and selection effects play dominant role in determining AGB in temperate and tropical forest, respectively. The roles of these underlying mechanisms are more pronounced with increasing spatial scales. β diversity, a hitherto underexplored facet of biodiversity, is likely to increase ecosystem functions by species spatial turnover, and should not be neglected in BEF explorations in the context of multifunctionality across large areas of spaces. Our findings have practical implications for forest management, and demonstrate that biotic heterogeneity plays an important positive role in ecosystem functioning.

Keywords: aboveground biomass (AGB); α- and β diversity; biodiversity-ecosystem functioning (BEF); functional diversity; spatial scales; species diversity

The importance of tree-related structures and tree continuity for biodiversity in boreal forests – how to prioritize forest for set-asides

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Although it is well known that both habitat availability and continuity are important factors in maintaining biodiversity, their relative importance in applied contexts is still unclear. The unclear situation is problematic as it has bearing on which conservation strategy that is optimal when it comes to preservation of forest biodiversity. Is it best to prioritize forest with long tree-continuity as set-asides over forest with shorter tree continuity, irrespectively of their structural richness? The unresolved issue is also highly relevant for the question if continuous-cover forestry is better at preserving biodiversity than stand-replacing clearcut-forestry. To clarify how the diversity of beetles, wood-inhabiting fungi and lichens depend on structural diversity and tree continuity we examined species diversity of these groups in relation to tree-continuity and forest structural diversity (richness and amounts of dead wood and old-growth trees) in north-west Sweden. This region still harbour a large area of forest that never been exposed to clearcut-forestry. Despite their long tree continuity, many of these forest have been exposed to selective logging, and their conservation value is of is debated. In our presentation we will show results demonstration how and why the response to tree continuity and structural diversity differ among species gropes. The results will be discussed in relation to1) how to prioritize among forests that should be exempted from forestry, 2) refine the methods currently used to assess the value of forests, and 3) refine criteria for identifying the most effective trees to leave as retention trees during forest harvesting. Our study contributes to increased sustainability by supporting decisions on which forests should be excluded from forestry and which can be managed, as well as improve guidelines for the retention forestry that is currently practiced, and the one that needs to be developed as alternative forestry practices, such as continuous cover forestry become more common in boreal forests.

The management of European forests impacts the resilience of understorey vegetation

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Ecological resilience is fundamental to maintain forest functions despite global changes. Although understorey hosts most forest plant diversity and is key in forest nutrient cycles and regeneration, its resilience is relatively unexplored.

We analyzed management influence on European forests' understorey resilience, as proxied by functional diversity (FD) and redundancy (FR) calculated on specific leaf area, plant height and seed mass. FD quantifies the complementarity of species responses, FR sustains functions despite species diversity erosion. We used understorey vascular plant species abundances in 2,096 sampling units across Europe, each associated with one silvicultural regime or with unmanaged forests, here used as a reference. We used generalized linear and additive mixed models to respectively assess the effect of different silvicultural regimes on FD and FR, and to explore their reciprocal relationship across silvicultural regimes.

Results indicated that intensive silvicultural regimes influenced understorey resilience by decreasing FD and increasing FR, thus buffering species erosion while jeopardizing the resilience to environmental changes. Low intensity management maintains resilience levels comparable to unmanaged forests, which displayed the best combination of FD and FR. European forests' ecological resilience would benefit from trait-based approaches, pointing to the application of multiple management approaches covering different pathways to ecological resilience.

The scientific support for integrating measures for biodiversity in production forestry

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Integrating nature conservation measures into production forestry is common today in many boreal and temperate countries with a main aim of maintaining and promoting biodiversity. Different forms are practiced from saving parts of the forest, often including border zones, retaining individual trees of presumed habitat value, to maintaining and creating dead wood. Although this integrated approach has been applied in certain forest types and contexts for centuries, large-scale application has expanded greatly in recent decades. A milestone was a scientific framework presented by Jerry Franklin, Univ. of Washington, USA in the late 1980s, based on disturbance ecology. A diverse terminology for the approach has developed since then, including terms such as retention forestry, green-tree retention, and variable retention. A large amount of research has been conducted to evaluate the effectiveness of the various components and several meta-analyses and overviews have been presented. Using boreal Europe as an example, I will summarize the type of research being carried out and evaluate the strength of the evidence base.

The sound of silviculture - Experimental soundscape ecology in temperate forests

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: A wide range of forests worldwide are subject to silvicultural interventions. Depending on economic or silvicultural objectives, these interventions are carried out with varying intensity and spatial arrangement. They may also include biodiversity-oriented practices such as deadwood retention. As many species produce sounds or vocalize for communication, the analysis of forest soundscapes is increasingly used for cost-effective biodiversity monitoring. However, a lack of experimental studies has hindered our understanding of vocalizing species communities. Here, we investigate the effects of different well-established silvicultural practices on the soundscape of a temperate production forest in a forest manipulation experiment in central Europe. We performed simultaneous sound recordings in 59 forest plots in the summer before and after silvicultural interventions by recording in intervals of one minute every tenth minute a 24h day. Interventions included logging at different intensities and the creation of standing deadwood, both in two different spatial arrangements (aggregated vs. distributed). The aggregated arrangement resulted in small-scale canopy gaps, while the distributed arrangement maintained closed canopies. From each recording, we calculated four common acoustic indices that well represent different aspects of the soundscape and its biodiversity with indices focusing on sound coverage along the frequency range (Soundscape Saturation), the sound diversity over time (Acoustic Complexity, Entropy of Variance Spectrum) or the pure activity (Events per Second). We used linear models to analyze the impact of logging intensity, spatial arrangement and standing deadwood on the acoustic indices and found differences in the forest soundscapes according to silvicultural interventions, especially when analyzing different intervals of the day separately. Our results suggest that different taxa play a key role in the generation of sounds throughout the day, thus shaping the soundscape response to silvicultural interventions, which highlights the importance of experimental soundscape studies and the focus beyond the dawn chorus. Together with emerging machine learning technologies and algorithms for species identification from sound recordings, experimental soundscape ecology may be another step towards a more precise biodiversity monitoring.

Woody species diversity, composition and vegetation structure in protected and unprotected areas of Chyulu Hills ecosystem in Kenya

T3.32 The scientific basis for how to safeguard biodiversity in production forestry

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Abstract: Chyulu Hills ecosystem is characterized by varying land use (management) schemes based on land tenure system from fully protected Chyulu Hills National Park (CHNP) and Tsavo West National park (TWNP); to Kibwezi Forest Reserve (KFR) which permit selective logging; to open areas represented by four community group ranches, Kuku A, Kuku B, Rombo and Imbirikani, where human settlements flourish with uncontrolled grazing, charcoal burning and farming. Few studies have looked at conservation success in protected areas, relative to non-protected areas in Kenya. The aim of this study was to determine whether government protection on forest reserves and national parks has effects on species diversity, composition and vegetation structure as compared to open areas where few restrictions on resource use exist. We hypothesized that heavily protected areas were the best conserved in terms of woody plants species diversity and stand structural characteristics. A total of 70 permanent circular plots were sampled in each of the land use scheme; CHNP, TWNP, KFR, Kuku A, Kuku B, Rombo and Imbirikani using stratified random approach with each plot measuring 17.84 meters in radius which was equivalent to 0.1 ha. All woody plants, both life and dead with a DBH $\geq$ 5 cm were identified, counted and assessed for DBH, height and crown diameter. Data was analysed and means of different variants were determined and compared with ANOVA across different areas. The results revealed that CHNP had the highest individuals' frequency followed by KFR and TWNP, while, Kuku A and Rombo had the least individuals. On floristic composition, genus *Commiphora* followed by *Acacia* were dominant in Kuku A, Rombo and Kuku B ranches; while *Diospyros* was the most common in Imbrikani, KFR and CHNP. In terms of diversity, TWNP had the highest followed by Kuku B and A while Imbirikani had the least diversity. This study concludes that protection does not influence the plants diversity of an area but affects the floral composition and vegetation structure.

Key Words: species diversity, composition, vegetation structure, protected, unprotected, Chyulu

T3.33 Top five business and policy innovation challenges to accelerate landscape restoration as a nature-based solution

Assessing multifunctionality and climate smartness of restored landscapes

T3.33 Top five business and policy innovation challenges to accelerate landscape restoration as a nature-based solution

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Abstract: Integrated implementation of various land management options is the key for successful land restoration programs. Integrated sustainable land management practices could improve land restoration success and enhance multiple ecosystem services generated by the landscape. Implementation of land and water management options at landscape level can cause tradeoffs due to conflicting land uses and varying needs of land users. It is thus essential to assess the climate-smartness of those landscapes in order to sustain the benefits associated with the management practices. We used various in-situ data, empirical and the Integrated Valuation of Ecosystem Services and Trade-offs models to assess the multifunctionality of landscapes and evaluate the associated benefits enjoyed in selected landscapes of Ethiopia. We employed a climate smartness landscape index to determine the climate-smartness of those landscapes by integrating multifunctional services provided by the landscapes due to the various interventions. We obtained a positive change in multiple ecosystem services due to land restoration efforts in four watersheds in Ethiopia. The result is substantiated by both modelling results and in-situ observation data. Even though the land management activities conducted in the study watersheds broughted a positive impacts, the optimal scenario shows that there are still opportunities to further enhance the magnitude and multifunctionalities of ecosystem services that would be obtained in the optimal land management scenario. All watersheds analyzed in this study showed climate smartness at the landscape level, with some level of difference among them. Gudoberet and Aba Gerima watersheds showed more climate smartness than the Anjeni and Debre Mewi. The study shows that investigating the multiple functions of more than five ecosystem services can be designated as multifunctional landscapes.

Keywords: Land degradation, landscape restoration, SLM, ecosystem services, InVEST

Can gender-conscious business models in large scale restoration address gender gaps and provide fair incentives to women?

T3.33 Top five business and policy innovation challenges to accelerate landscape restoration as a nature-based solution

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Abstract: The urgency to deliver restoration solutions demands aggregation and scale. While large-scale restoration offers promising solutions, the pace and scale with which restoration actions are implemented can also deepen inequalities, by structurally bypassing actors such as women who have lesser and limited rights and influence to land and land governance. Compared to men, women in land and land governance tend to have weaker rights, fewer resources, less say in decision-making, fewer positions of authority, less access to justice, and so on. The failure to adequately recognize and account gender gaps and gender inequalities in restoration is likely to create more harm to women, entrench gender gaps to land, finance, and restoration governance, and undermines gender equality. To address gender gaps and inequities in restoration, attention to both financial/non-financial incentives and social norms is needed. Using gender conscious operational practices of restoration businesses in Latin America and Africa, we describe diverse practices that are used to engage and benefit women. Our findings shed insights on the intersection of gender norms, relations of labor, and financial incentives at local and global level, and how these intersections shape the framing, entry-points, and range of benefits that can emerge from restoration. We also discuss the opportunities of using gender conscious models in addressing key land degradation challenges with multiple effects across Initiative 20x20 in Latin America and AFR100 in Africa. We argue that large-scale restoration needs to move beyond the simplistic framing of tree-planting and transaction models of inputs/outputs. We offer some recommendations for equitable transition through restoration.

Capacity building to accelerate landscape restoration

T3.33 Top five business and policy innovation challenges to accelerate landscape restoration as a nature-based solution

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Abstract: To support and scale up efforts to prevent, halt and reverse the degradation of ecosystems worldwide, the UN General Assembly proclaimed 2021 – 2030 to be the United Nations Decade on Ecosystem Restoration (UN Decade). One of the main pathways to achieve the mission of the Decade is the development of capacities to empower professionals and institutions involved in the field of restoration to design, implement, monitor and sustain effective restoration initiatives. To that end, UN Decade partners have pursued several efforts including: i) the development of a Capacity, Knowledge and Learning Action Plan for the Decade, as a joint effort of the members of the UN Decade Taskforce on Best Practices, established under the leadership of FAO to enhance knowledge dissemination and capacity development throughout the UN Decade. The plan identifies the gaps where knowledge products or capacity-development initiatives are needed across various stakeholder groups, based on the results from a global capacity needs assessment, a stocktaking of capacity-development initiatives and knowledge products, and several targeted consultations. Based on these efforts, the action plan specifies the terms of reference for eight key capacity- and knowledge-development initiatives, tailored to different stakeholder groups, and aimed to achieve three main objectives: develop individual and organizational capacity across sectors and scales; foster networks, partnerships and collective action mechanisms; and strengthen the enabling environment for ecosystem restoration; and ii) the development of several tools to help stakeholders plan and monitor restoration actions. As part of the UN Decade Monitoring Task Force, platform to report on restoration efforts has been developed. This Framework for Ecosystem Restoration Monitoring (FERM) provides a space for stakeholders to register their restoration projects and best practices and to visualize the geospatial data. Also, the Assessment, Understanding and Reporting Of Restoration Actions (AURORA) is an important tool that directly contributes to the Decade, assissing in the planning and setting up of monitoring systems according to restoration objectives.

FInance and policy challenges of implementing Assisted Natural Regeneration

T3.33 Top five business and policy innovation challenges to accelerate landscape restoration as a nature-based solution

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Abstract: Assisted Natural Regeneration (ANR) of forests has tremendous potential to provide cost-effective socio-economic and environmental benefits for ecosystems and landscapes. But implementation and upscaling of ANR confront many challenges at local, national and global scales. Three regional workshops (Africa, Asia-Pacific, Latin America-Caribbean) led by key stakeholders in the ANR Alliance identified major finance and policy challenges. Legal restrictions on harvesting naturally regenerating trees limit economic benefits and favor tree planting or commercial forestry over management of fallow vegetation or existing secondary forests, even on private land. In many cases, farmers must obtain approval from public forest agencies to harvest trees, requiring high transaction costs. In other cases, naturally growing trees belong to the government and cannot be used by farmers for economic gain. Few countries offer economic incentives, subsidies, technical support, or extension services for implementation of ANR. Investors are generally unaware that assisted natural regeneration can be a highly effective reforestation approach or perceive higher risks than investing in tree planting for carbon storage. Biodiversity benefits of ANR are taking a back seat to carbon storage in the rush toward carbon finance.

These obstacles emerge from a history of economic and land-use policies that favor either commercial forestry or strict conservation of natural forests, relegating natural regeneration to uncertain status and vague definitions. They also stem from outdated agrarian reforms that require clearing land to demonstrate use and obtain land-use rights. Forest regeneration is associated with indigenous and traditional communities' shifting agricultural systems, which are strongly penalized in many countries. Young natural regrowth areas are often viewed as "idle" lands that are not valued or protected. Regenerating forests lack an enabling policy context and are often excluded from reforestation and forest restoration programs. Practice of ANR is further disincentivized by conflicting policies across agriculture, forestry, and conservation sectors.

Pathways that enable ANR implementation include cross-sector collaboration and policy alignment, communicating knowledge on the benefits and feasibility of ANR in specific restoration contexts,

providing technical support for farmers and land managers, and designing economic incentives that value naturally regenerating forest ecosystems and their sustainable management.

My Farm Trees, implementing a blockchain enabled digital platform for farmer led restoration

T3.33 Top five business and policy innovation challenges to accelerate landscape restoration as a nature-based solution

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Abstract: My Farm Trees is a revolutionary digital platform to catalyze change in the way restoration is implemented with smallholder farms. It aims to improve the tracking of seed material, empower rural entrepreneurship and enhance value chains around nature-based solutions. We will present lessons learnt from the pilot phase of this GEF funded, IUCN Implemented and Alliance of Bioversity and CIAT CGIAR project executed in Cameroon and Kenya. We present the platform, farmers perspectives, barriers to adoption and scaling solutions that will help to catalyze restoration action that delivers local needs, and global impact.

Promoting the inclusion of youth in landscape governance and restoration: experience of the Latin American Model Forest Network

T3.33 Top five business and policy innovation challenges to accelerate landscape restoration as a nature-based solution

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Abstract: The Latin American Model Forest Network (RLABM) links 35 territories in 15 countries of Latin America and the Caribbean. Model Forests (MF) are multi-stakeholder territorial governance platforms in forest landscapes. In mid-2020, the RLABM identified the need to promote the inclusion of youth.

Through an online survey applied to MF representatives in 11 countries (17 adults and 45 youth) and interviews with 06 youth leaders, we obtained information on topics of interest related to landscape restoration and management, as well as forms of organization, patterns of representation and local leadership, and willingness to networking. Subsequently, the first virtual meeting of RLABM youth was organized, which included 04 sessions for the exchange of experiences led by young people and reflections on three key themes: innovation, sustainability and organization for change. Seventy young people from 13 countries participated, in gender parity.

The results showed that the empowerment of the youth of the MFs and the promotion of their initiatives is a priority. For capacity building, the thematic priorities cover different dimensions of ecological and productive landscape restoration, such as productive diversification, ecosystem and biodiversity restoration and conservation, local enterprise management, technological innovation, knowledge management, organization and leadership. Other priorities are to strengthen and provide institutional support to their organizations, guarantee their participation in decision-making, articulate them in networks, promote decent employment opportunities and access to seed financing for local enterprises.

Based on these results, since 2021 RLABM has focused its efforts on empowering young people for their inclusion in governance and landscape restoration processes. The main strategy has been to generate instances for the exchange and development of training activities whose curricula are based on the identified priorities. Both strategies have involved 232 young people from 18 countries.

For RLABM, young people are the driving force for change and sustainability, and for this reason, in the medium term, it is expected to give continuity to the training processes for youth leadership in the region, and to strengthen instances of dialogue and collective construction to address the challenges of landscape restoration in Latin America.

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

Breeding Melia volkensii for Improved Commercial Forestry in Drylands of Kenya: Plus Tree Selection, Seed Orchards and Progeny Trials Establishment

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: *Melia volkensii* is a fast growing drought tolerant and termite resistant tree occurring naturally in drylands of Kenya. The species produces high quality mahogany-grade timber that is harvested in 10-12 years. Overharvesting of trees of good form over time has resulted in reduction in quality of remnant populations. A Melia breeding strategy was initiated in 2010 with the aim of improving adaptability, productivity and timber quality. Main activities included: selection of Candidate Plus trees (CPTs), collection of scions and grafting, and establishment of clonal seed orchards. One hundred CPTs were selected between 2010 and 2012 in an 800-km range extending from northern to the Kenyan coast. Two 11-Ha first generation clonal seed orchards were established in 2012. In 2015, seed was collected from the orchards and seedlings raised to establish 8 progeny trials in various sites. Objectives of the progeny trials were to: Test the genetic worth of the CPTs; rank the parent trees based on performance of their progenies; and estimate heritability of traits assessed. Height, diameter at breast height (DBH), tree form and fecundity were assessed bi-annually from planting and annually from 5 years. Five-year family mean height range at different sites was 5.7 to 9.6 m (Marimanti), 4.2 to 9.9 m (Tiva), 4.1 m to 9.1 m (Kibwezi), and 5.4 m to 9.2 m at Kasigau. Mean family DBH was 11.7cm (Marimanti), 12.9cm (Tiva), 11.9 cm (Kibwezi), and 10.9 cm (Kasigau). Ranking showed the best families were CPTs 43, 26, 53 and 49. Family heritability was moderate, 0.48 for height and 0.32 for DBH, suggesting a potential for transmitting desirable characteristics to operational commercial plantations. Progeny of 76 out of 100 CPTs showed a positive General Combining Ability (GCA) for both height and DBH. Gains of 16% in volume were obtained by rogueing first generation orchard using Progeny trial results. Using forward selection, four hundred 2nd generation trees have been selected from the progeny trials. Establishment of second generation clonal seed orchards has been done for provision of further improved seed for commercial forestry in the drylands.

Keywords: *Melia volkensii, tree improvement, seed orchard, seed production*

CLONAL TEAK BASED AGROFORESTY SYSTEM FOR CARBON SEQUESTRATION AND FOOD SECURITY

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Teak (*Tectona grandis* L.f) is one of dominated species in the lowland plantation monsoon forest in Java Island Indonesia covering more than 1,2 million ha. Increasing teak forest productivity could be established through clonal forestry as a result of tree breeding producing selected clones with mean annual diameter increment > 2 cm/years. The total carbon sequestration of clonal teak at 8 year and 20 years is 116 C tons/ha (1,100 individuals/ha), and 205 C ton/ha (416 individuals/ha), respectively. Clonal teak plantation in Java is mainly planted as agroforestry system combining with food crops, i.e., upland paddy and corn. In the early clonal teak plantation, upland paddy corn under clonal teak plantation produces 5 tons/ha and 6.5 tons/ha, respectively. It suggested that clonal teak plantation-based agroforestry system could increase the carbon stored in the forest plantation and food security as climate change mitigation for reducing emission and sustainable forest ecosystem.

Comprehensive insights in lignified-callus and wound-induced adventitious rooting in ancient Platycladus orientalis

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Stem cuttings of endangered ancient *Platycladus orientalis* are high fidelity genetic resource for cryopreservation and propagation. However, low tendency of adventitious roots (AR) formation adversely affects regeneration. In this study, we explored causes of decline in AR formation in *P. orientalis* cuttings (5-, 100-, and 700-year-old) at different stages (S1-S3) and possible solutions. Proteomic analysis revealed upregulation of flavonoid and phenylpropanoid associated proteins including chalcone synthase (CHS), chalcone isomerase (CHI) and flavonone-3-hydroxylase (F3H), and down regulation of auxin transport associated proteins such as BIG and auxin responsive (AIR12) at S3 stage in cuttings of 700-year-old *P. orientalis* donors. Biochemical analysis confirmed over-accumulation of flavonoids, phenolics and lignin resulted in callus-lignification and halt in AR formation in cuttings of 100- and 700-year-old donors. Notably, wounding of lignified-callus significantly increased AR formation in cuttings of 100-year-old donors. Meristematic cells regulatory proteins including enolase (ENO) and elongation factor 1α (EF1α) involved in carbohydrate metabolism, and vitamin B6 biosynthesis proteins including pyridoxine synthase (PDX1) and aldehyde oxidase (PDXK) promote AR formation in lignified-callus on wounding of cuttings of 100-year-old donors. Our results revealed that lignification of callus inhibited, while wounding induced AR formation in cuttings of ancient *P. orientalis*. This study is expected to provide a theoretical basis for improving the rooting rate and shorten the rooting time of ancient *P. orientalis* and other difficult-to-root species cuttings.

Cooperative Pinus Improvement Program in Brazil for wood and resin production: Current results

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: *Pinus* is the second forest genus most commercially planted in Brazil. The principal economic products generated from these plantations are wood and resin. Its wood is widely used in furniture, cellulose, and paper production, civil construction industries, among other applications. The resin is applied in solvents, paints, varnish and adhesives industries, pharmaceuticals and cleaning products. Brazil is among the largest producers of sawn wood and resin in the world. In view of its economic importance, a cooperative project for genetic improvement of pine trees (PCMP), in Brazil, was created in a joint effort between Embrapa Florestas, Associação Catarinense de Empresas Florestais (ACR) and Associação Paranaense de Empresas de Base Florestal (APRE). Ten companies participate in the project with the aim of developing pine seeds and clones that exhibit high productivity and quality in both wood and resin. Selection strategies adopted include mass selection, intrapopulation recurrent selection and recurrent reciprocal selection. As a means of reducing the period of generation cycles and maximizing genetic gains over time, we resort to cloning, top-grafting, somatic embryogenesis and genomic wide selection. The preliminary findings of the PCMP include: generation of a germplasm bank of selected trees based on strict criteria regarding the shape of the stem and crown, resin production and characteristics of wood quality and resin, designated to compose breeding populations and improved seed orchards; establishment of clonal seed orchards of *P. taeda*, *P. elliottii*, *P. patula* and *P. elliottii* x *P. caribaea* hybrids; installation of a network of test of progeny and stands of *P. taeda*, *P. patula* and hybrids, with materials selected from commercial stands and also in first generation of progeny tests; obtaining strobili at early age (three years old) for some selected genotypes; advance in development of somatic embryogenesis protocols for *P. taeda*, hybrids and *P. elliottii*; interspecific hybrid seeds of *Pinus* spp. production;ongoing controlled pollination activities among tested materials; technicians and students training in the processes of grafting, controlled pollination and evaluation of parent trees. The collaboration between research institutions, universities, and affiliated companies has been the primary strength of this program.

Acknowledgments: The associated companies from Funpinus

Delineation of seed transfer zone for Pinus densiflora and its application to climate change

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: The seed transfer zone is an area where plants can be transferred with minimal risk of maladaptation. Establishing appropriate seed transfer zone plays an important role in promoting forest health and productivity. Rapid climate change may affect seed transfer zone and lead to maladaptation of forest tree species, so it is essential to consider climate change when establishing seed transfer zone. In this study, in order to estimate the seed transfer zone of Korean red pine (*Pinus densiflora*), transfer functions were generated based on the growth characteristics of 36 provenances in 10 test sites and six bioclimatic variables selected by correlation analysis. Based on the transfer function, critical seed transfer distance for each climatic factor was calculated and plotted on the map, and the seed transfer zone was determined by overlaying the maps for all climatic factors. Using this method of establishing the seed transfer zone, we examined how seed transfer zone would change under different climate change scenarios. The results show that the seed distribution zones of Korean red pine vary considerably depending on the climate change scenarios.

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Determination of resin production in clones of Pinus elliottii var. densa in São Paulo, Brazil

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: The species of the *Pinus* genus were introduced into commercial plantations in the South and Southeast regions of Brazil, driven by fund incentives from 1960 onwards. With the advancement of research and the creation of forest tree breeding programs, trees were selected to establish seed orchards for wood and resin production. The proposal aims to characterize the resin production in an untested clonal seed orchard of *Pinus elliottii* var. densa, with the purpose of identifying the clones with lower productivity to establish technical criteria for proper orchard management. Additionally, it aims to enable seed collection to validate overall productivity. The untested clonal orchard was established in 1986 in the Assis State Forest, São Paulo, Brazil. The grafted propagules are from resin-selected trees, with an intensity of 1:100,000. The spacing between clones is 6 x 6 meters, comprising 600 trees. The traditional method, consisting of 18-centimeter-wide panels with 23 streaks, was used for resin tapping. The resin production evaluation was conducted through three harvests between October 2020 and September 2021. Descriptive statistics were analyzed using the Selegen-REML/BLUP program. The average resin production for the three harvests was 2.04 kg, 2.27 kg, and 2.94 kg, with an overall average of 7.25 kg. The average resin per streak was 0.31 kg. Approximately 50 trees had a total resin production in the range of 10 kg, indicating a good average production for this species. The variation coefficients were of 39%, 36%, and 32% for the three collects of resin tapping, respectively. The correlation between resin collects and resin total production ranks was 0.80 for the first and second collections, and 0.75 for the third collection. Furthermore, the correlation between total resin tapping and the amount of resin per streak was 0.92. The most productive trees maintained their productive performances throughout the year. The obtained results will be considered for the management of the clonal seed orchard, to realize controlled pollinations, and seed and propagules collections to establish progeny and clonal tests.

Effect of different pretreatment techniques on the germination of Vitex keniensis

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: *Vitex keniensis* (Meru oak) is an economically important species in Kenya due to its durable wood and desirable grain. The species is also a documented source of edible indigenous fruits with the potential for juice and jam production. However, the increase in the overuse of forestland has resulted in the major loss of its natural habitat. Additionally, the seeds have continually yielded poor germination, making their propagation difficult. These events have resulted in the species being rare and endangered, despite its potential for diverse use in the production of wood and non-wood forest products. The current study aimed at determining the requirements for breaking seed dormancy. Fresh matured seeds were obtained from a seed stand and pretreated by nicking the seeds, and a combination of nicking and soaking them in cold water and potassium nitrate for varying amounts of time. The study also involved pretreatments on dried seeds. The results showed that the pretreatments varied statistically ($P>.001$) for germination capacity for the dry seeds. The viability of fresh seed was 52%, which improved to 62% when soaked in water for 48 hours. The dry seed had a viability of 42% whereas nicking with a combination of soaking in cold water for 48 hours improved the germination of the dry seeds to 60%. This, therefore, indicates the importance of pretreating the species before sowing to obtain optimum germination.

Keywords: *Vitex keniensis*, Fresh seed, Dry seed, Pretreatment techniques, Germination capacity

Effects of pre-treatment and substrate on germination and growth of Neocarya macrophylla Sabine

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Neocarya macrophylla Sabine is a species that plays an important role in providing ecosystem services. Despite its importance, the diversity and density of N. macrophylla stands have declined sharply as a result of natural and anthropogenic factors. A better understanding of N. macrophylla seedling production techniques is needed for effective reforestation. The aim of this study was to evaluate the effects of pre-treatment and substrates on germination and growth of N. macrophylla. To do this, a completely randomised design with three replications and twelve elementary plots of nine sheaths was set up. Three factors were studied: provenance (Enampore and M'lomp), pre-treatment (crushing and non-crushing) and substrate (cow and SONACOS manures and control). Seed characteristics, germination, growth parameters (height, diameter, number of leaves and lateral roots and length of main root) and dry biomass were measured or counted. The results showed that seed size and weight varied significantly ($pv<0.0005$) according to provenance. Seeds from Enampore were longer (3.41±0.04 cm), wider (2.89±0.03 cm) and heavier (16.15±0.32 g) than those from M'lomp. Pre-treatment significantly influenced ($pv<0.05$) germination rate and duration. Crushed seeds had the best germination rate (43.27±5.19%) and germinated much faster (26.23±1.61 days) than non-crushed seeds. The substrate had a significant influence on growth parameters and biomass. SONACOS manure favoured growth in height (8.92±0.17 cm), diameter (0.072±0.01 cm), number of leaves (10.05±0.18) and biomass (1.80±0.20 g). Leaves (2.03±0.16 g) and roots (2.10±0.16 g) produced more biomass than stems (0.69±0.05 g). Roots (64.88±2.15%) and stems (66.47±2.01%) recorded more moisture. SONACOS and cow manures gave the best performance for Neocarya macrophylla seedlings.

Effects of sowing conditions in the germination of Eucalyptus seed

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: A number of eucalypts are some of the most demanded commercial forestry species for forest products due to their favorable growth habit, quick maturity, and coppicing ability. *Eucalyptus grandis* and *Eucalyptus saligna* are the most popular species in Kenya. Production of seed of the two species in the country is faced with the challenge of separating seed from chaff and currently seed is availed to users as semi-processed with seed mixed with chaff. The germination potential of the two species is based, and reported on the number of seedlings on a weight basis rather than on germination percentage. The number of resultant seedlings varies greatly when seed is sown in different media and environments with most seedlings realized when seed is sown in the laboratory. This study set to develop techniques to enhance the number of seedlings produced when seed is sown with sand as germination media in the glasshouse. Semi-processed seeds of *Eucalyptus grandis* and *Eucalyptus saligna* were sown using three regimes. In the glasshouse, seed (0.1 g) was sown in 4 replicates at two depths (top-sowing, and 5-mm deep furrow) and subjected to two watering techniques; through the use of misting sprayer and watering can. In the lab, the same quantity of seed and replicates was sown on 1% agar. Top sowing and misting technique realized on average 4,800 and 3,800 seedlings of *E. saligna* and *E. grandis*, while furrow and water can technique realized an average of 2,500 and 2100 seedlings for *E. saligna* and *E. grandis* respectively. Comparatively, germination in the lab with agar resulted in an average of, 7,500 for *E.saligna* and 5,100 for *E.grandis*. The number of seedlings in the treatments varied statistically ($p<.001$). Tree nurseries raising eucalyptus seedlings in glasshouses using sand as a germination media would enhance the number of seedlings raised from a given weight of seed for the two eucalyptus species by adopting top-sowing and misting as a watering technique.

Keywords: *Eucalyptus grandis*, *Eucalyptus saligna*, Seed sowing techniques, Seed germination

Establishment of Seed Orchard in Cambodia

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Since 2016, the Institute of Forest and Wildlife and Research and Development of the Forestry Administration, Ministry of Agriculture, Forestry and Fisheries, Cambodia with collaboration of the Asian Forest Cooperation Organization are conducting research on seed orchard establishment for three native species namely 1. *Dalbergia conchinchinensis,* 2. *Pterocarpus macrocarpus,* and 3. *Dipterocarpus intricatus.* It is a ten-year project from 2016 to 2025 and aiming for implementing a long term tree breeding plan and strengthening the tree breeding capabilities of the young forestry administration officials. Thus, the implementing team has established a 24 hectars of progeny test plantation and 6 hectars of clonal and seedling seed orchard of the target species for selection of the good seed from well-performanted plus trees. The seeds and scions were collected from a one hundred native plus tree each species in the forests located in 11 provinces in Cambodia. The seedlings from seeds were planted in the progeny test plantation randomly, while the seedlings producing from scions using grafting technique were planted in the clonal seed orchard chronollogically. Pararelly, one of the major activities is to produce a mask production of seedling of the tree species from a tissue culture. laboratorian has trialed varios media for growing the seedling from tissue. It is also a part of capacity building of the young forester who are joining in the project. Moreover, the project provided supports to the university students in conducting research for undergaduated research thesis and supported field study visits for exploring varios forest restoration techniques, landscape restoration as well as the ground activities of the project. Furthermore, there are training local and international program provided for strenthening the capacity of the project staff and young forestry officials. All in all, it is a first research project ever in Cambodia to has a seed orhcard establishment. Resulting for considering as a model for further researching in the near future.

Fertility Variation and Gene Diversity in Forest Populations

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Fertility variation, defined as a difference of the ability to give progeny (i.e. reproductive success) among individuals, was reviewed by related available theoretical and practical literature to contribute, and to improve future studies on the subject. Fertility variation is a useful tool for different purposes such as gene conservation, seed production programs, managing forest genetic resources (i.e., seed sources), and evolutional and physiological study. Many papers and proceeding were published in theoretically or practically, or both on fertility variation to be improved it in last two decades. We reviewed the literature combined our own unpublished knowledge to examine fertility variation and its linkage parameters. Fertility variation and their related parameters (i.e., gene diversity, status number, effective number of parents, parental-balance curves) estimated based on reproductive characters is easy, cheap and light surveys used for different purposes in plant science for many years. It is getting importance and using widely because of these advantages, improved from paper to paper. While many research papers were published on fertility variation and linkage parameters recently, a review paper has not been published. So, a review on fertility variation and gene diversity in forest populations is presented int the session as a guide for future studies.

Flowering abundance is related to phenology of Norway spruce clones in clonal seed orchards

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: We studied the abundance of male/female flowering together with development stage of male, female and vegetative buds in a 10-year-old Norway spruce clonal seed orchard in central Lithuania. The clones originate from forward selection in field tests from ca. 20-year-old ortets. We studied 50 clones with ca. 10 ramets each during spring 2022 and 2023. The results showed that clones from north-eastern Lithuania started active growth and developed the male and female much earlier than the clones from other parts of Lithuania. There was significant non-overlapping of flowering between clones from different parts of Lithuania. Interestingly, the north-eastern clones had markedly less generative flowers than the remaining clones, some of them none. In spring 2022, no radiation frosts occurred in May. Our results indicate that phenology of the clones plays an important role during the process of bud differentiation in July of the previous year. In this way phenology may be associated with cone yield of Norway spruce clones in seed orchards.

Forecasting seed production in perennial plants: identifying challenges and charting a path forward

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Interannual variability of seed production, known as masting, has far-reaching ecological impacts including effects on forest regeneration and the population dynamics of seed consumers. Because the relative timing of management and conservation efforts in ecosystems dominated by masting species often determines their success, there is a need to study masting mechanisms and develop forecasting tools for seed production. Here, we aim to establish seed production forecasting as a new branch of the discipline. We evaluate the predictive capabilities of three models (foreMast, ΔT, and a sequential model) designed to predict seed production in trees using a pan-European dataset of *Fagus sylvatica* seed production. The models are moderately successful in recreating seed production dynamics. The availability of high-quality data on prior seed production improved the sequential model's predictive power, suggesting that effective seed production monitoring methods are crucial for creating forecasting tools. In terms of extreme events, the models are better at predicting crop failures than bumper crops, likely because the factors preventing seed production are better understood than the processes leading to large reproductive events. Understanding the drivers of seed production is crucial for ensuring the availability of reproductive material in the future. We summarize the current challenges and provide a roadmap to help advance the discipline and encourage the further development of mast forecasting.

FOREST TREE BREEDING IN MALAYSIA

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Forest plantation in Malaysia has encountered various challenges and the main problems being lack of superior planting materials and poor soil quality. The application of biotechnology in tree breeding such as the use of tissue culture, temporary immersion system as well as molecular breeding have greatly improved both the availability and quality of planting materials for establishment of forest plantations. This paper aims to provide information on forest tree breeding efforts in Malaysia with particular examples of R&D conducted by Forest Research Institute Malaysia (FRIM) since the 1950s. As the sole research institution responsible for conducting R&D in breeding of forest tree species, FRIM has vast experiences in conducting breeding trials which include selection of improved plant materials, establishment of clonal trial plots and monitoring of growth. In addition, breeding of plantation species that are resistance towards diseases have also been carried out.

Keywords: selection, improved planting material, breeding trial, seed production, pest and disease

Genetic improvement of Gmelina arborea for increased tree productivity in Kenya

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: In Kenya, *G. arborea* is one of the major exotic timber tree species in which is also used for wood carving due to its good workability qualities. Despite its numerous and wide range of products and ecosystem services, the high potentiality and maximum utility of Gmelina tree has not been met. Most trees in Kenya are slightly crooked with heavy and low branching characteristics while some have been attacked by pests and diseases lowering timber quality and quantity on sawing while limiting the productivity on other wood products hence the need for this study. This study is being conducted to genetically improve the tree species focusing on biomass production, fast growth rate, tree form and, freedom from pests and diseases. The improvement strategy has encompassed; testing of the phenotypically selected CPTs through progeny trials and establishment of seed orchards for improved seed production. Both the single tree and comparison tree methods were used for selection of *G. arborea* CPTs. In comparison tree method, candidate trees were first selected and screened for desirable traits in relation to the five surrounding trees referred to as comparison trees. Where the candidate tree exceeded the mean of the neighboring comparison trees, it was selected as a candidate plus tree. Preliminary findings have yielded selection of One hundred and twenty-six (126) CPTs from Kwale, Kilifi, Lake Victoria Basin, Kitui, Makueni and Elgeyo Marakwet counties covering 28 Gmelina population stands. Six F1 clonal seed orchards and two progeny trials have established in Arabuko Sokoke Forest, Kerio Valley, Siaya and Homabay. CAMCORE provenance/progeny trials have been set up in Gede and Migori to evaluate for survival and height performance of individuals within the families. Annual assessments are ongoing and data analysis so far has indicated significant variations between and within the families in the two traits at 48 months. The interim assessment of different individuals indicated large genetic improvement possibilities of *G. arborea* in Kenya.

Key words: *G. arborea*; improvement; breeding; productivity; Kenya

Genetic parameters of Pinus caribaea var. bahamensis in an open-pollinated orchard in the municipality of Assisi, São Paulo

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Tropical species such as P. caribaea var. bahamensis have relevance for the productivity of the country in tropical regions due to its adaptability to climatic conditions. This work proposed the characterization of the heritability and genetic gain of a test of provenance and open pollination progeny of P. caribaea var. bahamensis with the purpose of selecting the most productive progenies in wood production for future breeding programs. The test was implemented in March 1988 in the Assis State Forest (22º35'S and 50º22'W), in a randomized complete block design, with 72 progenies, one plant per plot, and 28 repetitions with 6 x 6 m spacing. The Selegen - REML/BLUP program was used for statistical analysis. Among the silvicultural characters analyzed for average heritability we highlight the wood volume and the diameter breast height (DBH), presenting indexes of 0.75 and 0.64, respectively. The genetic gain for wood varied from 0.79% to 28.48% and genetic diversity ranged from 0.01% to 1%. The number of individuals ranged from 14 to 986 plants, in four selection methods with 6 intensities. Heritability values for volume and DBH showed a strong indication of genetic gain. The selection proposal that showed the best genetic gain is the individual selection (28.48%) with the selection intensity of 2% and the number of selected individuals is 22 plants. The proposal that showed the best genetic diversity was the selection within progeny (ranging from 0.98 to 1.00), with a number of individuals ranging in selection from 72 to 986 plants. The selection methods mentioned are satisfactory because they demonstrate possible genetic gains and help in the choice of material for genetic improvement programs for wood production.

Genetic Qualities, Cold Hardiness, and Performance Evaluation of Locally Collected Lodgepole Pine Seeds from Stands of Seed Orchard Material in Sweden

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Lodgepole pine (*Pinus contorta*; LP) has become the dominant non-native tree species in Swedish forests. Forest regeneration with LP offers an efficient method for boosting forest production in northern Sweden.

The utilization of seed collections from practical plantations offers a low-intensity approach to capitalize on the improved traits resulting from initial plus-tree selection. To address an acute seed shortage, extensive stand seed collections have been conducted in Swedish LP plantations (F1 generation, seed orchard offspring's) that have been in operation for approximately 30-35 years. This study aimed to assess the genetic qualities, for particularly cold hardiness and growth traits, of such stand collected seeds in comparison to known Swedish and Canadian seed sources. The analysis included plant material from commercially collected stands, the seed orchards, and the original seed sources in Canada, in comparison with Scots pine (*Pinus sylvestris*; SP) seed sources. The freezing test results revealed that the stand-level collected seeds in Sweden exhibited comparable cold hardiness to the plantation-sourced seeds. Latitude of the collection site emerged as the most influential factor impacting cold hardiness. Furthermore, the study investigated potential differences in field test results between stand collected seeds and seed orchard derived progenies, as well as the influence of different seed sources on estimated variation and heritability. The findings contribute valuable information on genetic gain, genotype-environment interaction, transfer effects, and grouping in the breeding evaluation system. This research provides crucial insights into the quantification of disparities in growth, survival, and resistance between improved and unimproved material. The comparison between LP and SP, as well as the results obtained, hold significance for estimating genetic gain.

LP is advantageous for breeding strategies due to its early flowering, capability for rooting cuttings, and suitability for clone testing and rapid generation turnover. In the late 1970s, Sweden initiated a seed orchard program to ensure self-sufficiency in genetically superior LP material. The program involved plus tree selection in Canada, genetic testing of open-pollinated families in Swedish field trials, and establishment of seedling seed orchards for genetic enhancement.

Genetic Selection Using Linear Deployment for the 2nd Generation Seed Orchards of Quercus acuta and Q. glauca

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: The impact of climate change is causing a gradual northward shift in the distribution of warm-temperate tree species. To address this phenomenon, the Korea Forest Service is actively improving growth characteristics of *Quercus acuta* and *Q. glauca*, focusing on their high carbon absorption and adaptability to climate-induced stress. Seedling groups were propagated in 2022 at Jinju and Naju nurseries in South Korea, intended for establishing new seed orchards on Jeju Island. This study conducted genetic selection using linear deployment on the seedling groups of both species. Breeding values were calculated for mother trees in the base populations, considering biomass and seed production. The mean of initial breeding value was 2 and the standard deviation was 0.76 for *Q. acuta* base population and the mean was 2 and the standard deviation was 0.81 for *Q. glauca*. Three scenarios were simulated: 1) selecting all mother trees except for the lowest breeding value, reducing selection intensity by 10%; 2) selecting 34 and 50 mother trees in *Q. acuta* and *Q. glauca*, reducing selection intensity by 10%; and 3) selecting 34 and 50 mother trees in *Q. acuta* and *Q. glauca*, adjusting selection intensity based on seed orchard size and tree spacing. As the results, under the first scenario, when 50% of the seedlings were selected from the total, the selection difference was 0.343, the status number was 101.1, and the number of seedlings was 753 for *Q. acuta*. For *Q. glauca*, under the second scenario, when 50% of 50 mother trees' seedlings were selected, the selection difference was 1.067, the status number was 120.7 and the number of seedlings was 1070, which the selection difference was compared to 1.7 times for the first scenario as the same number of seedlings. Finally, if we create a 2-ha seed orchard for each species, *Q. acuta* has a selection difference of 0.315 and the status number of 104.0, while *Q. glauca* has 1.084 and 118.7, respectively. This study would provide valuable information for establishing genetically improved populations and contribute to enhancing carbon sequestration in forestry.

Genetic testing in a Larix kaempferi plantation using pedigree reconstruction and spatial analysis

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Genetic testing and selection for diameter growth in a Larix kaempferi plantation were conducted through the integration of pedigree reconstruction and spatial analysis. This study aimed to identify genetically superior larch individuals in a plantation as an alternative to progeny trial. Genetic variation assessment was precedently conducted to validate the suitability as breeding material. Genetic testing followed with a model incorporating pedigree information and spatial autoregression for accurate analysis. As results, the expected heterozygosity for mother trees and offspring was 0.672 and 0.681 respectively showing the retention of considerable genetic variation in the offspring. 188 offspring were assigned to 92 candidate mothers and one to six progenies were belonged to each family. Genetic testing employing the model considering phenotypic spatial autoregression structure improved model fitness compared to the result using model without spatial factor. The estimated genetic variance for diameter at breast height (DBH) was 9.086 in the former model, highly increased from 4.9E-5 in the latter model. Predicted breeding values for DBH ranged from -5.937 cm to 5.655 cm and the estimated heritability was 0.344. The genetic testing combining pedigree reconstruction and spatial analysis is expected to be an effective alternative to traditional progeny trials. It can facilitate the identification and selection of superior individuals for tree improvement purposes. The approach utilizing genetics and spatial information also would be useful to enhance the efficiency and accuracy of breeding program.

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Genetic Variation of Cone and Seed Characteristics in the Second-Generation Clonal Seed Orchard of Pinus densiflora

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: This study aims to investigate genetic variation in phenotypic characteristics of seed cones and identify superior clones for seed production in a second-generation clonal seed orchard of *Pinus densiflora*. The seed orchard was established in 2014 in Chuncheon, Republic of Korea, and comprised grafted seedlings re-selected through a progeny test. A total of 42 clones and 1,300 ramets were sampled, and cones were collected from them during the years 2020, 2021, and 2022. Various cone characteristics, including weight, length, width, dry weight, seed potential, aborted ovules, filled seeds, and empty seeds were examined. Analysis of variance (ANOVA) was performed to assess genetic variation and estimate heritability, as well as to conduct correlation analysis among clonal cone characteristics. As a result, there were significant differences among clones in relation to all cone characteristics. The heritability of filled seed production was estimated as 0.667, 0.927 and 0.757 for the years 2020, 2021 and 2022, respectively. Statistically significant variations were observed among clones in all cone features, except for the year 2020 due to a high rate of cone insect damage. Furthermore, correlations among cone and seed characteristics were identified, particularly between filled seed rate and mature seed rate, length, weight and dry weight ($p<0.0001$) in 2020, 2021 and 2022. This study provides genetic insights into the impact of clonal variation on seed production and emphasizes its significance in seed orchard management, along with genetic thinning and selective seed harvest based on phenotype, besides the selection of superior clones for establishing a third-generation seed orchard.

High stand density improves seed production in seed orchards of the masting species Picea abies

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Masting or mast seeding is the phenomena of synchronous and highly variable seed production between years by populations of conifers and other perennial plants. Examples of economic important tree species besides *Picea abies* is *Quercus robur*, *Fagus sylvatica*, *Picea glauca*, *Pinus nigra* and *Castanea sativa*. The physiological mechanisms and how they are linked to internal resource status and to external weather factors are still under scientific exploration and debate. Masting behaviour can be difficult to manage in the production of improved seed in seed orchards. Short term results may lead to incorrect conclusions. Here, results from a long-term thinning experiment in a *Picea abies* seed orchard will be presented.

How useful are the acorn resources? Quantifying the plant-available carbon in acorns using achlorophyllous oaks

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Seed size is an important phenotypic trait commonly associated with the overall fitness of young seedlings. However, determining the actual plant-available resources provided by the seed is difficult. We utilize a one-of-a-kind natural mutation that has created a population of achlorophyllous oaks (*Quercus robur* (L.)), plants without chlorophyll, to quantify the plant-available carbon in the acorns. The achlorophyllous oak population was discovered in spring 2022 in an 80-year-old Q. robur forest in southern Sweden. Growth and survival were measured in the achlorophyllous oak population, as well as a normal green (chlorophyllous) oak population. The two populations were followed from germination until all achlorophyllous seedlings had died. Interestingly, the achlorophyllous oaks survived almost a year on the acorn resource. By comparison, 76% of the normal green oaks survived the first year. The photosynthetic capacity was similar across the growth season for both the achlorophyllous and chlorophyllous oaks. For the achlorophyllous oaks, we were unable at any time to detect any carbon uptake, whereas the chlorophyllous oaks had a maximum photosynthetic capacity (A_{max}) averaging around 3-7 mmol m^{-2} s^{-1}. Leaf area-based day-time respiration was similar for both achlorophyllous and chlorophyllous seedlings. However, the leaves of achlorophyllous oaks were significantly thinner. The number of leaves, leaf area, and seedling height were similar between the white and green oaks, indicating similar seedling carbon investment independent of chlorophyll content and photosynthetic capacity. Our findings suggest that the acorn provides the young seedling with sufficient resources for growth and maintenance respiration in the first year, independent of photosynthesis. We are also modeling the total amount of carbon used by the seedlings, and thus the total amount of plant-available carbon in the acorns.

Identification and selection of individuals as seed sources for the restoration of the tropical dry forest in the Upper Magdalena River Basin

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: The tropical dry forests (TDFs) of Colombia have experienced a significant reduction in their original area due to human activity. Ecological restoration processes for TDFs have been developed with different strategies for the recovery of this ecosystem, one of which is the use of seed sources. Currently, there is a loss of tree individuals of native species, which leads to a reduction in seed sources and a decrease in the obtainment, quality, and availability of plant material that plays an important role in conserving genetic diversity and species adaptability in restoration projects. To address these challenges, a study will be carried out in the Huila Department, specifically in the environmental compensation zone of the El Quimbo Hydroelectric Plant, from July to December 2023. The objective of the study is to identify and select individuals with optimal phenotypic characteristics to classify them as seed sources, thus meeting the demand for forest seeds required to continue these restoration processes. The methodology to be used is based on previous studies conducted in this area, which provide information about existing seed sources in the project. Additionally, an increase in tree individuals with favorable characteristics for native seed production will be carried out. Physical, physiological, and sanitary analyses of the seeds will be conducted according to International Standards for native seeds in Ecological Restoration, adapted to the protocols of the ISTA (International Seed Testing Association). It is estimated that this research will result in native tree species adapted to environmental variables, pests, and diseases, contributing to the growth of forest genetic diversity and the availability of propagation material. Furthermore, it aims to contribute to Colombia's National Restoration Plan by providing relevant information for the recovery of Tropical Dry Forests.

Identifying and using a minicore PSR gene cluster to assess phosphate nutrition in plants and soils

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Adequate phosphate (Pi) nutrition is essential for plant growth and development. However, it remains a challenge to effectively assess whether the corresponding Pi status in plants and/or soils is appropriate for a given plant. Here, we show that Pi status in plants and soils can be assessed by a minicore phosphate starvation response (PSR) gene cluster (MCPG). The MCPG cluster is isolated from the common PSR genes in Chinese pine, Arabidopsis, maize, rice, soybean, and wheat by RNA-sequencing analysis. Moreover, we find that the MCPG cluster is conserved across species and is controlled by the Pi-central regulators of PHRs-SPXs. Furthermore, we find that the expression levels of the MCPG cluster are negatively correlated with Pi status in plants and soils. Based on this correlation, we developed a PCR method for the successful and standardized assessment of Pi status in plants and soils worldwide. Taken together, this study highlights the importance of MCPG cluster in response to Pi status and provides an effective molecular diagnostic method for estimating Pi status in plants and soils, which will be useful in guiding future precise applications of Pi fertilizers.

Influence of cone physical characteristics and extraction exposure period on seed yield of Pinus patula

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: *Pinus patula* is one of the serotinous coniferous species whose cone opening for seed release is influenced by temperature. This study examines the correlation between extraction exposure periods and cone physical characteristics on *P. patula* seed yield. Systematic random sampling was employed for tree identification in an even-aged clonal seed orchard, and the laboratory phase was laid down as a factorial experiment with two factors: cone physical characteristics and extraction exposure period at three levels. Seed counts were taken for cones categorized as; heavy, light, narrow, and wide at three extraction exposure periods 6 hours, 12 hours, and 24 hours in a constant oven temperature of 65°C. The experiment had 12 (L1, H1, N1, W1, L2, H2, N2, W2, L3, H3, N3, W3) treatments with 60 cones per treatment. The time spent counting and returning cones during the inter-stage observation ranged from 10 to 15 minutes. Data collected were tabulated and means analyzed using ANOVA with results generated as per the objectives. The number of seeds released within the hours of exposure was captured as the seed extraction rate. The first six hours yielded the optimum number of seeds per cone with the mean highest number of seeds from wide cones. The lowest mean number of seeds released observed was 28, from light cones, while the highest mean number of seeds was observed to be 56 from wide cones. Cone sorting based on size before extraction is recommended for optimized seed yield. The stages of seed extraction employed here can be used in mechanized seed extraction cabinets equipped with timers at controlled temperatures.

Influence of Cupressus lusitanica Mill. Cones and seed characterization on germination in Kenya

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: *Cupressus lusitanica* is a key plantation species with many uses leading to demand for seed. This species produces seeds within cones, which are collected for seed extraction. There are variations in seed collection and handling which compromise quality. Few studies focus on cone morphometry and seed characterization, thereby causing a gap in quality improvement through packaging and subsequent germination. Fifty cones were collected from each of the thirty identified trees within a clonal seed orchard. Cone characterization, seed extraction and germination were performed in the laboratory. This was a factorial experiment with three factors: cone diameter, seed diameter and seed density and their influences on germination. The present study separated the cones by diameter (20mm sieve) and weight. Seed were sieved (2mm sieve) weighed, floated and germinated. The results showed that seed size and density heavily impacted on germination and thereby showing that sorting through sieving and floatation would provide a low cost technique for seed quality improvement. The technique in the present study improved germination from 25% to 50%, and also reduced the number of seeds per kilogram from 290,000 to 105,000.

Macropropagation of Khaya senegalensis (A. Juss): A Vulnerable tree species

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: *Khaya senegalensis* (Juss). is one of the valuable timber tree species of West Africa which is vulnerable to extinction because of its high demand. The use of growth hormones for mass propagation of tropical tree species has become very important due to scarcity of viable plant materials. This study investigated the effects of organic hormone (coconut water and *Aloe vera*) and inorganic hormone (Naphthalene Acetic Acid (NAA) and Indole Acetic Acid (IAA) at different concentrations) on single stem cuttings of *Khaya senegalensis* (Juss) to ensure availability of quality seedlings for plantation establishment. Leaves of treated cuttings were reduced to half of their sizes to reduce the rate of evapotranspiration. These were set in sterilized riversand and replicated twice with 5 cuttings per replicate, and arranged in a completely randomized design (CRD) under a mist propagator. Untreated cuttings were also included to serve as the control. After 60 days, cuttings were assessed for number of roots, longest root, total length of root, percentage callusing, percentage sprouting and percentage rooting. The use of organic hormones had no significant effect on the number of roots of *Khaya senegalensis* at $\alpha_{0.05.}$ Organic hormones had a significant effect on root length but coconut water was not significantly different from the control and *Aloe vera*. Effects of inorganic hormones were significantly different from each other with NAA producing the highest number of roots (4.27cm), followed by control (3.5cm) while IAA produced the least (2.33cm). The control recorded 100% callus formation, rooting, sprouting and survival while inorganic hormones had <90% in the variables. Based on the findings of this study, it was concluded that cuttings of *Khaya senegalensis* seedlings could root and sprout with or without hormones. If it is necessary to use hormones, organic hormone, *Aloe vera* gel or coconut water at 100% concentration is recommended.

Mixed mating patterns and pollen introgression in Melia volkensii clonal seed orchard; implication for genetic improvement and germplasm production

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: *Melia volkensii* is a monoecious, insect-pollinated tree species endemic to semi-arid region of east Africa valued for high quality termite resistant timber, however, limited knowledge of its mating patterns is hampering advancement of its genetic improvement in Kenya. We evaluated mating systems, gene flow patterns and level of pollen introgression within *M. volkensii* clonal seed orchard using 12 microsatellite markers. Four hundred and eighty open pollinated progenies from ten clones and 200 potential pollen donors were studied. One hundred individuals representing the total number of clones within the orchard and 128 individuals from the orchard background population were used as the potential source of pollen. We conducted pedigree reconstruction to assign each seed's male parents, followed by determining the extent of pollen contamination, selfing rate, and, parental gametic contribution. High values of multi-locus (t_m = 0.933; 0.016) and single locus (*ts* = 0.919; 0.013) estimates of outcrossing rate indicates presence of mixed mating pattern with predominant outcrossing breeding system. The difference between tm–ts (0.014; 0.027) was low indicating absence of bi-parental inbreeding. Likewise, estimated correlation of paternity (*rp* = 0.029) was low indicating that many of the progenies did not share the same paternal genitors. The fixation index for maternal genotypes (*Fm*) within progenies was non-significantly low showing lack of inbreeding. The estimation of the probable number of pollinators (1/*rp*) indicated that about 69 pollen donors contributed in the fertilization of the progenies. The paternity analysis implicitly assigned 389 out of 471 progenies (82.6%) were assigned to 69 (69%) of the seed orchard clones. The unassigned 82 progenies (17%) did not match any of the 100 seed orchard clones and were considered to be derived from donors outside the orchard. Our findings indicate existence of adequate gene flow within the orchard probably due to predominant out crossing breeding nature and reproductive synchrony among genotypes. The seed orchard design and flowering synchrony with the background population could have contributed to the pollen introgression in the orchard. Review of the current isolation distance between the orchard and the background population should be considered to ensure integrity of the seed source.

Morphometrics of Pinus patula crown and its effect on cone characteristics and seed yield in Kenya

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: *Pinus patula* like other conifers have cones as an important unit for seed production. Cone production is however not uniform and often varies among compartments and sectors within the crown. This study sought to evaluate within-crown cone production patterns, cone characteristics and seed yield in a *Pinus patula* clonal seed orchard in Londiani, Kenya. Crown height was divided into 3 equal portions and a further subdivision done for each of the portions into 2 sections. From each crown section 10 mature cones were collected to total 60 cones per tree as a sample size. The cones were put in a preheated oven at temperature 65°C for 24 hours to open for seed extraction. This study observed cones collected from the top portion of the crown yielded the highest amount of seed (33.3±4.91 seeds) ($p<0.05$) while the bottom part had the lowest (14.4±2.76) ($p<0.05$). The study recommends collection of *Pinus patula* seeds from the upper part of the crown in unmanaged stands and further recommends that management through pollarding be done regularly to minimize within-crown differences.

Optimizing Genetic Gain and Diversity in Seed Orchards

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: In this presentation, we introduce a cutting-edge methodology designed to optimize both genetic gain and diversity in seed orchard crops. Our tool relies on the Mathematical Programming Language (AMPL) capabilities. This innovative system offers several marked improvements over some heuristics currently employed in various tree breeding programs. A significant advantage is the assurance of globally optimal solutions and the elimination of continuous software maintenance. The AMPL system distinguishes itself by separating model and data inputs. This results in a simplified process that enables quick modifications to the model statement, capitalizing on its straightforward algebraic format. Our practical guide details how to seamlessly incorporate genomic data, reproductive biology data, pollen contamination statistics, and other pertinent information into the optimization process. We argue that the ideal solution obtained from our tool should act as a benchmark. This allows tree breeders to compare other potential strategies or assess the efficiency of current seed orchards, all within the context of the comprehensive data available. Our methodology extends its utility to specific applications, such as genetic thinning, supplemental mass pollination, or selective seed harvesting. By employing our algorithm, tree breeders can make these processes more efficient and optimized. We hope this methodology will empower tree breeders to take full advantage of the potential of their programs.

Parental contribution dynamics and seedling cold-hardiness in the Scots pine seed orchard Västerhus

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Seed orchards are the most crucial source of genetically improved tree seeds for forestry. Ample yearly flowering of orchard rametes, regular and abundant seed crops, and uniform parental contribution from all orchard genotypes are prerequisites for stable crop production and the economic efficiency of breeding. In reality, variation in flowering is multifaceted, comprising yearly, individual, and age-related variation. Consequently, parental contribution to the crop deviates from the assumptions due to these irregularities and is further complicated by such factors as phenological asynchrony and clone representation. Finally, the inflow of alien pollen into the orchard results in the progeny with unknown genetic background and unpredictable traits. In the present study, we aim to understand the connection between the cone and pollen production within the orchard and the contribution to the crop from the orchard genotypes, calculate background pollen contamination (BPC) rate, and estimate the extent to which affects cold-hardiness of seedlings is affected by the external gene flow. The needle material for DNA extractions was sampled from seedlings (n=927) in the Scots pine orchard Västerhus that was organized following the linear deployment concept of multiplying ramet numbers according to their breeding values. We constructed sequencing libraries from three seed crops using a genotyping-by-sequencing (GBS) strategy and multiple single-nucleotide polymorphisms (SNP) markers to reconstruct parentage. We coupled this data with the pollen and cone records gathered in the orchard to assess the dynamics of clone contribution to the gamete pool in the orchard. Results from freeze tests performed on orchard seedlings were analyzed in order to link the BPC rate and the degree of cold damage among seedlings. The results elucidate the extent of yearly variation in the parental contribution to the crop from the orchard genotypes as well as the link between the unknown genetic background of the crop and the degree of freeze damage and may serve as a reference for orchard management.

Pedigree reconstruction in a black pine half-sib progeny test to assess paternal success and improve breeding efficiency

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Wind/Open pollinated (OP) progeny testing is predominant in tree breeding, and particularly in the first breeding cycle, aiming mainly in efficient backward selection or forward selection. The OP families are usually considered and being treated, as half-sib (HS) families, as mother trees are known and the number of pollen donors is considered to be large. However, the half-sibs are only real half-sibs if none of them resulted from selfing and if all of them were sired by different males. But this is seldom the case in OP families, and for this reason the estimates of genetic parameters are biased, leading also to the not accurate ranking of parental trees based on their breeding values. In the current work we performed paternity analysis in an OP progeny test by using microsatellite markers. The progenies originated from a black pine seed orchard established by following the honeycomb experimental design in order to minimize kinship in the produced seed/seedlings. The seed orchard consists of 60 clones originating from the geographic region of Central Macedonia in Greece, while each clone was represented in the orchard by 20 ramets. The results showed that clones differed in their paternal success and some of them scored overall a very high paternal contribution. True half-sibs (HS), full-sibs (FS) and selfs were identified per maternal genotype, but their number varied depending upon the maternal genotype. The results are discussed in terms of breeding efficiency and accurate ranking of parents based on their breeding values for growth traits, as well as in relation to male strobili production of clones and morphological traits of their pollen grains.

Physiological and molecular mechanisms of nitric oxide during seed germination

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Trees reproduce by producing seeds, and the seed dormancy-germination pro-cess, which initiates the tree life cycle, is crucial for the establishment of seedlings and their ability to survive adverse external environments. Seed germination is of great significance for nursery stock yield. Nitrogen is an essential nutrient for tree growth and development. Reactive ni-trogen species (RNS) have important regulatory functions in tree physiological activ-ities. Recently, nitric oxide (NO) has been shown to not only serve as an important nitrogen source during seed development but also to participate in a variety of stress responses in trees to high salt, drought, and high temperature. In addition, NO can affect the process of seed germination by integrating multiple signaling pathways. However, due to the instability of NO gas activity, the network mechanism for its fine regulation of seed germination remains unclear. Therefore, this abstract aims to summarize the complex anabolic processes of NO in plants, to analyze the interaction mechanisms between NO-triggered signaling pathways and different plant hormones abscisic acid (ABA) and gibberellic acid (GA), ethylene (ET) and reactive oxygen species (ROS) signaling molecules, and to discuss the physiological responses and molecular mechanisms of seeds during the involvement of NO in abiotic stress, so as to provide a reference for solving the problems of seed dormancy release and improving tree stress tolerance.

Physiological process determination and transcriptome analysis during seed germination of moso bamboo

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: This research explore physiological process of seed germination, the mechanisms in the main pathways during seed germination and the mechanism of gibberellic acid treatment on seed germination, that could be used as the foundation for bamboo seed production, expansion breeding, and research.

In this study, ultrastructural observations and transcriptome data analysis of the germination seeds with and without GA_3 treatment were performed. In addition, the germination-related indicators (germination rate, germination potential, vigor index, respiration rate), total starch content, crude oil content, and enzymes related to respiratory activities of non-treatment seed were measured.

The results indicated that: (1) the optimum seed water content of moso bamboo using different storage times was 12.4%, after moderate drying of fresh seeds, seed water decreased, germination rate increased, respiration rate decreased, and seed vigor increased. However, with the extension of storage time, seed water content decreased, and the seed germination rate, germination potential, and vigor index decreased, seed water content of moso bamboo largely influences vitality index and respiratory; (2) the degradation of carbohydrates including lipid and starch metabolism play an important role in providing energy during seed germination of moso bamboo. Total starch and crude oil decreased and the starch metabolism and the lipid body degradation pathway genes were consistently upregulated during moso bamboo seed germination. AP2 and bHLH proteins were the most common upregulated transcription factors related to seed germination and may play significant roles in seed germination. (3) The low gibberellic acid concentration treatment on germination seed accelerated the decomposition of starch and fat and promoted the vacuole formation of cells, but the high gibberellic acid concentration damaged organelles and increased the endocytosis of cells. After gibberellic acid treatment, GID1 and DELLA-related genes homologous to rice genes is not expressed, but the expression of PIF4, PIF5, GA_3 *ox*2, GA_2*ox*s, etc., were up-regulated.

Regulation of the vegetative to reproductive growth transition in conifers

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production
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Abstract: Conifers are the backbone of forest ecosystems in the Northern Hemisphere and the most widely planted tree species. Coniferous trees usually have a long vegetative growth period, and it takes years or even decades for some trees to enter the reproductive growth phase. There is considerable interest in how perennial trees reckon their growth times and developmental ages and enter the reproductive growth phase at a specific age. This is also a crucial issue for the breeding of trees with long juvenile period. Relative to the thorough understanding of the vegetative phase transition in angiosperms, a little is known about this process in perennial conifers. Based on the high-quality reference genome and annotation of *Pinus tabuliformis* (Chinese pine), we identified *PtDAL1* as an age timer, a MADS domain transcription factor (TF) gene that shows an age-related expression profile. Two regions, a 10.5 kb and a 6 kb segment, at the five-prime end of the first ultra-long intron in the *PtDAL1* showed a gradual reduction of CHG methylation as the age increased, which was highly correlated with its expression profile, suggesting that DNA methylation serves as an important epigenetic signature of developmental age in conifers. In addition, the PtDAL1 directly regulates the *PtDAL10* transcription by binding to its promoter region, resulting in a ternary MADS domain TF complex with PtDAL10 and PtMADS11, two potential candidate regulators of the vegetative to reproductive transition in Chinese pine. We provide insight into the molecular components associated with the PtDAL1, which integrates the vegetative to reproductive phase transition into age-mediated progressive development of the whole plant in conifers. These molecular components associated with the age-dependent cone-setting pathway may be used as a potential genetic tool to shorten the breeding cycle of conifers with a very long vegetative stage.

Reproductive systems for accelerated delivery of genetic gains in important quantitative traits in Acacia crassicarpa.

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: *Acacia crassicarpa* A.Cunn. ex Benth. is an important tree species in Asia. Its vigorous growth, disease resistance, and good bole form are valuable features for tropical forestry. Still, there are constraints to maximizing the delivery of genetic gains. Although feasible, controlled pollination is impractical for advancing populations requiring a huge effort to produce a few crosses per year. Vegetative propagation is possible only with juvenile ortets. Finally, there is limited knowledge about its wood properties. This study applied genomics to unveil reproductive systems, reconstruct full-sib families for trial testing, and evaluate the potential of genomic selection to accelerate genetic gains delivery. Additionally, important wood properties were characterized, and within-tree patterns of variation were investigated for efficient phenotyping.

One reproduction season of a seed orchard was characterized by genotyping 84,315 seedlings with forty-two SNP markers. 67.8% of the seed collected was derived from male parents within the orchard. The average number of male parents per family was 50, with the dominant male proportion at 23%. Cumulative combined male-female reproductive success indicated 50% of parents producing 80% of the seed.

Forty trees were selected for destructive sampling at 50 months and assessed for wood density, kraft pulp yield, α-cellulose, carbohydrate composition, lignin content, and S/G ratio. The mean basic density was 481 Kg/m^3, and pulp yield 53.8%. Ground-level sampling could reliably predict the whole-tree property for basic density, pulp yield, and glucose content.

Genetic control of quantitative traits was studied with multi-environmental trials. Growth traits, basic density, and straightness were predominantly additive, with heritability ranging between 0.09 to 0.45. Genetic correlation across sites was high for all traits. Straightness was independent, survival correlated with MAI, and growth traits correlated among themselves. Surprisingly, basic density was correlated with growth. Genomic models with 10 thousand trees outperformed pedigree-based models. Accurate individual selection resulted in valuable gains for all units of selection. The gain from within-family genomic selection was 18%, doubling the gain achieved compared to deployment based on family means.

This comprehensive study provides real answers to the conservation and breeding efforts of *A. crassicarpa,* allowing the maximization of the delivery of genetic gains.

Resin Tapping from Pinus elliottii var. elliottii clones in the state of São Paulo, Brazil

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: The resin tapping has great economic importance in the forestry industry for the Southern and Southeastern regions of Brazil. *Pinus elliotti var. elliotti* is the most widely planted conifer for resin tapping. This is due to its high productivity and adaptability to different soil and climatic conditions. The aim of this work was to characterize the resin production of an untested clonal seed orchard of *P. elliotti* var. *elliotti* to identify the most productive clones and manage the orchard based on technical criteria. The clonal seed orchard was established in 1984 with grafts from selected resin-tapping trees at an intensity of 1:100,000 in the municipality of Assis in São Paulo State. The orchard has a spacing of 6 x 6 meters and consists of 980 trees. In 2022, resin tapping clones was extracted based on traditional methods with a panel size of 19 cm and 29 streaks. Resin was collected and weighed during the months of March, July, and December of the same year. Statistical analysis was performed using the Selegen-REML/BLUP program. Since the species is not adapted to the planting local soil and climatic conditions, the graft survival rate was 52%. The average total amount of resin was 4.6 kg for the 29 streaks, with an average per collection of 1.55 kg. The maximum and minimum values for each collection ranged from 0.05 kg to 5.77 kg between months. The phenotypic correlation between the average amount of resin per harvest and the total amount was 0.92. The correlation between the total amount and the individual harvests was also high, indicating that the most productive trees maintain their performance throughout the year. In addition to seed, propagule and pollen collection from the grafts that produced above-average resin were harvested to establish clonal and progenies tests. Furthermore, the pollen was used to performance and control pollination. The clone’s productivity was validated based on the genetic tests.

Screening of Salix clones for morpho-physiological and biomass attributes under varying planting density and salt stress

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Global climate change has emphasized on utilizing perennial trees as a renewable source of energy. Genus *Salix* of family salicaceae is a well-known commercially raised short-rotation tree species that has immense utility in sports industry, phytoremediation and biomass production. In India there are about 31 indigenous and 4 exotic species of willow. Identifying high biomass producing clones could promote the use of short rotation high density *Salix* plantations thereby supporting crop diversification, restoration of degraded wastelands, meeting demand of wood based industries as well as enhancing the farmer's income. Keeping in view the economic potential of the species, selected forty two clones of *Salix* were procured from Department of Tree Improvement and Genetic Resources, College of Forestry, UHF, Solan, Himachal Pradesh and screened under nursery conditions in tropical environment, out of which twenty eight clones were evaluated under field conditions. The best performing four clones were established under different planting densities (1 x 1 m, 1 x 2 m and 2 x 2 m) using factorial randomized block design in February 2020 and were evaluated for growth and physiological traits for three consecutive years. Significant effect of different spacings and clones were observed for various growth and physiological parameters except stem straightness. Overall, the spacing of 2 x 2 m has been found to be most suitable for maximizing growth in terms of volume index, irrespective of clones in willow based short rotation forestry. The phytochemical profiling of bark and leaves of the best performing hybrid clones using GC-MS analysis has revealed the presence of various pharmaceutically important phytochemical compounds. Furthermore, the remediation potential of selected *Salix* clones has been evaluated in pot experiment under varied levels of salinity and the promising clone(s) are under field evaluation on problematic soils.

Keywords: *Salix*, clones, growth, physiology, biomass, spacing, salt stress

Seeds for climate-adapted forests: New strategies for management of seed orchards, seed storage and germination testing

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Climate change has serious impacts on Austrian forests: not only are the climatic optima and distribution areas of tree species shifting, but extreme climatic events are increasing, leading to destabilization of forests. Reforestation of disturbed areas thus will become one of the key challenges for forestry in Central Europe in the coming decades.
To enable "assisted gene flow", artificial regeneration will become even more important in the future. However, forest nurseries often cannot meet this high demand due to lack of suitable seeds. This is especially the case for oaks and silver firs, whose seeds cannot be stored in the long term, but which are at the same time particularly important for the establishment of climate-resilient forests. Furthermore, in recent years in Austria, decreasing germination percentages and/or harvest failure have been increasingly observed in these species, for which seed demand has steadily increased in recent years. Therefore, it is essential to better understand the physiology of seed production in oak and fir to develop improved management tools to enhance seed production at least in seed orchards. The goal of the project FORSEE is to develop practical concepts for intensifying orchard management to ensure a long-term supply of high-quality forest reproductive material.
Results from manipulation experiments in fir seed orchards will be used to develop treatment procedures regarding fertilization and irrigation as needed for continuous yields. The potential and effects of phytohormone treatments on uniform seed yields in oak plantations will be evaluated. In addition, we present the results for a series of fir and oak seed treatment experiments with the goal to optimize harvest and storage logistics for fir and oak.

Strobili, conelet and cone productions in clonal seed orchards of Anatolian black pine*

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Seed orchard is one of the most important seed source to produce improved seed crop for forestry practices for different purposes. Numbers of female and male strobilus, and conelet and one year old cone productions were compared together with estimations of variations among clones within orchard in three clonal seed orchard populations of Anatolian black pine [*Pinus nigra* Arnold. subsp. *pallasiana* (Lamb.) Holmboe] to contribute management practices of seed orchards. The seed orchards consist of 30, 30 and 34 clones selected phenotypically in natural stands 1994 (SO_1), 1991 (SO_2) and 1985 (SO_3), respectively. The reproductive data were collected on five grafts, chosen at random, from each clone.

The orchards produced >80% male strobili than female strobili. Conversion of female strobili to conelet and cone productions was about 50% and 15%. Clones within orchard showed difference for cone productions in all the orchards, while other characteristics changed according to orchards. Many biotic and abiotic factors could impact on the differences. The coefficient of variation ranged from for number of female strobili (36.8% and 29.3%) and cone production (71.9% and 74.1%) in SO_1 and SO_3, respectively. However, the coefficient of variation was between number of conelet (32.4%) and number of male strobili (41.9%) in SO_2.

Positive and significant ($p<0.05$) relations both phenotypic and genetic among the characteristics were estimated generally.

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Studies on Dof Transcription Factors from Moso Bamboo (Phyllostrachys edulis) Responding Abiotic Stress and Influencing Flowering Initiation

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: Moso bamboo (*Phyllostrachys edulis*) is the most widely distributed and extensive use among the bamboo species, it is one of the dual-use bamboo species that combines economic, ecological, and social benefits. However, moso bamboo collectively die after flowering, causing serious economic losses and ecological damage. Previous studies found that *PheDofs* might be involved in the flowering and abiotic stress response of moso bamboo and has many biological functions, but the mechanism was unclear. Six *PheDofs* genes (*PheDof1*, *PheDof2*, *PheDof4-1*, *PheDof12-1*, *PheDof12-2*, *PheDof26*) were isolated from moso bamboo by molecular biology method, having a conserved single zinc finger domain. *PheDofs* took part in ABA and GA3 stress responses. GUS staining showed that *PheDof4-1* was expressed in the roots and hypocotyls of transgenic *Arabidopsis*, and *PheDof12-1* was detected in the roots, hypocotyls, leaf vascular bundles, stamens, and petals of transgenic plants. Under drought stress, over-expressing *PheDof12-1* transgenic *Arabidopsis* seeds had earlier germination time, faster growth rate and had longer roots than wild type, which increased the drought tolerance of transgenic *Arabidopsis*. Under the condition of 150 mM NaCl, salt stress tolerance of transgenic *Arabidopsis* was enhanced after overexpression of *PheDof26* and RNAi interference. However, antisense expression of *PheDof26* reduced salt stress tolerance in transgenic *Arabidopsis*. Under drought and salt stresses, overexpression of *PheDof4-1* resulted in low germination rate, slow growth and seedling yellowing of transgenic *Arabidopsis*, stress-related genes *CBF2*, *CBF3*, *COR15A*, *KIN1*, *RD22*, *DREB2A*, *ERD10*, and *ZAT12* genes were down-regulated, reducing resistance of transgenic *Arabidopsis*. In contrast, antisense expression of *PheDof4-1* leaded to up-regulation of stress-related genes and increased tolerance to drought stress in transgenic *Arabidopsis*. By yeast two-hybrid library, the resistance-related protein PheeIF5A was initially screened to interact with PheDof4-1. The results of this study provided scientific basis for the research on resistance breeding and molecular regulation mechanism of moso bamboo flowering.

Utilizing an early cone-setting trait to implement a Rapid Cycle Breeding program for Norway spruce.

T3.34 Tree improvement delivery system: breeding, selection, and seed and seedling production

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Abstract: One of the largest challenges facing tree breeding programs is a long juvenile period. In Norway spruce (*Picea abies*), reproductive maturity is not reached until a tree is 20-25 years old. This makes it difficult to produce improved trees that are adaptable, disease/pest resistant, and productive in a rapidly changing climate. Therefore, the most valuable way to make genetic gains that can address these issues would be to reduce generation time.

We recently discovered a natural mutation within a miRNA156/529 binding site of a SQUAMOSA BINDING PROTEIN-LIKE transcription factor (*PaSPL1*). Trees with this mutation display an early cone-setting trait and produce cones and cone-like structures in 3-5 years. Using this trait, we aim to develop a Rapid Cycle Breeding (RCB) program to breed Norway spruce more rapidly and efficiently. Our strategy builds on three pillars that each contribute to a shortened breeding cycle. The first is to use Genomic Selection (GS) to identify genotypes with high breeding values with respect to yield, pest and disease resistance, and climate resilience. The second is to use recent advances in automated micropropagation of somatic embryogenic lines to create clonally propagated breeding lines. The third pillar is to temporarily introduce the early cone-setting trait in selected breeding lines to allow for a rapid transition into the next generation and a renewed round of GS. Our early work towards this started by transforming *PaSPL1* with different mutations in the miRNA156/529 binding site into *Arabidopsis* and *Populus* in order to better understand regulation of *PaSPL1*. We then transformed mutated *PaSPL1* genotypes into Norway spruce cell lines. Once trees are regenerated, we will evaluate early cone-setting and choose which mutated *PaSPL1* genotypes produce the most useful early cone-setting phenotype. Additionally, early cone-setting genotypes will be generated using CRISPR, and non-transgenic protocol using PEG-mediated transfection of protoplasts are also planned.

After the methods are evaluated and efficient protocols have been created, we will mass-propagate elite cell-lines of Norway spruce via somatic embryogenesis. These cell-lines will be transformed with the mutant *PaSPL1* and used in the RCB program. Offspring with mutant copies of *PaSPL1* will be segregated away.

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

Actors' perceptions of profitability along a bushmeat commodity chain in West Africa (Southern Benin)

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: Bushmeat trade is increasingly viewed as main factors of faunal extinction in Africa. This study aims at providing details on hunters' economic drivers, traders and consumers' behaviour and factors determining trading actors' perception about bushmeat trade sustainability. Data were collected from 120 bushmeat trade actors in southern Benin through direct interviews. Economic and financial indicators were estimated and compared using descriptive statistics. Factors affecting the actors' perception of wild animal hunting, trading or supply sustainability were assessed using binary logit. About 15 wild species were traded along the bushmeat commodity chain in southern Benin. Hunters gross product is higher during the dry season ($t= 10.3; p<0.0001$). The bushmeat trade during intensive hunting period allows traders to earn more commercial margin compared to weak hunting period ($t=12.8; p<0,0001$). Hunting reasons, number of hunters per household, availability of large fauna and bushmeat products selling prices increase actor's perception to continue long-term hunting activities while trading issues and regulatory measures on the wild animal trade decrease actors' perception of bushmeat trade sustainability. Consumers' monthly income and the opportunity to purchase on credit, influence positively their perception of wild animal consumption. Commercial hunting and bushmeat trade offer significant compensation to actors involved in the wild animal commodity chain in southern Benin.

An analysis of the wild meat trade in the Colombian Amazon.

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: The uncontrolled and increasing commercialization of wild meat has repercussions for the conservation of wildlife and the health of forest ecosystems, as well as the food security of local communities and the cultural connections that indigenous people have with wildlife. In the department of Vaupés in the Colombian Amazon, more than 80% of the population is indigenous belonging to 27 ethnic groups. A great proportion of this population has migrated from the interior of the department to the largest population center and provincial capital Mitú, in search of education, employment, medical services and, in recent years, attracted by state benefits. "San Victorino" is Mitú's main port, where the local populations trade fish, fruits, tubercles, insects, fariña, casabe, and wild meat obtained from the rivers, farms and forests of the region. We present results of a long-term monitoring of the commercialization of wild meat, conducted from September 2017 to date in Mitú. Through this monitoring we were able to identify the species of wild animals involved, the amount traded, and place of harvest. In total, 838 commercialization events were recorded, equivalent to 4,646.92 kg, from 9 taxa, among which the paca (*Cuniculus paca*) was the most traded species, with a volume of 2,503.8 kg, followed by the tapir (*Tapirus terrestris*) with a volume of 1,159.9 kg. Trade of wild meat came from 72 communities that marketed it with different intensity and proportion to satisfy the demand in the urban area. This commercialization situation identified in Mitú is a reflection of the Amazonian context, where commercial hunting to supply urban demand is the main driver for unsustainable overexploitation of wildlife. We discuss strategies to influence a constructive norm-building dialogue between the indigenous and environmental authorities that benefit the conservation of commercialized fauna species in the municipality of Mitú, as well as the greater Colombian Amazon region

Community wildlife management in a RAMSAR wetland in northeastern Colombian Amazon

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: Community wildlife management in a RAMSAR wetland in northeastern Colombian Amazon.

The reduction of wild species populations due to unsustainable harvesting levels is an acute risk for tropical forest integrity and future livelihood strategies for local communities. We present ongoing collaborative research from the Colombian Amazon department of Guaínia, were we are working with a group of 30 indigenous researchers from different ethnic groups (Curripaco, Puinave, Piapoco, Cubeo, Sikuani and Tucano) in the city of Inírida and in an internationally recognized Ramsar wetland area (complex of wetlands of the Estrella fluvial Inírida) which covers some 250,000 ha. Since 2019, and with the support GEF Heart of the Amazon Project, we evaluate the variety of species and quantities used for food and meat trade. Furthermore, we collect data on the availability of wild populations, to study the extent to which cultural use practices are sustainable and contribute to wildlife preservation. We use daily consumption and sale registration methods and estimate population abundances through linear transects, camera traps and counts by time or distance to compare abundances through catch per unit effort (CPUE). We find that seventy species are consumed, most commonly reptiles (turtles and alligators), and mammals like medium size rodents, peccaries and armadillos. A significant proportion of the volumes traded in Inírida come from areas adjacent to a Ramsar wetland. While the availability of populations is still under evaluation, indigenous researchers, local communities and their authorities are discussing management measures to ensure the viability of the resource in order to guarantee food security, cultural preservation, and maintain legal and sustainable economic alternatives

Do large herbivores enhance soil organic carbon storage and persistence in a temperate lowland forest?

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: Defaunation results in the production of ‘empty forests’, i.e., forests lacking large and medium sized mammal populations. The presence of animals is an integral component to ecosystem functioning of many forests but one important function is often overlooked; soil organic carbon (SOC) storage and persistence. The roles animals play in these processes have been highlighted in recent years making the continued defaunation of forests worldwide a potential source of GHG emission from soils as well as a major adversary of biodiversity. The majority of research into ‘empty forests’ has been carried out in tropical regions and little has been focused belowground, thus, in this study we aim to determine the effects of defaunation on how much and where carbon is stored in soils under an old-growth unmanaged temperate lowland forest in eastern Europe.

Soils were sampled at 15 sites in Białowieża National Park in June 2023 in deciduous and mixed deciduous areas. The sites consisted of an exclosure (7.5m x 7.5m), erected in 2000 to keep out all large fauna, and a nearby unfenced control plot of the same size. Five forest floor and 40cm soil core samples were taken in each exclosure and control. The soil cores were split at 0-5cm, 5-10cm, 10-25cm, and 25-40cm increments. All soil samples (600) were analysed for carbon content, nitrogen content, pH, EC, and bulk density. Forest floor samples (30) were analysed for carbon and nitrogen content. Soil samples were pooled per plot at the four depth increments (150 samples) and subjected to physical soil organic matter (SOM) fractionation yielding a differentiation of particulate OM (POM) and mineral-associated OM (MAOM). Carbon and nitrogen contents were analysed for each of these SOM fractions. We will demonstrate whether large herbivores have a clear effect on the storage of SOM in POM or MAOM, and thus the persistence of SOM.

The results from this study are shedding light on the cascading effects large herbivores have on belowground processes in intact forests. They will also help guide decision making and policies for restoration and rewilding efforts with goals of rehabilitating the GHG mitigation potential of forest ecosystems.

Effects of herbivore exclusion on soil greenhouse gas fluxes and biogeochemistry in the Białowieża forest

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: Large animals are important for maintaining forest ecosystem functions that sustain biodiversity and carbon storage. Animals mediate fluxes of carbon (C) and nitrogen (N) through effects on plant community structure (e.g. seed-dispersal and changing abiotic conditions) and chemical quality of organic matter entering soils. Forest soils constitute significant C and N pools that are important controls of atmospheric greenhouse gas (GHG) concentrations, but the isolated significance of animals in forest soil biogeochemical cycling is lacking. A better understanding of the faunal dimension of soil biogeochemical cycling and associated GHG fluxes will increase our mechanistic understanding of forests as possible nature-based solutions to climate change mitigation and inform contemporary efforts to (re-)introduce large mammals in so-called trophic rewilding projects.

In this study we show how soil C and N dynamics are influenced by multi-decadal exclusion of large herbivores (European bison, deer species) in the strictly protected zone of Białowieża Primeval Forest in Eastern Poland. By using 30 fenced exclosure plots established in 2000, we investigate changes in soil physicochemical properties and associated soil GHG-fluxes inside and outside of these exclosures. We expect to observe hot spots of soil GHG-flux in soils recently disturbed by large herbivores as a result of lowered soil diffusivity through trampling as well as deposition of labile organic matter through excrement. Furthermore, we expect that sustained long-term animal disturbances increase soil C and N pools as well as their persistence, congruent with expectations of increased aboveground C and N storage.

How is the distribution and diet of a reintroduced population of Crax blumenbachii Spix 1825?

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: *Crax blumenbachii* is an endemic and endangered cracid from the Atlantic Forest. Reintroduction projects for this species have been taking since the 90's and one of the biggest challenges is the low knowledge about their ecology. Thus, monitor reintroduced populations is an important ally in this process to ensure their conservation. The objective was to evaluate the diet and distribution of a reintroduced population of *Crax blumenbachii* in an Atlantic Forest fragment. The work was conducted at Fazenda Macedônia, in Minas Gerais, Brazil. The 631 ha property was divided into four regions: North, Center, Headquarters and South, and *C. blumenbachii* feces were collected from trails, roads, and built-up areas. Eighteen monthly campaigns were made between 2021 and 2023. The feces were georeferenced, and the seeds were separated, photographed, morphotyped and stored for species identification. 398 feces were collected, and 64.6% were found in the Headquarters, indicating a greater presence of birds. The release of this birds is made out in the Central (18.3%), near to the Headquarters, suggesting the dispersion of birds is relatively close to the point of release. The North (15.8%) and South (1.3%) had fewer records, reinforcing this strong relationship, since the South is farther from release point and Headquarters. 196 feces had seeds in their content and the proportion with seeds was higher in the Central (72.6%), indicating that although the largest number of birds in the Headquarters, they may be feeding on other sources there, such as insects and leaves. 97 species were recorded, and the Headquarters was the one with the highest number (58), probably due the landscaping of this region, which has many fruit trees, some of them from exotic species. Thus, we can state that the reintroduced individuals still have a strong relationship with the release site and the Headquarters, an area that suffers the greatest anthropic intervention, which increases the availability of resources for the reintroduced birds. However, measures, such as avoiding human contact and preventing access to water and food available to captive birds, must be adopted to reduce this dependency and ensure the dispersal of birds throughout the fragment.

Investigating the Relevance of 'Corridors' for Asian Elephant Conservation and Human Elephant Conflict Mitigation

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: The Asian elephant is one of the few remaining mega-herbivores on the planet, with a habitat that includes grasslands, tropical and deciduous forests, scrublands and cultivated lands in some cases. Due to habitat loss and fragmentation, the species is now classified as Endangered, with a reduction in population size and range. To mitigate the negative impacts of isolation, wildlife corridors have been proposed as an important strategy in conservation, therefore could be important for elephant conservation also. In Asia, elephant corridors have been widely adopted as an elephant conservation and human-elephant conflict management tool.

Sri Lanka holds an important position with regard to Asian elephant conservation and is the range country with the highest density of elephants and the third highest density of humans. The Human Elephant Conflict (HEC) in Sri Lanka is escalating, while the degradation of elephant habitats continues, necessitating active management for conservation and conflict mitigation. A number of elephant corridors at a landscape level have been proposed by the Department of Wildlife Conservation in Sri Lanka mainly for HEC mitigation but have still not been implemented. Other, smaller-scale corridors have been identified on radio tracking data, mainly from an elephant conservation point of view. Therefore, the likely effectiveness of the identified elephant corridors and their role in elephant conservation and mitigating HEC in Sri Lanka needs to be analyzed.

This study is to determine the conformation of identified elephant corridors to the definitions and specifications of wildlife corridors and assess their effectiveness in HEC mitigation and elephant conservation. This will be done using a combination of GIS and field data analysis. The analysis will include the physical characteristics of the corridors and linked areas, the legal status of the corridors, the presence of elephants and the attitudes and perceptions of residents within and around the corridors. Understanding the efficacy of elephant corridors and their relationship with HEC mitigation and elephant conservation will enable the development of effective conservation strategies and sustainable land-use planning in areas where HEC is prevalent, as well as help prioritize management actions and fund allocation.

Mediterranean riparian forests under new biotic interactions: stand structural changes and management implications

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: Riparian forests are one of most threatened ecosystems in Europe; the exposure to land-use changes and global warming, coupled with new biotic interactions, will contribute to increase biodiversity loss and induce unpredictable structural shifts in the mid-long term. In particular, Mediterranean riparian ecosystems are recently being recolonised by the Eurasian beaver (*Castor fiber* L.). This species is considered an "ecosystem engineer" because it modifies riverscapes by using woody vegetation for feeding and sheltering purposes (e.g., creation of lodges and river dams). In many riverine areas, the impacts of this large rodent on the tree layer can also shape woodlands that are already managed for hydraulic safety issues. We selected a cluster of three rivers to study compositional and structural changes of Mediterranean riparian woodlands under different pressure of beaver gnawing activity. We collected qualitative and quantitative data both at plot and stand level. Our results provide new insights on the topic by integrating information from studies in the Continental and Boreal sites. The main gnawed trees belong to *Salicaceae*, however trees can also be selected depending on the stand structure. Diameter mean of gnawed trees is significantly lower than not gnawed ones. Most of the selected trees fall into low diameter classes (< 15 cm), even if stand tree size distribution affected the diameter preferences. Over 90% of the gnawed trees are entirely harvested, with stumps as remnant elements. Main changes on stand structure are observed in the first ten meters from the river bank; beaver gnawing activity is significantly influenced by the interaction among tree distance from the river and diameter size classes. Structural and biodiversity indices help deepening multi-scale effects (at plot/stand level) of beaver activity. Our approach can be replicated in other Mediterranean sites to predict mid-term riparian forests vegetation changes due to beaver population expansion. Moreover, the collection of standardized data will facilitate dissemination by the scientific community aiming at informing stakeholders on the benefits and possible disservices linked to beavers in riparian forests.

Re-storying forests as animated through foundational fauna

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: Once upon a forest the humans came to save

Some species over others, told all how to behave

Restoring a vision based on ideas of the Wild

Sometimes disturbing fauna, not yet reconciled

We can tell a different story, restore something else

Listening to stories deep down in the cells

Re-storying the forest from a different point of view

Including new perspectives that tells us something new

Forest and fauna, two corridors of thought

Emphasis aligning to what we have been taught

Shifting our focus to how they interact

Can break our assumptions but leave our goal intact

As Land is far more than the dirt on which we stand

Including the relationships readily at hand

So is Forest more than what the eye first sees

Have we failed to see the Forest focusing on trees?

It is time that we let trees share the centre-stage

Because a humans and plants entangle and engage

With insects, herbivores, predators and dryads

In what we think of as multispecies triads

Choose a group of humans, an animal and plant

And relations emerge that before seemed rather scant

Re-storying the forest and animate the woods

See the social life beyond services and goods

If cognition is a verb rather than something that 'is had'

Human exceptionalism was nothing but a fad

Cognition of plants might be slow but has been found

Created in interactions with the environment around

Using creative language can help us think anew

Theorize a Forest that we didn't know we knew

Rhyming up our reasons shows us rhizomes of thought

How they're tied to feelings in way that might be fraught

Postscript:

Policy discussions argue that restoring degraded forests can support improved well-being. Yet restoration planning often falls short of this objective. This is, in large part, due to our inability to "tell a better story" that includes relations beyond species dyads. We outline an emerging research agenda for how creative, artistic, and storytelling methods can forge new directions to build richer, place-placed expressions of forest restoration agendas in support a broader vision of multi-species thriving.

Traditional Ecological Knowledge (TEK) for sustaining tropical forest wildlife and local livelihoods.

T3.35 Wildlife use and defaunation in the world's forest - what do we know about its impacts and responses?

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Abstract: Healthy forests are crucial for biodiversity and people. The sustainable use of forest wildlife by local and indigenous communities plays an important role in local social-ecological relationships. Science has only recently started to engage with local indigenous systems of knowledge referred as Traditional Ecological Knowledges (TEK). However, there are several methodological challenges for researchers who seek to integrate different types of knowledge, including TEK, to inform and understand the sustainability of wildlife use in tropical forests areas.

We draw on Participatory Action Research (PAR) and participatory methods with two indigenous communities in the Colombian Amazon region. We present findings on the social-ecological relation of local indigenous hunters in the two study sites and reflect on the role of traditional ecological knowledge in the regulation of wildlife use in tropical forests. Together with local researchers we developed a process of knowledge co-production and created diverse local cartographies containing traditional ecological knowledge on species distribution and social-ecological information. We complemented this data using camera traps, semi structured interviews with wildlife hunters and traditional leaders, drawing on ethnographic methods including participant observations and daily field interactions.We show how the immense knowledge that indigenous communities have of their territory and how the local TEK can contribute to a more sustainable use of wild fauna. We also describe how some drivers in the local context influence and change TEK.

The insights into knowledge coproduction we present, describe how dialogues of knowledge co-production methodologies can inform other initiatives involving TEK and wildlife use in the Amazon region. We present our study in a global context with the interest to connect to other different scenarios where these results can be applied and are looking forward to receive feedback that could enhance our ongoing research process.

T4.1 Actors and the dynamics of forest management institutions: concepts and cases in the Global South

Bridging actors and institutions in forest resource use and management in the global south: Theorizing on the framework conditions

T4.1 Actors and the dynamics of forest management institutions: concepts and cases in the Global South

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Abstract: The separate treatise of actors on the one hand and institutions in global forest use and management literature represents a yet-to-be-resolved scientific impasse. Consequently, questions related to how actors steer the process of institutional formation and change on the one hand, and how institutions and institutional change plays out on actors on the other hand, remain partially understood in forest management literature. While studies agree on the need to jointly analyze actors and institutions, a comprehensive theoretical proposition which speaks to both actors and institutions is lacking. Yet, theoretical constructs which show actors-institutional interactions and the conditions under which they collectively shape natural resource (forest) management choices demonstrate potentials as an extension of the knowledge frontier in the field of natural resource management. The foregoing lacunae perhaps, explains why policy recommendations are yet to address the natural resource management conundrum in diverse parts of the Global South. A holistic appreciation of forest management processes therefore requires fostering the "marriage" between actors and institutions; that is, determining how institutions set inclusion/exclusion criteria for actors to constrain and/or enhance forest use and management practices, and how actors on the other hand, employ their power elements to enforce, modify, make less effective or redesign institutions in forest management. This paper provides reflections on the tentative conditions/assumptions underlying an actor-cum-institutions theoretical framework in the context of forest use and management in the global south.

Distal flows and distant benefits – the case of tree plantations in North Borneo since 1982

T4.1 Actors and the dynamics of forest management institutions: concepts and cases in the Global South

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Abstract: Forest and agricultural spaces in Southeast Asia have been subject to contestation throughout history. Various actors, ranging from local communities and indigenous groups to state actors and multinational corporations, have participated in shaping forest landscapes and determining allocation of resources. The increasing involvement of international actors has introduced new dimensions to these dynamics, influencing the direction and magnitude of change.

One central question is then who are benefitting from former and current dynamics? What and who is enabling such transformations? We argue that any assessment of social and environmental outcomes in forest-agricultural frontiers will require a historic and critical global political economy perspective, as these outcomes are often shaped by distal flows of ideas, commodities and finance, and actors' underlying worldviews and aspirations for development and gain.

Malaysia, and the north Borneo state of Sabah in particular, are not exempt from these changes. Here, tree plantations were seen as a silver bullet to poverty reduction, sustainable development and to meeting global and domestic demands for timber and biomass. Our case study of Peninsular Bengkoka, built on a literature review and interview material, is a region that is still one of the poorest in socio-economic and environmental terms in Malaysia, despite the presence and promises of domestic and international actors and activities. Distal flows are deeply linked to these dynamics.

Shifting cultivation farming practiced by the locals in the Bengkoka Peninsula was deemed "primitive" by the Sabah government, a common colonial trope, and a resettlement and afforestation programme to plant 60,000 ha of *Acacia Mangium* was introduced to the locals in 1982 to encourage "start of a new life". Initial financing came from a World Bank loan, and expertise were provided by the World Bank, Australian and Japanese forestry and development consultants. As of today, plantation management, harvesting and processing is linked to complex and constantly changing public-private corporate structures with diverse flows of financing, including Australian, American and Finnish equity funds with global investors, accompanied by varied sustainability discourses. Yet, such investments have led to territorial exclusion of local land users, as precarity prevails in Peninsular Bengkoka.

Endogenous and exogenous actors in Forest Landscape Restoration: Insight from the Western Highlands of Cameroon

T4.1 Actors and the dynamics of forest management institutions: concepts and cases in the Global South

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Abstract: With the heightened global political and scientific interest in restoring degraded forest landscapes, governance issues on Forest Landscape Restoration (FLR) have recently received extensive scientific attention. However, studies on FLR-related exogenous and endogenous actors' interests and the extent to which they shape institutional arrangements are currently unclear, especially in the context of Cameroon. This paper attempts to fill this lacuna by analysing FLR-related actors' interests and how they influence FLR-linked institutional arrangements in rural Cameroon. We used a households survey complemented with expert interviews, key informant interviews, and focus group discussions to obtain data for the study. The analysis of the study's data revealed that endogenous actors show more interest in the cultural, social, and economic benefits of FLR but less interest in the ecological and politically related benefits of FLR than their counterparts. Also, most actors use more dominant information to shape other actors, while incentive measures are less employed. Additionally, dominant information and incentives exerted by actors resulted in full or partial compliance with associated institutional arrangements, while coercive and disincentive measures are linked with non-compliance with the respective institutional arrangements. Therefore, relevant FLR exogenous and endogenous actors should use a combination of dominant information and incentives to motivate compliance with FLR-related institutional arrangements.

Keywords: *Endogenous and exogenous actors, Forest Landscape Restoration, interest, institutions, sub-Sahara Africa*

Health-shocks and the dynamics of Forest management institutions: a comparative analysis of the Ebola virus and COVID-19 pandemic in Uganda

T4.1 Actors and the dynamics of forest management institutions: concepts and cases in the Global South

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Abstract: The dynamics linked to forest management institutions in sub-Saharan Africa continue to gain scientific and policy traction as indicated by renewed interests triggered by health-related shocks. It is therefore imperative to analyze the institutional change in forest communities within the context of health-related shocks. This paper draws from communities around the Busitema Forest Reserve of Uganda to explore the perceptions of forest users on the triggers of the Ebola virus and the COVID-19 pandemic and discuss forest management institutional responsesrds these health shocks. The paper is informed by field evidence; household surveys (n=135), focus group discussions (n=4) and expert interviews (n=8). The findings reveal that adherence to formal and informal institutions remains high. Furthermore, health-related shocks precipitate institutional change in a bricolage-like process, this manifests through the transposition of existing institutions to new functions, changes in rule application, the introduction of new institutions, and the modification of old ones. However, this study indicates that the scale of disease outbreak determines institutional change; compared to the COVID-19 pandemic, the Ebola virus did not induce substantial forest management institutional changes around the Busitema Forest Reserve. We argue for an actor-driven analytical approach to further enhance our understanding of the dynamics around forest management communities in the context of health-related shocks.

Nongovernmental organizations as interest groups and their roles in policy processes: Insights from Indonesian forest and environmental governance

T4.1 Actors and the dynamics of forest management institutions: concepts and cases in the Global South

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Abstract: The traditional conceptions and claims of nongovernmental organizations (NGOs) have profiled NGOs as civil society representatives and as benevolent philanthropic actors of development in the Global South. However, recent phenomena indicate NGOs often acting in opposition to their benevolent claims. This study attempts to move away from the normative concepts of NGOs and develop an analytical framework fitted with the current empirics in environmental governance. Using theories of organized interest groups in a democratic political system, we analyze the extent of NGOs fulfilling their roles as organized interest groups (OIGs), where they should take roles representing the interests of particular groups within societies and exerting political influence on governments on the basis of these common interests. We use empirics from Indonesian forest and environment-related governance, and our framework is called "Representation–Influence Framework,"which assists in establishing more systematic coherent typologies of OIGs. Analyzed from the perspective that NGOs claim to serve as representatives of specific groups within societies, we establish three overarching categories of OIGs, that is, 1) en route to fulfilling the claim, 2) breaking the claim, and 3) opposing the claim. We further detail our framework into a subset of nine OIG typologies. In this way, we provide pathways to begin deconstructing the common simplifications and misunderstandings about NGOs. For empirics, we identified 38 OIGs in the cases of social forestry and timber legality policies and populated them according to the typologies. We found that most of them are en route to fulfilling the claim of representing the groups' interests, although their political influence on the government is, in most cases, limited.

Keywords: NGOs; Interest Groups; Representation; Influence; Forest Policy; Environmental Governance; Indonesia

Power manifestations in forest ecosystem services use and management institutions: Empirical insights from community forests of Nepal

T4.1 Actors and the dynamics of forest management institutions: concepts and cases in the Global South

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Abstract: Community Forest (CF) has gained momentum worldwide in the last four decades. Studies show that power and institutions are inextricably interwoven. However, the actors' power manifestations in reshaping community forest management institutions persist in fragmented or tacit forms. This paper attempts to fill the gap by responding to the questions: who are the actors and their resources of interest, and how do these actors manifest power to (re)shape forest management institutions in community forests of Nepal, one of the pioneer countries for community-based forest management in the global south. We drew data from the eight CF that were chosen, which represent four different geographic regions of Nepal, by interviewing actors and conducting focus group discussions. The facts acquired from the interviews were supplemented by a review of provincial and federal policies and regulations, the forest management plan and annual report, and meeting minutes connected to the chosen CF.

The preliminary findings show that: i) there were differences in power dynamics among geographic regions concerning interest in specific forest ecosystem services (FES) and forest management outcomes. ii) despite many similarities, the actors differed in their ability to use power resources, such as coercion, (dis)incentives and dominant information to reshape FES management institutions; iii) The powerful actors, such as the government and the CF executive committee manifest all power resources, whereas non-state actors (donors, and civil society organizations) mostly use dominant information and incentives, and market actors manifest incentives; and iv) local actors, with better socio-political positions or networks, economic wellbeing, ethnicity and gender, could navigate and adapt diverse formal and informal institutions and power resources. This paper thus clearly demonstrates how external and elite local actors shape or reshape FES management institutions and outcomes. This paper further suggests the future direction of research and practices to clearly understand the consequences linked to the dynamics of actors' power and promote sustainable FES management in the CF.

Keywords: Community forestry, forest ecosystem services, institutions, power resources, power manifestation

Who should benefit from global forest governance incentives at domestic level? Insights from the Democratic Republic of Congo

T4.1 Actors and the dynamics of forest management institutions: concepts and cases in the Global South

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Abstract: State bureaucracies have a dominant position with respect to the ownership of forestland and related resources in the tropics. This situation is one of the major legacies of the colonial period in African countries like the Democratic Republic of Congo, DRC. In those countries, forest-dependent communities struggle to retain the upper hand over the local management of forest resources. These communities have been resisting the marginalization of their rights in autocratic regimes, especially in the context of an increasing assimilation and limited sight of tropical forests as carbon storage and climate change mitigation zones. DRC has about 60% of the Congo basin forest areas (approximatively 100 million ha of rainforests), has been active internationally in claiming compensation in global forest governance arenas to leave its trees stand for climate change mitigation purposes. The debate on the exploitation for development ambitions versus conservation for biodiversity and climate change mitigation has become a fundamental societal battle and sensitive political issue among key actors involved in the governance of forestland resources in DRC. One of the major conflicting political issues in this debate is associated to what should be the most equitable benefit sharing system for the financial rewards expected from global forest governance incentives to keep rainforests standing and forest carbon stored in DRC? Using institutional choice and recognition framework, this paper aims at addressing this question with a specific focus on the challenges in transforming into practice the rhetoric of reducing deforestation through an incentive-based mechanism (REDD+) in the context of institutional weaknesses and social inequality. Our findings show that the REDD+ project has failed to meet the expectations of both the state bureaucracy and the forest dwellers. Both actors deployed cunning and resistance strategies that led to the poor performance of the projects in resisting the top-down approach of REDD+ implementers.

T4.2 Carbon and nutrient cycling in urban forests

Bootstrapping to estimate the variability and uncertainty of equivalent carbon dioxide quantifications

T4.2 Carbon and nutrient cycling in urban forests

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Abstract: The carbon forest projects in managed forests are an important opportunity to remove the greenhouse gases of atmosphere through improve forest management. This study utilized the Bootstrapping technique to create multiple resamples by randomly sampling forest inventory plots with replacement. The focus was on quantifying equivalent carbon dioxide. A total of 16,281 sample plots in a forest community covering 28,210.0540 hectares were used for analysis. Different sample sizes were selected, ranging from 100 to 1000 plots in increments of 100, and each sample size was resampled one thousand times. Confidence intervals at 90%, 95%, and 99% levels were computed for population mean and total estimates of equivalent carbon dioxide. By applying Bootstrapping, the distribution of population mean, total estimates, and sampling errors were obtained to assess variability and uncertainty. The statistical distributions followed a normal distribution pattern for various sample sizes. When considering a sample size of 1000 plots, the sampling error for population mean and total were 2.35%, 3.60%, and 4.30% at 90%, 95%, and 99% confidence levels, respectively. The estimated population mean for equivalent carbon dioxide was approximately 218.4087, 218.5257, and 218.3596 tons of CO2e per hectare at 90%, 95%, and 99% confidence levels, respectively. The baseline estimate for equivalent carbon dioxide was 6,161,322.3727 tons CO2e, 6,164,620.4740 tons CO2e, and 6,159,935.8490 tons CO2e at 90%, 95%, and 99% confidence levels, respectively. The results indicated that sample sizes of 400, 600, and 800 plots ensured a sampling error of less than 5% at 90%, 95%, and 99% confidence levels. Therefore, resampling through Bootstrapping proved to be a powerful tool for statistical inference, providing a data-driven approach to estimating uncertainty in the population distribution and determining appropriate sample sizes for carbon inventory in carbon forest projects.

Development of quantitative models to estimate carbon storage and uptake by urban landscape trees in Korea

T4.2 Carbon and nutrient cycling in urban forests

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Abstract: The increasing concentration of CO_2, which negatively affects environmental, social, and economic systems, is a serious challenge globally. Urban landscape trees play a key role as carbon sinks to mitigate climate change. However, there are only few information on the calculation of carbon reduction by urban landscape trees in Korea. The objective of this study was to develop quantitative models to estimate carbon reduction by urban landscape trees using a direct harvesting method. To this end, this study selected 13 tree species, which are commonly planted as urban landscape trees in Korea: *Abies holophylla*, *Acer palmatum*, *Camellia japonica*, *Ginkgo biloba*, *Ilex rotunda*, *Lagerstroemia indica*, *Machilus thunbergii*, *Pinus densiflora*, *P. koraiensis*, *Prunus yedoensis*, *Quercus myrsinaefolia*, *Taxus cuspidata*, and *Zelkova serrata*. A total of 131 trees (10–11 trees for each species) were sampled at a regular interval. These sample trees were dug in the field, and the fresh weights of each part of the trees, such as stem, root, branch, and leaf, were measured. To convert fresh weight of the sample trees to dry weight (hereafter referred to as biomass), the collected specimens of each part were dried in an oven at 85 °C. The ratio of dry weight to fresh weight was calculated to estimate the dry weight for the part and tree total. The biomass was converted to carbon storage by multiplying its value by 50%. The annual carbon uptake was computed by analyzing the radial growth rates of stem diameter at breast height (DBH). Thereafter, quantitative models were derived to easily estimate carbon storage and uptake per tree using the DBH as an independent variable. All the quantitative models exhibited good fitness with high r^2 values. Carbon storage and uptake of the study species and their differences between DBH sizes increased as DBH get larger. This study provided scientific information for urban landscape trees to overcome limitations of the previous studies, which substituted coefficients from forest trees. This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education (NRF-2022R1I1A1A01071990).

Effects of species and growing situation for carbon storage in urban trees

T4.2 Carbon and nutrient cycling in urban forests

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Abstract: In the context of carbon footprints connected to urban areas, trees are often exclusively considered as carbon sinks, potentially mitigating carbon release from human activities. However, before an urban tree becomes a carbon sink it will instead contribute to carbon emission due to operations and activities in its nursery production, planting, establishment and following maintenance. The extent of the carbon emissions and the time needed for the trees to become carbon neutral depends on a large complex, where species-specific growth and carbon storage capacity, as well as spatial organisation of the trees and chosen planting bed substrate, will have great impact on the time needed to carbon neutrality.

The objective of this study was to investigate how carbon sequestration capacity and carbon storage in urban trees are affected by species selection and planting strategy, as well as to estimate the carbon footprint of an urban tree's complete life.

In this study we have made comparisons in growth patterns and carbon storage capacity between single trees and tree stands, planted either in parks or as street trees, in three species commonly used in an urban context in Sweden. We used dendrochronological sampling to evaluate growth rates in different situations, and included this data in life cycle assessments to gain knowledge of critical aspects in an urban tree's carbon budget.

The results will be discussed in relation to how planning and management of urban trees can be performed to improve sustainability in urban areas, from a carbon-perspective.

LiDAR-based allometric equations for quantifying urban tree aerial biomass and crown traits in Canada

T4.2 Carbon and nutrient cycling in urban forests

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Abstract: *In many cities and regions, the contribution of urban forests (UF) to the carbon cycle, as well as the regulation of key ecosystem services (air filtration, cooling, etc.) are still poorly understood. Allometric equations used for quantifying these elements are often not representative of local species and environmental conditions. Additionally, little is known on the effects of growing site conditions (e.g., streets, parks) on tree allometric relationships within urban settings. Particularly, in Canada, most allometric equations comes from United States data or from natural forests, casting a large uncertainty and potentially significant bias on both carbon and ecosystem services estimations for the UF. Focusing primarily on Montreal and its most abundant species, this study addresses the current lack of models and knowledge gaps by 1) developing allometric equations quantifying aerial biomass and tree crown traits for Canadian urban trees using a novel LiDAR-based method and 2) evaluating the effect of species identity and growing sites on the allometry of these trees. Data were mainly acquired from a terrestrial and mobile LiDAR inventory (2021-2023). Tree biomass was estimated combining tree individual volume (estimated from LiDAR-derived 3D models) with their wood density (obtained with local samples). Leaf area index of each tree were derived from LiDAR point clouds validated with in situ measurements. Non-linear models were generated to obtain allometric equations using diameter at breast height (DBH) and crown dimensions as predictive variables. Preliminary results suggest a high divergence of street trees allometry in comparison to analogue equations from natural forests in Canada. Notably, at equal DBH, broadleaf species in cities tend to have a higher predicted biomass than those of natural forests. Overall, these results corroborate numerous studies demonstrating the importance of allometric equations that are representative of urban tree growing patterns.*

Spatial patterns of topsoil macronutrients in urban forests across eastern China

T4.2 Carbon and nutrient cycling in urban forests

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Abstract: Macronutrients (e.g., nitrogen, N; phosphorus, P; potassium, K; calcium, Ca; magnesium, Mg) have important biological and ecological functions that support crucial ecosystem services. However, little is known about the large-scale patterns of soil macronutrient concentrations across urban forests. By measuring concentrations of macronutrients in topsoil samples (0-20 cm) from forest patches in 27 urban parks across nine large cities in eastern China, we analyzed their spatial trends and main drivers. Topsoil N concentrations, P concentrations, and N:P ratios in urban forests showed no significant latitudinal trends. Compared with natural forests, urban forests showed lower coefficients of variation of topsoil N concentrations, P concentrations, and N:P ratios. The spatial variation in urban topsoil N and P was mainly explained by climatic drivers and simultaneously mediated by pedogenesis and/or park age. Topsoil K concentration in urban forests showed a decrease from cities in the north to cities in the south, while topsoil Ca and Mg concentrations both showed a unimodal trend along with the latitude. The spatial trend of topsoil K concentration was mainly explained by mean annual temperature (MAT) and preurban soil order, while the spatial variations of topsoil Ca and Mg concentrations both were controlled by mean annual precipitation (MAP) and MAT. Our findings highlight the distinctive patterns of topsoil macronutrient properties across urban forests in the world's most rapidly urbanized region.

Vegetation structure, composition and carbon storage in three sub-urban areas of Harare, Zimbabwe

T4.2 Carbon and nutrient cycling in urban forests

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Abstract: Urban trees and forests provide important ecosystem services for urban residents including maintaining urban biodiversity, carbon sequestration, regulation of microclimate, regulating air pollutants and supporting human health. A study was done to assess structure, composition and carbon storage potential of trees in three sub-urban types (high, medium and low density) of Harare, Zimbabwe. Transects were made in each sub-urban type where the trees were identified and height (m) and diameter at breast height (cm) were measured. Height and diameter were used to estimate biomass and above ground organic carbon stock. Results showed that a total of 56 tree species were growing in the three suburban types of Harare. Fruit trees were more (60%) than indigenous (20%) and ornamental (20%) trees. The fruit trees were significantly more in high density suburbs than low and medium density suburbs whilst ornamental trees were more in low density than medium and high density suburbs. The structure of trees showed diameters and heights ranging from 5cm to >100 cm and 1.5 m to 20 m respectively. Species diversity was statistically similar for all suburbs. Tree biomass carbon stocks were more in indigenous trees than exotic species, with low density suburbs having significantly more biomass (7.09Mg^{-ha}) than medium density (4.7Mg^{-ha}) and high density suburbs (2.56Mg^{-ha}). Similar differences were in carbon storage. Urban households should be encouraged to play their role in climate change mitigation through planting trees around their homesteads. Furthermore, peri- urban farming should discourage tree destruction for agricultural purposes and promote agroforestry.

T4.3 Climate solutions by the forest sector: Opportunities, challenges, and responses

Evaluating forest carbon leakage under different protocol designs in the U.S. voluntary offset market

T4.3 Climate solutions by the forest sector: Opportunities, challenges, and responses

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Abstract: Forest carbon offsets can play important role in climate mitigation policies for governments and companies in the U.S. and around the world. For these offsets to be widely adopted they must be quantified using a methodology that ensures the integrity of the emissions reduction. An important component of an effective carbon offset methodology is the treatment of leakage, or the change in greenhouse gases (GHGs) outside of an accounting system due to GHG changes within the accounting system. Despite the known importance of accounting for leakage, few studies exist that have attempted to quantify it in a manner that could be adopted by an accounting methodology. We modify an intertemporal partial equilibrium model of the U.S. forest sector to assess the market, land use, and greenhouse gas (GHG) implications of a voluntary carbon offset program for improved forest management. Recent work has found that these voluntary market responses can differ from mandatory participation in ways that previous work had ignored. We improve upon past studies by differentiating leakage rates from offsets derived by leaving forest stocks intact thus avoiding emissions and offsets derived from removals from the atmosphere through tree growth. We then apply that standard to evaluate the impacts to both offset market participants and non-participants across a range of carbon prices. Results include marginal abatement costs (MAC) curves for each group individually allowing comparison of emissions profiles over the range of carbon prices. The difference between these two MAC curves provides insight into forest landowners' responses within the market equilibrium context. In addition to quantifying potential GHG additionality and leakage impacts of landowner participation in a voluntary carbon offset market in the U.S. forest sector, our results also highlight the complexity of accounting for those policy impacts within a consistent market equilibrium framework. This complexity is evident by evaluating the impacts of the voluntary carbon offset program on commodity prices, forest products manufacturing, and harvest levels in addition to GHG fluxes.

Examining Wild Food Sources in Mount Makiling Forest Reserve, Philippines to Promote Global Climate Regulation and Forest Financing Mechanisms

T4.3 Climate solutions by the forest sector: Opportunities, challenges, and responses

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Abstract: Food insecurity and climate change are prevailing issues of the 21st century. These issues are interconnected with one another and have adverse impacts on other sectors of the world. Thus, proposed solutions need to take into account multiple factors surrounding the issues and address them in a manner that does not exacerbate existing problems. The use of wild food sources such as fruit trees, can be a viable method to increase food availability, diversify diets, and decrease carbon emissions. This study assessed the productivity of wild food sources by estimating the food sources' biomass from the 10 randomly selected plots within the 2-ha permanent biodiversity monitoring area (PBMA) at Mount Makiling Forest Reserve, Philippines. The biomass values were calculated using the allometric formulae from Brown (1997). Following the methodologies of Diamante et al. (2019) and Zeng et al. (2019), these were subsequently converted to carbon sequestered to estimate the economic value of the global climate regulation service of the food sources. There were 434 tree individuals inventoried across the 10 plots, however only 33 wild food sources had a dbh ≥5 cm. The food sources in the 1000 square meter area studied were found to store 28.57 tonnes of carbon. Additionally, these wild food sources can be leveraged to develop finance mechanisms for forests. The estimated monetary values range from $342.79 or PHP 17,948.27 to $3,513.56 or PHP 183,969.79 when taking into account both the shadow price and the social cost of Carbon. The lack of human presence on the site (unmanaged) suggests that good management can lead to greater carbon offsets. This study only estimated the economic value of the global climate regulation service, however, other ecosystem services such as water regulation and aesthetic value may be considered. More importantly, assessing and monitoring the carbon offsets from wild food sources in forest projects and communities can be a flexible and effective way to expand their funding sources while addressing challenges with food insecurity and climate change.

Keywords: above ground biomass, carbon sequestration, ecosystem services, food insecurity, wild food sources

Forest management strategies from climate mitigation and adaptation perspectives

T4.3 Climate solutions by the forest sector: Opportunities, challenges, and responses

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Abstract: Setting forest management strategies has become increasingly important in current climate change discussion. Forests are seen as one of the alternatives to enhance carbon stock within forest's ecosystem and as product because of their ability to store carbon and substitute other carbon intensive products. Enhancing carbon storage in the forest and harvesting of products require substantial changes in management regime. This poses the challenges in the integration of mitigation and adaptation strategies in forest management. Little is described yet about the effectiveness of implementing strategies from both mitigation and adaptation perspective. To address this need, we aim to explain the complexity in timber production, carbon dynamics and its relation to species composition, forest structure, ecological and economic indicators, extent of disturbance and vulnerability in managed clear-cut, selection, and set-aside forests.

This study aims at evaluating the consequences of forest management strategies implementation from climate mitigation and adaptation perspectives. We select four different forest stands managed for long time under selection cutting system to simulate production and other properties of forests under different type of management regimes. We aim to describe forest management system from forest growth, harvesting potential, carbon balance, and ecological and economical perspectives. We apply a comprehensive analysis approach to relate resulted forest conditions into the forest dynamics and its complexity to explain production, ecological, economical and forest disturbance indicators.

We use first-hand inventory database to implement forest management strategies in the Heureka system. Heureka system is equipped with forest growth model, forest planning model, carbon accounting in both below and above ground biomass, and is integrated with Q-model to describe soil carbon. Further, based on prices of forest products, it is able to evaluate the land expectation value. Our evaluation on four different forest stands from different geographical locations in southern Sweden describe the complexity of management decisions in terms of mitigation of climate change and economic returns. Pay back calculations for carbon and economic returns are compared with industrial and ecological perspective. We aim to present results for maximum potential harvest, carbon sink and adaptation strategies.

Key-words: continuous-cover forestry, Heureka, carbon benefits, net present value, ecosystem-services.

Forestry and climate change mitigation: Experiences from Quebec (Canada)

T4.3 Climate solutions by the forest sector: Opportunities, challenges, and responses

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Abstract: The IPCC recognizes forestry as a critical element for climate change mitigation. We have estimated that for Quebec, a province of eastern Canada that possesses a large, primarily boreal, forest territory and a well-developed wood industrial network, an ambitious portfolio of actions mobilizing the forest lands and the wood processing industries could generate annual reductions varying from 0.5 to 6.7 Mt CO_2 eq/year by 2030. Implementing these actions requires detailed knowledge of the dynamics of forest ecosystems and the links between forests and societal needs for materials and energy. In this context, our results suggest that partial-cut harvesting, when used as an alternative to clear-cut harvesting in the boreal forests of Quebec, can be a promising way of supplying high-quality wood products to markets, maintaining carbon stocks in ecosystems and contributing to the resilience of boreal forests under a changing climate. Conversely, afforestation measures such as tree planting on abandoned agricultural lands do not appear to provide benefits in the context of Quebec. Most of these agricultural lands supported forest ecosystems before their clearing for cultivation, and field data suggest that they can revert relatively quickly to natural succession leading to a forest cover and sequestering large quantities of carbon without the need for artificial plantation. Moreover, the decrease in surface albedo and associated increase in radiative forcing incurred by the establishment of a coniferous plantation on a previously non-forested land can be substantial due to the high latitude and long snow-covered winters of Quebec; the deciduous-dominated natural succession (or plantation of deciduous species) can mitigate this effect. Nevertheless, our research demonstrates that improving the management of the end-of-life of wood products by preventing their landfilling (which is still very common in Quebec) through increased wood cascading use (for example, through a more extensive deployment of panel manufacturing based on recycled wood) or increasing the recovery and use of landfill methane would yield significantly higher climate benefits than any forest management action.

T4.4 Closing the forest transition theory – forest restoration policy and practice gap

Analysis of the environmental Kuznets Curve for forest transition: the case of Fujian province in China

T4.4 Closing the forest transition theory – forest restoration policy and practice gap

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Abstract: In recent decades, the international community has become increasingly concerned about several important environmental challenges including deforestation and forest degradation. Based on the remote sensing image data and socio-economic statistics of 32 sample counties in Fujian province, we investigate the impact of socio-economic and institutional factors on forest transition. We use a panel threshold regression model to group sample counties and examine the link between forest transition and economic growth at various economic development levels in the BTH region based on the environmental Kuznets Curve (EKC) theory. In the sample counties with various levels of economic development, we found different relationships between forest transition and per capita GDP. "N" and inverted "N" shapes represent the EKC of forest transition in the low- and high-income groups, respectively, and most data show that deforestation reduces with economic growth. Policy changes to reduce deforestation are recommended to promote coordinated and environmentally friendly development in the region.

Carbon fluxes in World´s forests: Losses of tropical intact forests and C gains predominantly elsewhere

T4.4 Closing the forest transition theory – forest restoration policy and practice gap

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Abstract: Terrestrial carbon (C) sinks have persistently removed about 30% of the carbon dioxide (CO_2) emitted from burning fossil fuels and land-use change over the last three decades. Forests are critically important in modifying the carbon budget of the atmosphere.

In 2011 Pan et al. published the article *A large and persistent carbon sink in the world's forests* in *Science*; a global research paper. We will present an update of those estimates as well as a critical reflection of the methods behind these estimates. Latest results indicate fluctuations of the forest carbon sink, continued losses of intact tropical forests, and resilience of the global forest ecosystems in so far despite emerging changes in the global climate. Some large regions like Europe and Canada are starting to show sink saturation effects or acting as a source.

These estimates are to large extent based on national forest inventories. Do they still suffice with long data release times? Will national forest inventories develop next to remote sensing? Forest inventory methodologies have evolved since 2011. In this presentation Yude Pan and co-authors discuss applications of forest inventory methods in carbon budget research. Can remote sensing and modelling approaches replace or complement field observations of Net Annual Increment and biomass drain? Clearly in assessing disturbances remote sensing has evolved rapidly. Also, other methods will be discussed to assess the forest carbon sink.

All methodologies confirm significant historical losses of tropical intact forests. New scientific results show both increases and decreases of forest carbon stocks depending on World regions. The

credibility of forest inventory data varies between biomes inviting other methodologies to support forest inventory approaches and to make scientific contributions. Reverting deforestation and degradation of World´s hot-spot forests represent ultimate challenges in efforts to prolong the era of forest carbon sinks.

Forest transitions, causal explanations, and reforestation policies

T4.4 Closing the forest transition theory – forest restoration policy and practice gap

Bradley Walters[1]
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Abstract: The idea that our understanding of forest transitions (FTs) and forest transition theory (FTT) might inform reforestation policies is intriguing, but far from straightforward. The coherence and meaning of FTT is much debated and fast-evolving, so offers little concrete guidance to policy makers and practitioners. Understanding the causal dynamics of land-use changes that lead to reforestation in specific places is thereby essential for policy prescriptions in those places. Yet this too raises a variety of causal-analytic (i.e., methodological) challenges - the focus of this paper - for both researchers and policy makers. So-called 'forest transitions' reflect a complex interplay of socio-economic and biophysical causes in which local and/or regional contexts and contingencies may be decisive. We need clear-eyed explanations of these changes and the human and geographical contexts within which they occur to identify opportunities for constructive policy intervention. Drawing from recent research in the Eastern Caribbean, I describe and illustrate how causal explanations of land use change and reforestation can be done well and with an eye to informing policy. In short, this entails starting with a clear specification of on-the-ground changes of interest (e.g., expanding or contracting forest cover; agricultural land abandonment; etc.) and then seeking to explain these changes by following chains of causation outward in space and backward in time, accounting for policy influences if and where relevant. The explanatory role of general theories, causal mechanisms and causal histories is examined in relation to current philosophical views about explanation and with reference to the Caribbean case study. The importance of precise 'event specification' for delineation and evaluation of causes is also highlighted and illustrated. Specific policy recommendations based on the case study are considered, and general suggestions then made to guide explanatory research in ways that might better inform effective policy and other practical interventions. The paper concludes with an appeal to epistemic humility: in a world characterized by complex and fast-changing human-environment interactions, even good causal explanations should not imbue overconfidence in what can be predicted or controlled in practice.

From Sustainable Development to Inclusive Development: Understanding just transition in forest carbon sequestration project.

T4.4 Closing the forest transition theory – forest restoration policy and practice gap

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Abstract: Since the first period of the Kyoto Protocol, developing countries such as China, India, and Brazil have conducted more than 3,500 CDM projects through the United Nations Framework Convention on Climate Change (UNFCCC) platform (UNFCCC, 2023b). However, an increasing empirical studies have identified livelihood risks associated with CDM projects, such as ecological displacement caused by restrictions on traditional livelihood practices caused by afforestation projects. These examples underscored the results of CDM projects that often do not meet the design goals and the sustainable development goals of host countries during the project implementation process, so that it is needed for an alternative understanding of the core concepts and methodology - that is, in light of the trade-offs between economic growth and ecological sustainability in global climate cooperation and their implications for developing countries, it is important to adopt a multi-dimensional approach to achieving more inclusive development goals.The concept of just transition has gained increasing attention in the global climate cooperation framework since the Paris Agreement was adopted in 2015 and widely applied in addressing climate change issues in developing countries. This article which analyzes the just transition in international climate cooperation and focuses on three questions: (1) addresses the issues of unequal rights between developed and developing countries in international climate cooperation which constructed under the Western discourse and technology; (2) uses the emerging concept of just transition to provide a new perspective on the differences between the design and the reality of international climate cooperation projects in developing country; (3) combing the concept and research framework of ID, this research considers an addtional demention of political relations and its influence on the just tansition progress in developing country. To reach the ends mentioned above, this article employs the just transition framework to analyze the participation process of China in the CDM international emissions trading mechanism, uses the Qualitative Comparative Analysis (QCA) method on 4 project communities and 22 households to identify the key combinations of conditions required for the farmer housholds to achieve a just transition in domestic contexts under the CDM mechanism.

How Spatial Pattern of Population Distribution drive forest cover changes: case of China

T4.4 Closing the forest transition theory – forest restoration policy and practice gap

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Abstract: Over centuries, urbanization and rural depopulation have been prevailing across the world, but how to impacts to global forest cover change has been in questioning. This research took China as a case to examine interrelationship between population spatial pattern and forest cover changes in over 50 years. The results are: 1) migration of rural population are not necessarily lead to the forest cover increase; 2) however, over 50 years, distance between population and forest distribution gravity gradually enlarged in China, reducing dependence rate of rural people's livelihood on forests; 3) there is great variation among regions, and forest policy and proper enforcement are dominant factors to nurture forest cover increasing while rural depopulation. Population increase contributes to forest loss in large extent, and stabilization of world population and proper policy in depopulation are essential to achieve global forest transition.

Key word: Forest transition, Zero forest cover loss at 2030, rural depopulation, forest policy

Land- use histories of planted tree cover caution international agenda promoting reforestation

T4.4 Closing the forest transition theory – forest restoration policy and practice gap

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Abstract: Multiple national and multi-national schemes promote extensive tropical reforestation under the auspices of climate-change mitigation and environmental remediation. The necessity of economic incentive and public participation in such schemes has meant that such reforestation has generally taken the form of commercial tree plantations as well as agroforestry. The history of such tropical planted tree cover does not bode well for the desired environmental outcomes of such schemes in the absence of strict oversight. Here, the land-use histories of 5000 1-ha plots of planted tree cover were reviewed via visual interpretations of satellite imagery over 1990-2015. Plots were sampled pantropically within the extent of current (2015) planted tree cover and represent all major tropical plantation regions. Visual interpretations allowed for unprecedented scrutiny of the frequency by which planted tree cover – including sparely-treed lands or temporarily-cleared lands otherwise dedicated to planted tree cover – replaced natural forest cover versus managed scrublands or similar, as well as the timing and nature of land-use transitions culminating in planted tree cover. A very small proportion of plots had planted tree cover continually since 1990. Most plots were initially natural forest. Land-use transitions from natural forest to planted tree cover rarely featured intermediate stages of managed lands (e.g., agriculture) and, where they did, managed land uses were typically fleeting. Overwhelmingly, therefore, planted tree cover has replaced forests of greater environmental value, and done so relatively directly. Landsat vegetation indices of the plots, observed at roughly monthly intervals over 1985-2020, affirm consequently how vegetation coverage declines, and soil exposure increases, for years or decades following transitions to planted tree cover. The logical policy response to prevent such historical trends from repeating is to strictly limit incentivized reforestation to verifiably long-cleared lands, invariably being grazing lands on the spatial and economic peripheries. The recent and arguably successfully implementation of such a scheme in Panama will be outlined. The practicality of such an administrative approach to incentivized 'forest' production, given ambitious reforestation targets, remains uncertain and ultimately recalls debates over the relative merit and simplicity of ‘doing nothing’ to allow natural reforestation instead.

Tree-planting assistance and forest transition of communal lands: Implications for integrated land restoration and development projects

T4.4 Closing the forest transition theory – forest restoration policy and practice gap

Wil De Jong

Abstract: Local communities, living in or near forests and dependent on forests and other natural environments to meet livelihood needs are often mentioned as beneficiaries and protagonists of forest and land restoration. In forest transition debates the same communities are also recognized as contributing to forest recovery when land use intensification and forest restoration of communal lands takes place. Our paper disentangles how communal forest transition and communal endogenous or externally supported forest restoration interact. Forest transition on communal lands are long term processes resulting from multiple intra and extra communal drivers. Externally supported communal forest restoration usually is only one of those drivers, and such restoration is more likely to be successful and will contribute to sustained communal forest transition if it concurs with other, positive communal forest transition drivers. This insight has implications for forest transition theory, but also for how and where communities may be involved in forest and land restoration efforts.

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

Gamified learning of long-term opportunities and limitations of forests in climate change mitigation

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: The biological growth dynamics of trees (growth curve) and the age structure of forests essentially determine the current level of forest growth at the area level on a certain site, whereas long-term cutting possibilities are determined by the growth curve and total area of forests. Cuttings affect growth mainly through manipulating the age distribution, either between stands in even-aged systems or within stands in uneven-aged-systems. In the long term, the difference between cuttings and removals, which is very closely connected to carbon balance of forests, necessarily approaches zero regardless of the selected level of cuttings. Furthermore, the growth at the area level has an upper limit, and reaching that requires maximum sustainable level of removals. However, especially in boreal conditions, forests grow slowly and these basic principles of growth dynamics are poorly understood, e.g., by policymakers and the general public. Based on gamified visual analytics, we present an interactive tool that allows exploring how the forest age structure, growth, removals and the difference between cuttings and growth develop over several centuries under different simple cutting scenarios set by the user. The tool illustrates forest dynamics by animating the age distribution of forests over time. For example, we allow scenarios where the difference between growth and removals has been set (fixed carbon sink scenario) and scenarios where cuttings are restricted to any level, including those that exceed the maximum sustainable level. The input data for simulations includes the age distributions and growth curves based on the National Forest Inventory data of Finland. The tool has been recently used in demonstrating growth dynamics to forest researchers, forestry students and policymakers in Finland.

"Can Social Media Revolutionize Forest Ecosystem Service Marketing? Unlocking Potential through Networks and Influencers!"

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: Payments for ecosystem services (PES) schemes are considered a promising economic instrument for diversifying the income of forest owners and rural communities while supporting biodiversity and climate mitigation. Social networks and social media influencers (SMIs) possess the ability to establish credibility with their large audiences through perceived expertise, sharing personal experiences, and opinions. As a result, they hold influence over consumers' decisions. Therefore, modern world business and society hold great expectations of social media`s impacts. This study aims to find which social media-related techniques, methods and instruments support the process of forest ecosystem service (FES) marketing to change the behavior of the local providers and consumers of PES programs, facilitate engagement, particularly with rural participants who otherwise would not have been aware, trusted, able, or willing to join the program.

A literature review established a framework of key factors related to social media (SM) and SMIs. The interaction of these factors was analyzed by a network graph using Gephi software. A survey of three PES case studies in Europe provided an overview of the importance of these factors and insights into PES actors' behavior on social networks. Considering the actors` characteristics, the framework identified influential factors like SM platforms, content types, SMIs characteristics, and socio-economic impacts on environmental services consumption. Survey results showed that almost half of the participants confirm the positive role of social media tools for promoting the forest ecosystem services provision. YouTube emerged as the preferred platform for forest owners, regardless of their role as buyers or providers of FES. Short videos and live interviews garnered significant attention across all the actors regardless of age and gender. Additionally, 45% of respondents considered reliability as the key characteristic of SMIs.

By understanding the impact of SM and SMIs and addressing the identified barriers, it is possible to foster greater participation and engagement in PES initiatives, leading to a more sustainable and environmentally conscious society. Although, further research and practical implementation contribute to enhancing the effectiveness of SM on PES programs and accelerating their adoption.

Assessing the value and transparency of eco-labels: Contrasting business and consumer perspectives

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: Eco-labels have been hailed as an essential communication tool that enables consumers, both individual and organizational, to assess the environmental performances of various products and services – thus playing a critical role in informing their decisions. This apparent usefulness of eco-labels has led to the development of multiple labelling schemes, but the global market is now inundated with over 450 eco-labels covering various sectors and products. However, majority of eco-labelling programs fall short of providing credible and transparent information regarding producer's compliance, or which sustainability criteria are covered. Another key question is whether consumers (both individual and organizational) recognize and trust eco-labels – and if so, what are the parameters that sets one eco-label apart from others. In particular, there seems to be a lack of robust methodology in assessing the transparency, democracy, impartiality and sustainability impacts of eco-labels. Our study takes an initial step toward answering these problems. We explore the possibility of developing a scale that organizations (through agents such as procurement/supply chain or environmental officials) and consumers could use to assess the viability and utility of adopting or purchasing products and services through an ecolabel evaluation. Our initial findings from interviewing such agents and consumers suggest major differences in how the performance and trustworthiness of existing eco-labelling schemes are evaluated. Subsequently, we indicate the need for developing a standardized rating scale for eco-labels that accounts for both organizational and individual perspectives and facilitates a coherent evaluation of these labels by multiple stakeholders. We also raise the call for enhancing the transparency of eco-labels which may be key to increasing consumer and producer confidence in them – thus paving the way for their increased utility as a decisional and informational tool in sustainability transition.

Don’t let them fall behind – the value of real life connections in a digital world of forest communication

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: There is no one size fits all when it comes to communicating forest science. In Austria, the transition to climate-smart forests heavily depends on the involvement of private forest owners as they manage more than 80% of the forested area. But there is not “the traditional forest owner” who can be reached in one specific way. Societal changes affect forest ownership, shifting it from mainly farm- or family-owned business to a more diverse set of “new forest owners”, which include a lot of “non-farming” and urban forest owners. With the ownership not only the connections to and demands on the forest change, but also the position of the owners in the forestry community.

This requires novel and user-centric ways of communicating new findings and to help practitioners develop their understanding of climate-smart forests and their management. The Austrian Research Centre for Forests BFW set up several projects focused on science communication for different target groups – from traditional practitioners to middle school students.

Since many of the new forest owners are forestry laypersons, the forest information platform www.klimafitterwald.at was created as a one-stop shop with information and tools like an advisor search and a tree species traffic light system, providing an initial assessment of appropriate tree species for one's own forest. Another main output is a series of light-hearted informative videos about what to do when inheriting a forest. For more traditional forest practitioners regular practice days have been integral for knowledge sharing in the community. Transferring them into a virtual environment with sessions streamed from the forest to the comfort of living rooms across the country enabled us to reach many more people from diverse and non-forestry backgrounds than before the pandemic.

Even though the use of podcasts, social media, and videos has become a key branch of communicating forest related information, it is still vital to forge real life connections between practitioners and scientists. Therefore, a fundamental part of our work is face-to-face communication, with communities and organisations requesting our experts for events and personal advice on the ground on topics such as tree species selection and biodiversity conservation.

Exploring Public Perceptions of Forestry and Ecosystem Services: Insights into Scientific Knowledge Communication and Strategy Development

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: Recognizing the significance of effective external communication and the sharing of scientific knowledge, this study emphasizes their critical role in garnering long-term support from society and policymakers to achieve the goals of multifunctional forestry, foster the development of ecosystem services, promote resilient forests, and effectively address the challenges of climate change.

By utilizing participatory methods and conducting problem tree analysis through focus groups, the study successfully identified the central problem associated with the public perception of the forestry sector, notably the need for a comprehensive long-term communication strategy.

Extensive qualitative research involving over 3,000 respondents confirmed that the forestry sector is predominantly viewed negatively, particularly among urban populations and young individuals. This negative perception was further amplified during the bark beetle calamity. The sector is often perceived as outdated, focused primarily on economic concerns, struggling to address the bark beetle calamity effectively, and failing to implement scientific knowledge and methods in practice.

To address these challenges and improve the public image of the forestry sector, a communication strategy has been developed. This strategy aims to reshape the forestry sector's positioning in the public perception map and challenge negative stereotypes. Key elements of the strategy include implementing a quintuple helix platform and fostering collaborative engagement among academia, government, industry, civil society, and the public.

The research was supported by the NAZV project QK23020008.

Films as human rights: through the lens of Indigenous peoples in post pandemic era

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: Films as human rights: through the lens of Indigenous peoples in post-pandemic era

Among various forms of communication, a combination of audio-visual formats like films is increasingly used in promoting human rights. Indigenous Peoples' rights to forest food in India are being amplified through a film, TARA *Alpinia nigra*. This article examines how common resources, such as wild edible forest food, when turned into commodities violate basic human rights to the culture and health of India's Indigenous Peoples. When a human rights violation happens, it means that person's humanity has been denied. Often, human rights violation is expressed in statistics (numbers) or via legal bindings (treaties, policies), which fail to have a human touch. Filmmaking on human rights violations touches that human element by shedding light, camera, and action by amplifying the voices of the 'human beings', the real protagonists. This article demonstrates the role of film in documenting the 'way of living and traditional right to sustainable forest food for Assam's – North-East province in India – hunting-gathering Indigenous communities. It elaborates how films can become a powerful medium when the human 'rightsholders' are given a space to voice their opinions in front of the lens. The conclusions point out two ways forward as a post-pandemic approaches: (a) the films become a lens of justice by letting real people talk in front of the camera rather than voice-overs by the 'beholders' of human rights, and (b) Indigenous Peoples are aware of their traditional rights to forest food as commons.

This abstract is published as a book chapter (Bose, 2023), and the presentation will be modified to only highlight the dimension of how filmmaking could be a powerful tool for Indigenous people's human rights to forest food and resources and governance. The presentation could be adapted to a short 5 min speed-talk to a normal presentation talk of 15min depending upon the need of the session.

Reference: Bose, P., 2023. Films as human rights: through the lens of Indigenous Peoples' forest food. In B. Wernaart, Applied Human Rights, by Wageningen Publisher, Netherlands. Open access to book chapter link is here https://www.wageningenacademic.com/doi/abs/10.3920/978-90-8686-943-5_5

Forest Fires and Forestry Communication: Lessons from the Largest Forest Fire in Slovenia

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: Large-scale forest fires are increasingly common in Central and Southern Europe due to the impact of climate change. In this presentation, we provide an overview of the communication response to a forest fire that occurred in the Goriški Kras region of Slovenia in July 2022. Effective communication, media engagement, and stakeholder relations played a vital role in the forestry sector's response to the fire. Daily press releases, press conferences, and social media platforms were utilized to keep the media and the public informed. Communication activities also facilitated emergency logging efforts, which involved over 500 volunteers to assist in the response and prevent the fire from spreading.

Moreover, this event represents the most significant incident in Slovenian forestry to date in terms of media response and engagement. Communication activities were crucial in securing funding, volunteers, and other forms of assistance for post-fire restoration efforts. They also facilitated coordination among the public forest service and numerous affected forest owners. The involvement of the local community and various expert services in the post-fire forest management plan was facilitated by these communication efforts. The presentation also addresses the challenges and obstacles encountered during the response.

Finally, we present empirical guidelines and lessons learned for coordinating communication responses to forest fires, which can serve as a reference for future incidents.

Forests and transformative governance - Insights from TRANS-lighthouses

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: The project TRANS-lighthouses aims to gather evidence on material and immaterial results of nature-based solutions in order to rethink and reframe how social and ecologically just solutions are created. TRANS-lighthouses integrates a network of nature-based solutions' lighthouses for urban, rural, coastal and forested areas. Lighthouses is a metaphor for a set of local arrangements and instruments grounded on a concerted and networked group of multiple actors committed to enhancing the contributions of nature-based solutions towards interlinked ecological, social and economic targets. This will be done by testing new governance models and co-creation approaches and tools. One of the Lighthouses with two case studies from Lagoa (Azores) and Upper Allgäu (Germany) is dedicated to solutions in, around and with forests and co-designing the solutions in an inclusive, just manner and analyzing the mechanisms of co-creation and their governance.

The assessment case of the Upper Allgäu will examine the success factors and lessons learned from the Mountain Forest Initiative. The initiative was started by the local forest administration in 2008. It tries to tackle to support owners to adapt their forests to climate change to secure multiple ecosystem services provided by multifunctional forestry. An increasing share of forest owners have lost skills and awareness for forest management and are unaware of the urgency to act. The goal is to work together as equals with forest owners to enhance the situation of the forests by co-creating solutions.

The pilot case of Lagoa (Azores) will work in an inclusive way to increase the sustainable recreational use in the unique forests in the area. Facing health issues in the local population, the idea is to jointly develop, co-create as well as unlock the potential of forests not only for tourism, but to enhance and stimulate physical activity of the local population to increase health and wellbeing together with a broad range of stakeholders stretching from land management, schools, citizens, NGOS to hospitals.

With the project start on May 1, 2023, we intend to present first outcomes and results with a focus on forest landscapes after one year of intense work in the study cases.

Hackathon: An innovative combination of forestry, forest technology and health care

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract:

In the post-pandemic era, with communication and exchange being more crucial than ever, innovative methods are making their way into the forestry, forest technology, and healthcare sectors. One remarkable example is the Hackathon, traditionally associated with the IT industry. However, it has now ventured into the realm of forests and health, bringing together professionals from diverse fields. This exciting competition aims to foster communication, collaboration, and interdisciplinary learning, creating a platform where novel ideas can flourish at the intersection of technology, forestry, and healthcare.

The Austrian Research Centre for Forests (BFW) organized a hackathon at the Benedictine Abbey of Göttweig in Austria as part of the Erasmus+ -Project Green4C. The hackathon brought together 19 young experts from different disciplines, aged between 15 and 35. Four teams, consisting of students from the fields of wood technology, forestry and health science, worked together for 24 hours to design health stations in the healing forest using only natural materials, without screws or glue to connect the elements. These stations should offer preventive health services and therapies. The aim was to promote interdisciplinary cooperation and learning among the participants.

The hackathon promoted exchange between disciplines and allowed participants to learn from and work with each other. The intensive collaboration accompanied by a design thinking process led to the development of detailed and holistic wooden models that included sound elements, various seating and resting options, meditation places and therapeutic games. These models were masterpieces that combined the three disciplines of wood craft, forestry and therapeutic science, with the forest serving as a unifying element.

A ten-member jury evaluated the models based on criteria such as innovation, overall concept and implementation. After the evaluation, it was decided that all four therapeutic health stations would be implemented in the healing forest of the Benedictine monastery of Göttweig. The hackathon not only offered the opportunity to practically apply the multifunctionality of forests, but also promoted a new and unique exchange between experts from the fields of health, crafts, art and forestry, who acted as mentors and provided valuable impulses.

Lessons in Podcasting

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: In this interactive session, the presenters will demonstrate effective techniques for podcast interviewing, describe techniques for podcast script development using a real-life example, suggest ways to approach podcast recording to engage diverse global audiences, and share tips on podcast dissemination. Why? Because podcasting is a great way to share science!

In today's busy world, more and more people are turning to podcasting as a form of entertainment and information-gathering. The world of podcasting has bloomed in the last several years, with an estimated 424 million global listeners in 2022[1]. According to one survey, 32% of 18+ listen to podcasts during their commutes[2]. Podcasting is a way to bring science in a digestible format to a broad set of listeners. While podcasting could be as simple as recording yourself talking on your telephone, that is not exactly a best practice. Competition for listenership is high. Quality podcasting is required if you want to retain a listener-base.

Hayes and Bolanos recently teamed up on the launch of IUFRO's Branching out: the Forest Podcast[3]. They will draw from this experience and working on other successful podcasts to provide insights on making your own podcast a success.

[1] PodcastIndex

[2] https://explodingtopics.com/blog/podcast-listeners

[3] https://www.iufro.org/news/article/2023/04/12/branching-out-episode-1-april-2023/

TREEgital: Digital knowledge transfer about forests

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: The Corona pandemic has given a strong boost to digitalization in school education. With the project TREEgital we are embracing this development by providing knowledge about forests for schools, using digital tools to explore the importance of forests as living, recreational, and economic spaces, as well as to emphasize their role in climate and biodiversity protection. The thematic focal points of TREEgital are biodiversity and climate change, as well as career guidance for young people regarding green and sustainable jobs in the broad environmental and forestry sector. Additionally, we impart digital competencies to equip students with the skills needed in today's digital world.

To achieve these goals, we develop methods and digital educational products for school use: One of these methods is the utilization of augmented reality (AR) in the developed app "Öswald." AR technology enhances the learning experience by overlaying virtual elements onto the real-world environment, allowing students to interact with and explore the forest in a dynamic and engaging way. Another method is the creation of career guidance YouTube videos with a specific focus on STEM subjects. These videos aim to inspire and inform students about potential career paths forest-related fields. By showcasing real-life professionals and their work, students gain valuable insights into the diverse opportunities available in these areas. Furthermore, the project features a video-podcast called "TreeCast", in which forestry scientists are invited to share their research and experiences. Topics covered in the podcast range from climate change and biodiversity to pest management and soil health. The social media series "Ask the Expert" gives insights into the professional world of scientists and forest research.

Through these methods TREEgital seeks to leverage digital tools and resources to foster meaningful and interactive learning experiences, making forest knowledge accessible and engaging for students in the digital age. The educational materials not only impart knowledge about biodiversity, but also focus on Education for Sustainable Development (ESD) and the implementation of the Sustainable Development Goals (SDGs). This takes a sustainable approach to teaching, providing students with knowledge and skills to take responsibility in a globalized world.

What is considered good written communication about forest? Issues, concerns and practices revealed by a systematic review

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: To better address questions related to how we communicate forest science into the future and take informed, evidence-based decisions, it can be insightful to examine what has been done up to now, how it has been done and why. Moreover, if to move away from a « content paradigm » towards a « performance paradigm » of communication, the understanding of what audiences expect, need and want is an essential component to any action-oriented, user-centric communication initiatives.

Stakeholders communicating about forest rely on a variety of written material to deliver their messages. Those messages, designed to be published and read in order to reach a variety of readers in a broad range of situations, can aim to inform, educate, support decision-making or ensure accountability, for example. How are those stakeholders communicating about forests? What are their main concerns? What do they consider to be effective, successful written communication about forests, or indicators thereof?

To comprehensively grasp how written communications about forests is appraised, we conducted a mixed-method systematic review of research papers published between January 1989 and March 2020. To retrieve those papers from 14 selected electronic databases, the search words Forest* AND Communication, combined with one or more of 27 specific keywords shared with adjacent disciplines (linguistic, composition studies, information design, among others) were used. The material was evaluated for eligibility, focusing on professional or technical documents designed in a workplace context for an adult readership, and coded according to a predetermined set of criteria.

The results show a growing but limited interest in understanding what makes written communication about forest effective, and barely any explicit definitions of what a good performance should entail. Almost half of the papers analyzed were only tangentially focused on the documents for their communication purposes. Recommandations, when formulated, mainly focused on content, content delivery and the process which may facilitate or impede content quality. A small number of mostly quantitative user-focused studies were conducted almost exclusively by practitioners working in an extension or outreach communication setting.

Those results call for a more systematic and sustained efforts into taking the user experience into account.

What the bug?! Cross-generational storytelling: Innovative methods for science communication about forest insects

T4.5 Communicating and Connecting: Post-pandemic approaches to sharing scientific and traditional forest knowledge to inspire trust, engagement and positive change

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Abstract: Topics such as the biodiversity crisis are often hard to communicate, leading to a dwindling awareness and even increasing levels of scientific skepticism among the general public. The project "What the bug?! Cross-generational Storytelling" focuses on accessible science communication around forest research, with a special emphasis on forest insects. The aim of the project is to explain forest research processes in a participatory way. By using modern storytelling methods, the project aims to reach different target groups, including young people and senior citizens, enabling the cross-generational transfer of knowledge.

An interactive science quiz is designed to introduce young people to forest insects and their importance in a globalized world shaped by climate change. Phenomena such as the flight technique of click beetles or the perception of forest fires by the black pine beetle are illustrated interactively and participative in experiments. Science in miniature format can be experienced: The formulation and testing of hypotheses is tried out.

In science storytelling cafés we create spaces and opportunities for exchange about this multi-layered topic that affects us all more than we might think. The storytelling café is a low-threshold and participatory method of biography and memory work that focuses on autobiographical narratives and promotes dialogue between the participants rather than discussion. The science storytelling café can also be used as a method for raising awareness by enabling participants to draw attention to societal challenges such as climate change, insect decline and globalization, and to address possible solutions.

The project aims to improve science communication about the forest, raise awareness for forest research, fosters species knowledge among the population and teaches why this knowledge is important. The project thus contributes to education for sustainable development (SDG 4) and the protection of life on land (SDG 15).Through cross-generational knowledge transfer and innovative methods, young people and seniors are addressed to raise interest in scientific processes and to reduce science skepticism.

T4.6 Conflicts in Forest Settings

Analysing conflicting stakeholder perspectives in multifunctional forest landscapes using a complex systems approach

T4.6 Conflicts in Forest Settings

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Abstract: Background: Climate change and biodiversity loss, along with long-term urbanization trends and a societal-scale transition towards renewable materials and energy, threaten the world's forests. In addition, natural and cultural values associated with forests have become key selling points for nature-based tourism and recreation. Policy responses at multiple levels therefore increasingly stress the need for multifunctional forest landscapes (MFLs) to supply an increasingly diverse suite of ecosystem services. However, a key challenge remains the perceived incompatibility among different stakeholder interests.

Aim: In a new 4-year transdisciplinary research program we aim to improve understanding of the complex, dynamic factors that influence what different stakeholders want from forest landscapes, and how these factors interact to constrain or enable a shift towards MFLs.

Methods: We use place-based landscape studies in Sweden, where stakeholder positions are polarized by deeply entrenched conflicts and by a desire for competing functions and benefits from forests. A complex systems approach, using qualitative modelling, spatial and network analyses, allows us to map and analyse key factors and core system dynamics (including feedback loops) and to identify constraints and opportunities influencing attempts to overcome conflicts in forest landscapes towards MFLs.

Results: Our recent and ongoing studies indicate that conflicting economic considerations continue to dominate different stakeholder perspectives. In particular, perceived threats to natural and cultural values of forests resulting from intensive forest management practices were shown to drive multi-stakeholder coalitions in support of a transition to MFLs. Further, we identified several institutional, socio-cultural and environmental drivers that influence conflicting management objectives and practices. These drivers interact to steer emergent conflict-resolution processes relating to a shared vision, support, learning, and new management practices. Key constraints included lack of trust, power imbalances and weak links between governance levels.

Conclusions: Our results make important contributions to the development of a causal model for exploring the drivers, impacts and solutions to conflicts in forest settings. However, the success of MFL initiatives in Sweden depends on a shift away from intensive forest management. Further research is therefore needed concerning the causal mechanisms supporting and/or constraining transition pathways from clear-felling to clear-cut free forest management.

Applying machine learning to media analysis improves our understanding of forest conflicts

T4.6 Conflicts in Forest Settings

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Abstract: Conflicts over the management and governance of forests are increasing. Previous media studies in this area have largely focused on analysing the portrayal of specific conflicts. This study aims to review how a broad range of forest conflicts are portrayed in the Swedish media, analysing their temporal, spatial, and relational dimensions. We applied topic modelling, a machine learning approach, to analyse 53 600 articles published in the Swedish daily press between 2012 and 2022. We identified 916 topics, of which 94 were of interest for this study. Our results showed that media coverage of forest conflicts is increasing, and that the conflicts receiving the most coverage relate to hunting and fishing (35 % of total coverage), energy (24 %), recreation and tourism (11 %), nature conservation (8%), forest damages (6%), international issues (5%), forestry (5%), reindeer husbandry (4%), media and politics (2%), and mining (1%). Some of these conflicts were continuously reported upon, while the coverage of others exhibited seasonal or event-related patterns. Four conflicts received most of their coverage in specific regions, while others were covered across the whole of Sweden. Several of the conflicts related to each other, forming three clusters of issues focused respectively on industrial, cultural, and conservation conflicts. Our results emphasise the value of using topic modelling to review the temporal, spatial, and relational dimensions of how conflicts are reported upon in the media.

Climate adaptation of biodiversity conservation in managed forest landscapes

T4.6 Conflicts in Forest Settings

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Abstract: Biodiversity conservation in managed forests needs new complementing approaches given the threat from rapid climate change for which we present two main strategies: (1) The *resistance* strategy focuses on actions to increase the capacity of species and communities to resist change. (2) The *transformation* strategy includes actions that ease the change of communities to a set of species that are well adapted to the novel environmental conditions. We suggest a number of concrete tools for policy makers and managers. Tools from the resistance strategy include: identifying and protecting climate refugia for cold-favoured species; reducing the effects of drought by protecting hydrological networks; and actively removing competitors threatening cold-favoured species. Under the transformation strategy, we suggest tools like: enhancing establishment of forest species favoured by the new climate, but currently disfavoured by forest management, e.g. by planting them at suitable sites outside their main range; and increasing connectivity across the landscape to support the expansion of warm-favoured species to new suitable sites. Finally, we suggest applying a landscape perspective and managing for both retreating and expanding species in parallel. The two different strategies (resistance and transformation) should be seen as complementary ways to maintain a rich biodiversity in future forest ecosystems.

Conflicting forest discourses in journals and amongst professionals

T4.6 Conflicts in Forest Settings

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Abstract: The academic literature is rich in varying and divergent understandings of forest, and it has been observed that discourses around forestry and forest use are often highly national- and sectoral-based. This means that not only is there a variation between countries in how forest is treated, but there is also a variation amongst how different disciplines treat forest issues within a country. In many cases, there may also be conflicting understandings expressed between those focusing more on production and those focusing more on protection. To study the potential variations in present literature in the case of the relatively strongly forest focused country Sweden, this study investigated material found in a structured literature review on forest management. Results illustrate the more limited variation between articles classified as Agricultural and Biological sciences (where Forestry is a sub-category) and Environmental science. However, they also illustrate a variation in how forestry is treated in specific articles across categories, which corresponds with a more production-oriented perspective versus one focused on environmental considerations. These results were followed-up in focus groups with participants from forest production- and environmental-oriented sciences.

Conflicts about clearcutting: an opportunity to question the forest social order

T4.6 Conflicts in Forest Settings

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Abstract: Protests and conflicts against clearcutting have increased tenfold in the last ten years in France. NGOs and citizen movements are so active that they are succeeding in suspending and even stopping many harvesting operations in the most productive forest regions. How did this social movement emerge and how are forest owners' associations reacting to this strong social mobilization against clearcutting? Is it just a difficult period to get through, or a transformative moment that is here to last? Using a socio-constructivist theoretical framework to analyze the rise and fall of social problems, we will show that clearcutting conflicts are not new but often go back several centuries. We will also show how ENGOS and local citizens' movements are joining forces today to put clearcutting regulations on the political agenda through highly effective grassroots and internet communication campaigns. Conflicts are also stimulated by the "greening" and "climatisation" of social debates, which means that every logging action should be evaluated according to its ecological and climatic impacts. Clearcuts illustrate these conflicting views by questioning the impact of forest management operations - whether logging or reforestation - on the landscape, ecosystem services and the ambivalent role of forestry in the economic development of remote rural areas. More generally, these protests are putting into question the forest social order that usually prevails in the forest sector Despite some moments of violence, and according to Georg Simmel' approach of conflicts, we show thatconflicts can be a positive moment to discuss the social contract between citizens, forest owners' organizations and forest policy makers. Finally, we will show how these conflicts lead some forest owners to reconsider certain forestry techniques such as clearcutting.

Conflicts arising from green infrastructure plans in Swedish forest: how reactions to maps affect and impede soft policy implementation

T4.6 Conflicts in Forest Settings

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Abstract: Sweden has a long tradition of forest ownership with strong property rights over resource management decisions. Private owners also manage more than half of Sweden's forest area. Under Sweden's liberal forest governance, forest stakeholders' acceptance is crucial for implementing novel instruments to landscape management, such as green infrastructure plans. Involving industrial and non-industrial private forest owners is, however, not a simple task. Based on analyses of green infrastructure plans and interviews with officials in charge of coordinating the plans at County Administrative Boards, the study aims to explore (i) the act of mapping areas with a high amount of key habitats and nature values and (ii) the resulting conflicts and the hinders to implementation of governmental tasks. The green infrastructure plans aimed at gathering knowledge, mapping nature values and listing actions to guide all stakeholders on how to include green infrastructure in their managing decisions. We examine how maps tend to be conceptualized as solely the creation of new knowledge, supposedly scientific and objective in its nature. Yet, there was an underlying realization that maps are able to indirectly affect resource distribution for nature conservation or limit forest owners' decision space. Further, we explore how coordinators adapt to the opposition by forest stakeholders of the actual maps and the concept of a government mapping their private property. Our discussion centers on how maps, albeit considered pure spatial knowledge, represent a soft policy instrument for environmental governance and resource prioritization in forest settings. Our study underscores how different departure points to knowledge and its significance create conflicts and subsequent adaptations in working strategies or the stagnation of environmental initiatives

Diverse human values combined and reflected in the modern forest policy and education system in East-Asian countries

T4.6 Conflicts in Forest Settings

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Abstract: Conflicts in forest settings arise from the recognition of diverse human values and benefits of forests. However, viewing historically, the forest policy and education system in modern period had been formed with the combination and reflection of those multiple values in East-Asian countries.

Taking China and Japan as examples, this research focused on the values and footprints of those who greatly contributed to the formation of the modern forestry administration and education in these two countries.

Not only did they aim to establish a sustainable timber production system, but they also recognized the importance of forests from the perspective of water and soil conservation based on local circumstances. The significant connections with landscape architecture, botany, and tree taxonomy were also confirmed. Having these roots, the modern forestry and public foresters, sometimes regarded as having simplified scientific viewpoints, played the remarkable roles to harmonize and resolve conflicts based on local human actors with different values and benefits of forests in East Asia.

Forest restoration paradigms and conflicts in Europe

T4.6 Conflicts in Forest Settings

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Abstract: Forest landscape restoration (FLR) is gaining importance in Europe. This study aims to analyse how forest restoration is understood in a European context, identify forest restoration conflicts, and explore the relationship between both understandings and conflicts. To achieve this, 46 semi-structured interviews were conducted with stakeholders in 12 FLR case studies in 12 different European countries. The results show three distinct ways in which forest restoration is understood, i.e., 'forest restoration paradigms', which arise from how different actor groups problematize forests and their management. Looking deeper, these 'forest problematizations' are determined by the ecological and socio-ecological context and the collective values, beliefs, and knowledge of actor groups. In addition, when these underlying values and interests clash in a certain context, forest restoration conflicts emerge. For effective FLR implementation in Europe and decision-making processes, it is important to understand how stakeholders perceive forest restoration and the contexts in which different understandings emerge.

How to Frame Bengal Tigers: Conservation Narratives and State Politics versus Local Ecosystem Ethos and Livelihood Realities in Bangladesh's Sundarban

T4.6 Conflicts in Forest Settings

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Abstract: The Sundarbans mangroves are a world-famous Bengal tiger habitat and home to a complex social-ecological system with a long history of colonial exploitation, exclusionary forest governance and systematic marginalization. The region's global ecological significance has driven conservation- and climate-focused development interventions, among which the tiger/wildlife-human strategy needs a critical re-assessment of their effectiveness. Drawing on political ecology and grounded in qualitative methodology, this exploratory case study examines the dominant narratives and national policy discourses surrounding the tiger and *de facto* local social-cultural context in the Bangladesh Sundarbans to understand how conservation crises are framed, conflicts are presented/constructed, and solutions are devised.

The study illustrates overlapping and contradicting discursive representations of tigers as a central and dominant theme in policy discourses, both materially and symbolically, across various levels of governance. Two major findings: First, we outline the region's layered popular tiger narratives (e.g. globally endangered, national pride, climate victim), and argue why the state-donor coalition tends to simplify the region's complex human-wildlife interaction into a binary Tiger-Human conflict centered around instrumental competition over resource extraction. Secondly, this study highlights shortcomings in the state's official record of tiger attack fatalities compared to community-level recorded causalities and explains this gap through conflicting interests and visions between the regional forest department and community's de facto livelihood risk strategies.

Our analysis examines Sundarban's wildlife narratives and livelihood-related stories embedded in social-cultural contexts with local perceptions, knowledge bases, cognitive framing, power relations, and moral values. It argues that transregional politics of framing tiger conflict in a monolithic way have overshadowed or sidelined the root causes for local wildlife conflict. This has legitimized band-aid solutions such as territorial compartmentalization, stricter law enforcement and restrictions on livelihood activities although they are ineffective or inappropriate to local socio-spatial-cultural tiger-related perceptions and ecological values. Moving beyond the central binary of tiger narratives, this study offers a re-interpretation of tiger perceptions and strategies, embedded in a thorough understanding of the underlying political-economic drivers, resource governance interests and rural power dynamics to address the Sundarban's conservation-development conflict more effectively, and sustainably.

Keywords: Conservation policy, traditional values, conflict mitigation, climate adaptation, indigenous livelihood

Private forest owners' acceptance of breeding and regeneration strategies for increasing the share of broadleaves in Sweden

T4.6 Conflicts in Forest Settings

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Abstract: There are divergent opinions on the management of forests among rightsholder and stakeholder groups, politicians, and in the general public. When management changes to meet challenges associated with increases in forest damages associated with climate change and still deliver a range of ecosystem services, it is especially important to understand peoples' opinions. To outline legitimate management strategies, there is a need to understand opinions that differ between groups, opinions shared between different groups, but also the heterogeneity within groups. When stakeholder groups learn how another group is endorsing different opinions, rather than one coherent view, or get a better understanding of why a particular opinion is being endorsed, there may be a basis for dialogue.

Diversification of forest management strategies and tree species is an approach to handle future challenges to forests. Forests currently dominated by conifers may be diversified by adopting broadleaves, but this can be done in different ways using different breeding and regeneration strategies, including traditional breeding, assisted migration, planting non-native hybrid tree species, or genetically modified tree species. While studies have revealed that acceptance towards breeding strategies in the public vary, little is known about forest owners' views on their place in the current diversification of management to adapt to climate change. This study examines private forest owners' (also called family forest owners) acceptance of breeding and regeneration strategies to increase the share of broadleaves based on data from a large survey of a random sample of forest owners in Sweden (n = 5000). Analyses focus on the within-group variations on acceptance, and considers for example the place-based, social and psychological variables that may be used to explain varying levels of acceptance. By analysing these attitudes of private forest owners – a key rightsholder group in Sweden – it is possible to identify both mean level of acceptance but also within-group variation as a basis for an improved understanding of how this group differ from, or overlap, with other stakeholder groups in this context.

Social representations and social licence in emerging climate adaptations for fire-affected forests

T4.6 Conflicts in Forest Settings

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Abstract: Forests are changing with increased fire frequencies that are linked to climate change. Managers seek a social licence for new types of interventions to support forest resilience. However, this is made complex by differing views among the public and stakeholders about how humans should relate to 'natural' forest ecosystems. We investigated support for practices such as forest thinning and restoration and explored nuances in people's thinking about forests through the concept of social representations. These are systems of values, beliefs, norms and practices that are thought to emerge through informal social interactions and are drawn on as people respond to new situations such as climate change. We conducted ten focus groups with members of interest groups and the public to identify responses to forest change and components of social representations. We then conducted a survey of 475 residents to characterize social representations and measure support for practices. Four main social representations were identified and named for the values and human-forest relationships which helped define them: Shaping forests; Partnering forests; Defending forests; and Relating forests and society. Participants appeared to draw on these in forming views about unfamiliar forms of management. The practice of thinning for ecological resilience originates within the 'Shaping forests' social representation, which includes the belief that people should intervene to improve forests, but is not a good fit with other social representations, such as 'Defending forests', in which human intervention is believed to be detrimental to forests. Overall, gentler interventions were more supported, however participants also recognized the need to experiment with many different methods, acknowledging that one approach would not fit all contexts. They urged governments to incorporate local, Indigenous and scientific knowledge in the development of new practices, alongside professional expertise. There is now a window of opportunity to build new relationships and social licence as new adaptive practices are trialled and as members of the public are still forming their views about them.

The conservation effort response to the incursion of armed group into protected areas: insights from the W-Arly-Pendjari Complex in West Africa

T4.6 Conflicts in Forest Settings

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Abstract: The sudden incursion of armed groups in 2017 into the W and Arly parks, located respectively in Niger and Burkina Faso, poses a serious threat to conservation efforts in one of West Africa's largest transboundary natural world heritage sites the W-Arly-Pendjari Complex (WAP). Responding to such a conflict requires quick adaptive management for conservation managers, who are often unprepared and have no clear strategies to such threats. The question is therefore how conservation managers respond to such situations in practice. Using disaster response as an analytical framework, this paper aims to describe how conservation managers have dealt with these issues in order to assess their performance in tackling them. Our results show that conservation responses to the security crisis have been multi-faceted, depending on the WAP countries. It ranges from a withdrawal of conservation actors from the parks (Niger and Burkina Faso) to a continued active management in the Benin component. The resistance of Benin can be to some extent associated with the fact that solid foundations were put in place before the crisis. A focus on a community strategy that met the needs of the forest dependent communities to reduce their vulnerability is a clear key factor in building a local alliance in the face of such a disaster. The main challenges for conservation managers are their limited capacity to tackle the new problem but careful attention needs to be paid on the false perception of addressing the crisis solely from a military point of view. The emergency response is often weak as it depends on what external support can or is willing to offer. Such an approach easily falls into symbolic gestures far from eliminating the issues.

Unravelling Tensions: Analysing Social Networks of Forest Biodiversity Conservation Implementors

T4.6 Conflicts in Forest Settings

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Abstract: In Germany, the recent impacts of drought, heat and related bark beetle outbreaks have brought conflicts over multifunctional forest management into view. In the negotiation process between management, use and protection of forests, biodiversity conservation is a crucial endeavour to achieve the conservation of species, habitats and ecosystems. Respective biodiversity cartas and policies have been formulated on international, national and regional levels, but a focus on problems of ground-level implementation is lacking.

Overall, policy implementation has had a secondary role in policy analysis, attributing a higher importance to policy formation. Nevertheless, policy implementation is a highly interactive process, determined by implementors themselves, their knowledge and social networks. The latter of these are an important variable in the decision-making process and provide a first explanation for (non-)collaborations within the implementation process. To gain a better understanding of social networks in these processes, social network analysis provides a language and methodology to make relationships visible. Thereby, a special interest is placed on negative or 'difficult' ties, which have been described as particularly harmful, as they can lead to high levels of disappointment, frustration and anger – hindering the implementation of conservation measures. With the exception of extreme cases, social networks are combinations of positive and negative interactions, incorporating material, emotional and reputational aspects. Most focus has been placed on positive ties, analysing different forms of relational states and events, while research on negative and 'difficult' ties has been lacking. Social negativity ranges from behaviours that provoke conflict, over insensitive behaviours, to behaviours that interfere with a person’s ability to achieve goals. Difficult ties are generally described as another form of social negativity, in which the presence of people is felt to be difficult.

Identifying such negative or difficult ties within social networks of implementors contributes to a better understanding of implementation barriers, conflicts and final outcomes. Through a case study in the Black Forest (Germany) a local social network of forest biodiversity implementors will be explored, analysing the causes of forest conflicts and identifying possibilities of developing and supporting – or even intentionally creating – relationships for the purpose of more successful forest biodiversity implementation.

Where do deer belong? Reframing wildlife management conflicts through place-based initiatives

T4.6 Conflicts in Forest Settings

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Abstract: The creation of new forests, agroforestry systems and urban treescapes in the pursuit of net zero will generate many more common spaces where wildlife and humans will connect. These spaces will simultaneously form new habitat for wild deer and venues for people to use and engage with. Evidence consistently shows that forests are viewed strongly as places *for* wildlife – spaces in which other species can and should thrive without human interference. This sits alongside evidence that highlights forests as sites where people seek out encounters with wildlife. Significant benefits can flow from wildlife watching and similar experiences, but wildlife management infrequently considers the promotion and enhancement of these interactions.

Whilst deer management in the UK has evolved into a more collaborative and inclusive enterprise, it remains targeted towards a relatively stable set of values, interests, and objectives oriented towards protecting productive forestry and the structural ecology of native woodlands. Narrowly constructed existing approaches frame wild deer as over-abundant with consequently negative impacts within forest settings. Arguably, inclusive place-based approaches more effectively recognise and encompass deer contributions to the desirable characteristics of, and benefits generated by, forests. Our analysis focuses on examples of place-based initiatives - that is, activities which enable communities to recognise and acknowledge the ways in which wildlife and people co-produce local places. This has considerable potential to reframe contemporary wildlife management conflicts in forests.

We will present case-study analyses that explore the potential influence of place-based initiatives on ways in which diverse stakeholders (e.g. community members and land managers) value deer, how they understand potentially problematic wildlife species and their own impacts, and their perspectives on where deer belong. Our aim is to identify place-based initiatives and actions that can build (co-create) positive relations between communities and their local wildlife. This reframing will move us beyond the core research of documenting public ‘attitudes to’ particular management methods (such as fencing, culling, etc), towards an understanding of the processes via which we can create resilient communities that have a developed consideration of the diverse and broad connections between themselves, wild deer, and their local environment.

Which characteristics support forest recreation? – A discrete choice experiment to evaluate visitors' preferences for forest recreation in Germany

T4.6 Conflicts in Forest Settings

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Abstract: Measuring visitors' preferences for forest recreation began to gain momentum in Germany in the 1980s, when scientific interest in recreational use of forests and society's attachment to green spaces was high. Today forest recreation is an example of cultural ecosystem services that is increasingly integrated into multi-objective forest management. When public planners ask forest managers to consider recreational value in developing management plans, foresters often fear that doing so will involve conflicting goals and a restricted decision space. But is that fear backed up by up to date research or rather the opinion of urban forest managers afraid of losing opportunities for timber production?

In comparison to other ecosystem services, forest recreation may never generate high enough payments to match the social value of this ecosystem service, at least in Germany. However, scientific studies often report high financial values based on forest recreation evaluations. Especially in urban and suburban areas, the relevance of forest recreation for multi-objective management can be very high and proved its importance in multi-objective forest management.

We use a discrete choice experiment to model a forest visitor's decision between predefined forest alternatives, to evaluate which characteristics are matter to people using forests for recreation. Moreover, due to the multi-dimensional, preference-based valuation technique, we can portray the importance of forest characteristics for visitor's utility functions. We use willingness to travel as measure to calculate financial values for forest recreation in Germany. Focus group discussions have highlighted the importance of mixed composition of single stands along a forest road. Variability of contiguous stands was valued as important characteristic for high forest attractiveness for recreation. Therefore, our study concentrates not on the attractiveness of single stands as often seen in other studies, but wants to evaluate the composition of different stand types. By selected management interventions and innovative visitor guidance concepts, forest managers can modify forest recreation and the related public perception. We believe intensified research about forest recreation helps to strengthen the connection between society, forests and supports understanding for multi-objective forest management.

T4.7 Digital transformation in forest governance – the Good, the Bad and the Ugly

And the forests tweets will echo with laughter? - German "forest death 2.0" in the hybrid media system

T4.7 Digital transformation in forest governance – the Good, the Bad and the Ugly

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Abstract: Large-scale forest damages induced by drought, heat and related bark beetle outbreaks are some of the first signs that make the effect of climate change visible and tangible to the public in Germany. With the first damages in 2018, a heated debate emerged that was quickly framed as *forest death 2.0*. In the light of the climate crisis, actors seek to position themselves in the debate, highlighting the urgency in implementing their proposed measures to *save* German forests.

In order to understand these struggles for discursive power, my study is conceptually embedded in the complex entanglements between legacy and new media that Andrew Chadwick defines as *Hybrid Media System*. My empirical work comprises the analyses of different forms of public and political communication, including newspaper articles, position papers and twitter data. By drawing on different concepts of discourse and framing theories, the results show the multi-faceted and overlapping problematizations of the forest crisis, that is yet shaped by a structurally consolidated polarization between forestry and nature conservation discourses. In line with existing literature on social media debates, I show that this polarization is further increased in the twitter debate through the surge of a third discourse on climate scepticism, that is disregarded in media and political communication. With this contribution I seek to contribute to the understanding of the relation between digital and traditional forms of communication in forest controversies as well as the surge of polarization in times of crises. Doing so, I critically reflect on deliberative perspectives on digital media, as besides “the Good” and “the Bad” it opens up a space for “the Ugly” that might echo back in the then seemingly narrow gap between forestry and nature conservation.

Content creation and streaming by forest machine operators – current trends and impacts on forest-related discourse.

T4.7 Digital transformation in forest governance – the Good, the Bad and the Ugly

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Abstract: The digitalisation of forest-related discourse has transformed the way in which the sector interacts in the public sphere and has led to the creation of a distinct 'digital town square' for forestry. Moreover, with the rise of mobile applications like TikTok, video content creation and live-streaming capabilities have provided people at the operational level of the forest sector with new opportunities to present their work and talk directly with the public. Furthermore, these activities are gamified, increasingly monetised, and professionalised in a way that has led to the blurring of the lines between work and play - a phenomenon known as 'playbour.'

In this study, the experiences of forest machine operators in Finland and their motivations behind creating online video content and taking part in live streaming are examined. From previous studies, it is known that forest machine operators are attracted to the profession through factors such as the working environment, the independence of the work, seeing the immediate impact of their work, as well as having the opportunity to 'play' with big and modern machinery. However, due to the monotonous nature of the work, which is being increasingly automated, social aspects of the job, including identity, standing in the community, and well-being, are also identified as being particularly important. This, coupled with the new digitalised social-networking possibilities, has led to intrinsically playful behaviour that is also providing new streams of income.

This new paradigm is investigated through online surveys and contextual interviews. The effect that content creation is having on the forest machine operators' well-being and workability is evaluated. Furthermore, the study explores the degree to which these content creators are self-censoring as they anticipate pushback from the traditional holders of discursive power - state forestry organisations, forest managers, forest owners, machine manufacturers, and other related stakeholders.

This study provides insights into the nature of, and motivations behind, contemporary forest discourse. It highlights how developments in digital platforms are leading to the democratisation of forestry communication, and how real-time conversations may be shaping the discussion around forest conflicts and governance.

Institutional design for equitable governance of hybrid forest commons

T4.7 Digital transformation in forest governance – the Good, the Bad and the Ugly

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Abstract: Genomic technologies are crucial for the conservation and adaptation of forests in the face of numerous threats. Vast genetic databases facilitate rapid screening and international scientific collaboration. The storage of these delocalised digital resources in addition to physical forest genetic resources (FGR) has given rise to concepts like twin or hybrid commons. Commoners in both systems face unique but interrelated challenges. Whereas local FGR managers have to navigate the policy landscape surrounding a forest, forest scientists and bioinformaticians have to navigate a myriad of global regulations governing Digital Sequence Information (DSI) on genetic resources, a policy term for genetic sequence data.

Recently, Parties to the Convention on Biological Diversity decided that fair and equitable access and benefit-sharing (ABS) obligations apply to DSI. The benefits arising from the use of DSI should be directed towards the conservation of biodiversity and its sustainable use, specifically by indigenous peoples. Through this decision global data governance has been tied to local forest governance. Therefore, issues of fairness and equity are now extended **across** two commons between states, stakeholders and scientists, and between DSI users and FGR managers and stewards.

First of all, the agenda-setting power over forests is increasingly shifting towards data users with the risk of making local voices 'invisible'. On the other hand, there are opportunities to take local autonomy and discourses of FGR stewards to a global level, for example via Indigenous Data Sovereignty discourse. Secondly, although open access to DSI allows North-South collaboration, it can exacerbate existing inequities in science by excluding actors without data skills or equipment. Thirdly, because values and norms are embedded in global data, the digitalization of forests might dominate how others should understand and manage forests, replacing local ways of knowing.

There is no literature that has explored this *glocal* and polycentric governance of DSI and FGR. However, we argue that any institutional design should: 1) include value-centred approaches to research capacity-building for the use of DSI, 2) elucidate relations of environmental justice in this governance coupled system, and 3) establish duties between the DSI and FGR commoners for achieving just and equitable outcomes.

Mediated Battles for the Forest: comparing discursive power in hybrid media systems in the Baltic Sea Region

T4.7 Digital transformation in forest governance – the Good, the Bad and the Ugly

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Abstract: The increased interest in forests as the basis for a growing bioeconomy has led to an intensification of conflicts, expanded national debates and heightened media interest. Media reporting amplifies already entrenched conflicts between different users of the forest, and this is further fueled by social and digital media. Concerns about factuality and misinformation in the debate have also been raised. Media are the main sites of public discourse, and it is therefore important to analyse how digital and social media change the way debates are circulated and represented, and the potential consequences this has for governance and power relations. In this project we trace how *discursive powe*r is wielded and circulated through framing forest debates in hybrid media systems of three Baltic Sea countries - Estonia, Germany and Sweden. Around half of EU's forested area lies within the Baltic Sea region, making this a key area for a growing bioeconomy in the EU and a forest-conflict hotspot.

Mediated forest conflicts can be seen as discursive power struggles to define problems, identify relevant knowledge or arguments, and propose solutions. Previous forest research in each of the countries shows polarized and emotional debates between forestry and conservation alliances (Savioja 2017; Mack et al 2023; Jakobsson et al 2021). Theoretically we draw on the concepts of 'hybrid media systems' 'discursive power' and 'framing'. Hybrid media systems sets the focus on how the adaption between legacy and social media changes norms, logics and practices (Chadwick, 2017). Actors who harness these logics gain discursive power. This paper presents the comparative framework for locating discursive power (Jungherr et al, 2019), the motivation for studying particularly intensive peaks of mediated forest debates, and the identification of key arguments and actors. For the forest-rich Baltic Sea region, identifying how discursive power frames contributes to polarization or compromise contributes to an understanding of the media's role in the governance of sustainability transitions.

Shared resposnbility for biosecurity: Myrtle Rust in New Zealand and mainstream media framings of responsbility for action

T4.7 Digital transformation in forest governance – the Good, the Bad and the Ugly

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Abstract: Globally managing biosecurity incursions, unwanted pests, and diseases are a growing concern as the climate warms. In some contexts this has resulted in shifts towards a shared responsibility between government agencies, industries, communities and Indigenous people. However, shifting responsibility can introduce new complexities in biosecurity systems at a time of significant socio-ecological change. Myrtle rust *(Austropuccinia psidii)* is a fungal disease posing a threat to plants and trees in Myrtaceae, including ornamental and culturally and economically important species. In Aotearoa New Zealand (A-NZ) this includes iconic tree and forest species like pōhutukawa, mānuka, rātā, and ramarama. Since myrtle rust arrived in A-NZ in 2017, mainstream online media reporting has covered the response to the incursion, and its ongoing spread throughout the country. To explore how 'shared responsibility' for biosecurity is framed, we have undertaken a discourse analysis of mainstream online media reporting on myrtle rust in A-NZ.

Our analysis identifies five themes; the description of myrtle rust, different conceptions of 'borders', the contested portrayal, and distribution of responsibility for decision making across different actors (government, industry, communities, and Indigenous Māori people), and the role of science and different knowledges in biosecurity. Our findings show that at the start of the incursion, media reporting was high. Myrtle rust was framed primarily through a Western science lens which emphasised the risks myrtle rust posed to A-NZ's primary sector. The Central Government was framed as being primarily responsible for managing the incursion response, with support from industry and communities (primarily in terms of following containment protocols). As myrtle rust became established and the incursion response ended, media reporting decreased, and framings began to shift. Increasingly local government, researchers, communities, and Indigenous groups were framed as being responsible for action, and having knowledge that may help inform action. The risks posed by myrtle rust also shifted to highlight more socio-cultural considerations, such as the loss of iconic native trees. These findings show how 'shared responsibility' for biosecurity has shifted over time and place and indicate the inclusion of more diverse knowledges and values in relation to biosecurity research and action in A-NZ.

Situating forest policy and governance issues through digital methods

T4.7 Digital transformation in forest governance – the Good, the Bad and the Ugly

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Abstract: The web and social media platforms are increasingly becoming sites of knowing, reporting on and interacting with forest and nature conservation. This can bring opportunities for researchers to repurpose online materials to explore forest-related issues, practices, experiences and perspectives in different contexts. Yet, studying social media poses a number of challenges for researchers. For example, researchers need to adapt to changes made by social media platforms (e.g. Facebook, Instagram, Twitter and Reddit limiting API access). At the same time, social media platforms have specific features, practices and cultures that researchers must attend to and account for. How can research questions and methods be adjusted in order to study the online mediation of forest cultures and issues?

Drawing on multiple collaborative research projects with the European Forest Institute, the Public Data Lab and King's College London, this work explores the use of digital methods (Rogers, 2013, 2019) to study online engagement around forests and forest issues - and how these may enrich research on forest governance, policy and practice. Through the study of issue networks, actors and media practices, it suggests what can be learned about how forests are articulated, activated and recomposed in online spaces - and the implications of this for forest research.

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

An Indicator-based Composite Index for Assessing and Reporting on Forest Sustainability

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Forests are one of the world's vital terrestrial ecosystems, providing many services and benefits which support the livelihoods of about 350 million people globally. The dependency on forests for people's livelihoods in developing tropical countries like India is higher than in developed countries. This further necessitates a need for comprehensive monitoring and reporting of forest sustainability on different social, ecological and economic indicators for evidence-driven decision-making to manage forest resources effectively. However, India's current national forest monitoring is confined largely to a few ecological indicators, limiting the understanding of forest resources' social and economic contributions among policymakers and decision-makers. In this context, the current study presents a multi-dimensional perspective on forest sustainability based on a newly developed indicator-based composite index. The relevant social, ecological and economic indicators were identified through a literature survey of standardized national and international frameworks and stakeholder consultations. A total of 36 relevant indicators were selected for developing the composite index, including ecological (12), social (13) and economic (11) indicators to capture a holistic assessment of forest sustainability. The paper also highlighted the rationale for including each of the major indicators, which is critical to realize the full potential of forests through effective management. The data on these indicators have been collected from different sources and Government records to check the availability and identify existing information gaps. Furthermore, we have computed the score based on the newly developed forest sustainability index in one of the forest divisions to identify each indicator's contribution to the overall sustainability of forest resources. Thus, the study provides a data and evidence-driven decision-support mechanism for effective assessment and reporting on forest sustainability.

An Overview of Global Bamboo Forest Certification: The Status Quo, Challenges, and Prospects

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Illegal logging is one of the main causes of deforestation and forest degradation. As a voluntary market-driven mechanism, sustainable forest certification aims to reduce illegal logging in forests and promote sustainable management practices by creating a transparent, independent tracing and auditing mechanism. To date, around 11% of global forest areas have been certified under forest certification schemes. Biologically, bamboo belongs to the grass family and is classified as a non-timber forest product. Owing to its high fiber quality, many bamboo panel-based products, such as flooring, furniture, and kitchenware, are traded as alternatives to timber products in the global market. Therefore, bamboo and its products must adhere to the same legal requirements and public procurement policies as timber, such as the European Timber Regulations and the Lacey Act in the United States. Forest certification is widely acknowledged as a means of ensuring the sustainability and legality of forest sources by European countries and the United States, which are the largest importers of bamboo products. By identifying the differences between bamboo and trees in terms of their biological features and management, this paper provides an overview of the current development of global bamboo forest certification in terms of certification standards, practices, and markets; analyzes challenges and future trends; and offers recommendations for creating interest in this issue and taking further action.

Keywords: sustainable forest management, bamboo, certification, chain of custody, trade

Calibrating collaborative forest management through the lens of social, economic and ecological policy instruments in Bangladesh

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Sustaining and scaling up the benefits of a pilot intervention will require a clearer understanding of the political process and a transformative national framework that may support policy and institutional governance landscapes. Policy instruments, integral to the policy-political process, set the limits and directions of policy implementation. A greater understanding of a well-known set of implementation instruments and underlying reasons for choice and actors' rules of behaviour are vital to analysing the effectiveness of policies. We witnessed a notable policy shift in the governance of community-based forest management in Bangladesh – from social forestry (SoF) – to co-management (CoM) – to a collaborative (CoL) approach. However, the question comes: why has it been crucial to making such frequent shifts, what changes happened with the policy instruments across the governance process, and how has the transformation been essential to achieve conservation and sustainable management of protected forests? Hence, the study aims to investigate the trend and fusion of policy instruments through the lens of social, economic and ecological dimensions, reasons for choices and actors' rules of behaviour to evaluate the policy effectiveness. The study, therefore, hypothesises diverse formal and informal interests and multiple actors' power capabilities determine the instrument choices that may not ensure the sustainability and conservation of protected landscapes. The study employs a mixed qualitative-quantitative research method based on content analysis of relevant policy documents and expert interviews. The theoretical viewpoints regarding interests and power discourse and the evidence-based explorative analysis would serve as a basis to draw results about the power players and the driving interests taking such a significant stake in the resources management decisions. Among others, one important finding is that powerful development actors (foreign donors) and their allies make decisions regarding choices of policy instruments utilising their expert identity and funding portfolio. Adopting and implementing policy instruments see a lack of participation of state and community actors, stagnant scale-up operations and a paucity of resource mobilisation that cannot ensure sustainability and conservation of protected landscapes. The research gives a policy direction to help manage the protected areas and support undertaking strategic development decisions (e.g., financing, cooperation and policymaking).

Customizing the political effects of international forest policies in selected developing countries

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Based on a larger collaborative research programme, this contribution aims to analyse the political effects of selected international forest governance initiatives in developing countries. It does so be employing international regime theory and combining it with the emerging concept of "customizing" international institutions during implementation or transposition into domestic national and sub-national contexts. It employs cases from Bangladesh, Indonesia, Argentina .

Determinants of benefits of Participatory Forest Management income generating activities in Upper Imenti Forest in Meru County, Kenya

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: This study focused on identifying factors affecting the benefits of Participatory Forestry Management (PFM) income generating activities in Upper Imenti Forest from community perspectives and whether they are dependent on status of participation in forest management through membership of Community Forest Association (CFA) or not. Cross-sectional survey research design was applied for collecting quantitative data using a semi-structured questionnaires for 384 household stratified on the basis of PFM participation status. Using Statistical Package for Social Sciences version 25, Binomial regression with Wald Chi-square was analysed to identify factors perceived to be significantly influencing benefits for PFM participants and Pearson Chi-square to compare factors perceived to be affecting PFM and non-PFM participant.data. CFA members' participation in PFM was significantly and positively affected by benefits of PFM income generating activities and forest products accessed in the forest. Benefits linked to Plantation Establishment for Livelihood Improvement System (PELIS) for CFA members were significantly reduced by enforcement of moratorium policy since February 2018, diseases and pests, poor PELIS guideline adherence and animal damage. Benefits related to state forest access for firewood by the CFA members were negatively influenced by the moratorium policy. Diseases and pests affected benefits associated with bee keeping significantly. Comparing factors under different PFM participation status, crop production was significantly affected by policy changes, pest and diseases, animal damage and PELIS guideline adherence for CFA members than for Non CFA members. Policy changes also affected the CFA members significantly in firewood collection and access to fodder in the state forest than the Non-CFA members. Hence, sustainable community participation in Upper Imenti Forest management requires: increasing PFM benefits, addressing factors reducing benefits and enhancing active participation of CFA members in PFM related decision-making processes.

Key words: Participatory Forest Management, Community Forest Association, sustainable community participation, access to forest products, moratorium policy, income generating activities

Do incentive- or penalty-based policies better promote tropical forest conservation? Experimental evidence from Brazil

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Maintaining and restoring tropical forest cover is widely regarded as essential for biodiversity conservation and climate-change mitigation. At the same time, significant populations in these regions depend on agriculture and other non-forest land uses for their livelihoods. Convincing land users to reduce their activities that convert forests or prevent reforestation requires a mix of policy tools, like payments for environmental services or more conventional interventions such as forest-cover requirements with fines for not meeting them. However, which tools are most effective is far from a settled question, and is complicated to answer because of the cost and scale of testing them. In this presentation, we will share results of an ongoing study in São Paulo state, Brazil, that tests the relative effectiveness of four different intervention forms. These are either incentive payments vs. fines, conditioned on either individual-level vs. community-level land-use limitations, for four possible combinations. We test these interventions in the microcosm of an experimental game played by groups of eight small farmers from rural communities. The players are farmers in a watershed, and individually decide how much land to cultivate, but their harvest per unit of land increases with the ecosystem services provided by the intact forest in the landscape, which in turn depends on aggregate choices of all the players. This sets up a collective-action dilemma where payoffs increase with increasing individual land use, but decline with increasing group land use. To incentivize their decisions, players are paid an amount in local currency proportional to their in-game harvest. The game is divided into three stages, with one of the four possible intervention types implemented only during the second stage. This gives us both baseline and post-intervention stages, allowing assessment of both immediate (i.e. during intervention) and lasting (i.e. post-intervention) impacts of the interventions. All four intervention types are being tested in each of eight rural agricultural communities, along with collection of post-game interview data to help understand players' decisions. We will present results on which intervention types worked the best, and look at various lines of evidence as to why those interventions were effective.

Does protected area establishment result in pre-emptive forest clearing? Insights from Madagascar's protected area system expansion

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Slowing tropical deforestation is a major global policy objective given its role in tackling the combined challenges of climate change and biodiversity loss. Establishment of protected areas (PAs) is a commonly used tool. However, PA establishment might potentially result in unintended consequences; specifically pre-emptive forest clearing as people anticipate the upcoming policy restrictions, which has been anecdotally identified in other policy contexts. This is the first study to systematically investigate the phenomenon, and to explore whether it undermines benefits from PA establishment. We focus on Madagascar, whose PA network expanded by more than 400% between 2003 and 2017, using the synthetic control method to assess deforestation outcomes in some 300 administrative units overlapping with 25 PAs established as part of this expansion. Results suggest that pre-emptive forest clearing did occur in a large number of units. In most units, PA appears to have brought net gains in avoided deforestation, but worryingly, in many other units, pre-emptive forest clearing completely negated the intervention's gains. These findings raise concerns about the prevalence of this phenomenon in Madagascar, and potentially elsewhere, and highlight the need to revisit the assumptions underpinning the theories of change informing area-based forest conservation interventions.

Dynamics Driven by New Player: Exploring Chinese Engagement in the Forest Sector of the Democratic Republic of the Congo

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: This conference abstract sheds light on the persistent issue of tropical deforestation and its complex underlying dynamics in the Congo Basin region. Despite having multiple policies around the globe to tackle tropical deforestation, the exploitation of forests continues to be driven and justified by the promise of development and increased societal welfare. Historically, European colonial powers such as Belgium, France, and Germany have played significant roles in forest exploitation and land conversion, leading to economic gains for their nations. In recent times, China has emerged as a new influential player in the region, further contributing to the intricate web of interests, narratives, and power dynamics. Yet there remains a limited understanding of their narratives, operations and interaction with local dynamics.

This research contributes to understanding Chinese actors in tropical forests of Congo Basin in a particularly less understood case country, Democratic Republic of the Congo (DRC). We employ mixed method approach by using bilateral trade data between China and DRC from 2015 to 2022 obtained from both customs, and qualitative data from fieldwork in DRC and China including archives and interviews.

This study increases the understanding of the main trends in China-DRC trade and investment in forest sector, and understanding of the Chinese companies associated in the forestry economic activities. The main findings include who are the operators, their operational preferences, strategics, as well as their engagement with other main stakeholders, particularly those in deforestation policy domain such as local community, Chinese and DRC's government, Civil Society Organizations, international communicates, among others. It highlights how the growing presence of Chinese actors interacts with the existing dynamics of interest, narratives and power, and draws insights on to what extent the new player affects the policy agenda towards effective, efficient, and equitable policy change in global forest policies.

This study addresses a critical knowledge gap by unravelling the dynamics instigated by this new player in the DRC's tropical forest. It contributes to a deeper understanding of the complexities faced by forest policies in the Congo Basin region and provides valuable insights to inform future policy decisions in this domain.

Environmental Sustainability and Economic Complexity: Implications for the Brazilian Forest Sector in a New Developmentalism Strategy

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: The relationship between economic scale and its impacts on the environment is neither linear nor stable across economies and over time. It depends on the production structure and technologies adopted. Consequently, it is imperative to expand the share of segments that adopt "clean" technologies compared to those reliant on non-renewable natural resources and carbon-intensive methods. This can only be achieved through ecological structural change. This necessitates a continuous process of production sophistication in terms of economic complexity, which does not occur spontaneously due to market failures and the risks associated with investments in cleaner technologies and innovations. Due to the great diversity of aspects involved in this process, the developmental literature recommends a policy mix that combines fiscal, industrial, trade, and regulatory policies in a national eco-developmental strategy. This strategy should consider the accumulated knowledge on structural change and natural resource management. Specifically concerning the forest sector, public policies should unlock investments in sustainable forest management to increase its contribution to the supply of food, fibers, and forest raw materials with the potential to replace fossil resources, as well as to capture and store carbon and provide other significant environmental services. Additionally, there is potential for developing new products with a high level of technological content through advancements in forest research with native species, such as biofuels and biomaterials for the construction, cosmetic, pharmaceutical, chemical, textile, and other sectors. Therefore, this study aims to discuss the relationship between environmental sustainability, ecological structural change, and forests, and the implications for an eco-developmental strategy. This discussion takes place in the Brazilian context, where a variety of policy instruments exist to combine forest protection and sustainable use while simultaneously achieving carbon emission reduction goals. Furthermore, forest policy management is decentralized among federal, state, and municipal governments, affirming the literature's recommendation that the state's role in a national eco-developmental strategy involves policy coordination, providing information during policy management, harmonizing policy instruments, and supporting all actors in identifying opportunities for economic diversification that contribute to environmental sustainability. Consequently, it is suggested that the national eco-developmental strategy must have a high priority on the governmental agenda.

Forest Certification and Environment, Social, and Governance: The Case of Malaysian Timber Certification Scheme

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: The term Environment, Social, and Governance or ESG, which was mooted by the United Nations in 2004, has gained attention among investors and related stakeholders, globally. Recently, there has been increasing demand for ESG commitments in the forest-related sectors, where investors and related stakeholders require forest-related businesses to demonstrate their ESG commitments. The forest certification standards have emerged as the potential tool to meet ESG commitments. In this context, the Malaysian Timber Certification Scheme or MTCS is a forest certification standard that assures that forest and forest products are managed in a sustainable and legal manner in Malaysia. Thus, this study will explore how the MTCS-forest certification standard supports ESG commitments. The FTSE Russell's ESG data model, a model that allows investors to understand how businesses manage ESG commitments, was used in this study. The MTCS-forest certification standard supports ESG commitments, such as the protection and conservation of biological diversity, ecosystem services, and water resources, indigenous peoples' rights, workers' rights, forest management planning, monitoring and assessment, and legal compliance, among others. This shows that the MTCS-forest certification standard provides a positive impact on a broad range of ESG commitments. Thus, the MTCS-forest certification standard is a potential selection tool to fulfil ESG commitments and to provide investors and related stakeholders with an understanding of ESG practice in the forest-related sectors.

From awareness to knowledge and action: a case-study on challenges and outcomes of forest governance in the subtropics

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: In face of deforestation and forest degradation in fragmentated landscapes, forest governance needs action plans based on reliable and updated data of key variables. These are commonly provided by regional/national forest inventories. Here, we report the 30-year journey pursued since the raising of society's awareness about the extent of damages caused by land use changes, towards the creation of effective forest policy instruments, in the Brazilian state of Santa Catarina. First, the increasing pressure of the public opinion for protection of the Atlantic Forest lead to a federal law enforcement during the 1990ies; however, this was poorly communicated and often misunderstood as an authoritarian top-down approach. Disregarding concerns of the rural population, it resulted in resistance at local level. Later, the state government adopted actions to align land use and regularization of rural properties, thus ceasing deforestation and increasing conservation efforts. The environmental agency and police were reinforced through 18 well equipped regional offices. A continuous state forest inventory, in the molds of the brazilian NFI, was designed in 2006 to provide reliable and updated data on forest extent, composition, biomass stock/dynamic and conservation status. This assessment is now performing the third measurement cycle. A working group of stakeholders, from private/public sectors, scientists and NGOs, was created in 2012 to design a policy framework on forest and land use governance. The new policy, ratified in 2013, aims the maintenance of smallholders' livelihood, biodiversity conservation, valorization of forest lands and payment of ecosystem services. Priority programs were proposed to 1) promote silviculture of native tree species, for rehabilitation of degraded forests and commercial plantations; 2) manage secondary forests, based on traditional forms of land use rotation, as on selective cutting; 3) integrate territorial planning, licensing, inspection and environmental regularization of rural properties; 5) establish a forestry extension service to advise forest owners in good forest management. As an example of endogenous development, with own financial means, the state inventory filled a knowledge gap about state's forests, enabled full public access to collected data, now allowing society to claim the deployment of the new forest policy, truly geared to collective interests.

Impact of Indonesia's general-purpose ecological fiscal transfer on forest cover: a comprehensive evaluation approach and early results

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Indonesia has initiated significant reforms in order to reduce GHG in the land-based sector. Among the country’s most ambitious and recent reforms is the introduction of forest cover of subnational jurisdictions as an indicator to allocate general-purpose fiscal transfers (DAU), Indonesia’s largest and most significant fiscal transfers, from central to subnational governments. With an explicit link to forest cover, this new fiscal transfer policy is expected to change the incentive structure for reducing deforestation in Indonesia. Scientific evidence on the impact of Ecological Fiscal Transfers (EFT) is scarce, and existing studies in the early-moving countries of Brazil and India are not directly comparable to the Indonesian case of general-purpose fiscal transfers. In this research, we first adopt a political economy framework and use the Transformational Change literature to analyze the underlying policy processes leading up to this ambitious policy reform. Secondly, we present a detailed research protocol, aimed at providing evidence of the impact, and impact pathways, of Indonesia’s EFT policy for general-purpose transfer and related fiscal transfers, as well as the early results of this research. This protocol is based on a mix of robust qualitative and quantitative methods for causal inference using quasi-experimental methods and process tracing, and which share common prerequisites, to produce a sound theory of change. We further emphasize three scientifically-sound and policy-relevant questions: (1) To what extent and under what conditions do EFTs create an incentive effect that is strong enough to change the behaviors of local policy makers and to overcome the effect of business-as-usual incentives promoting deforestation (e.g. the general elections that will occur in 2024 in Indonesia)?; (2) Using quasi-experimental approaches, how do we measure the additional impact of a policy that is implemented nation-wide and whose implementation is not staggered?; (3) Through which mechanisms do such collective incentives influence the individual decisions of land users and contribute to overcoming the typical challenges faced in collective action settings, such as free-riding and elite capture?

It takes two to trade: who shapes flows of wood trade in Congo basin and how?

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Demand for timber in, and exports (referred to here as flows of timber) to wealthy nations have led to extensive deforestation in the countries of origin over the past decades (Rudel, 2005). Though seemingly modest on the global scale (only 1% of global traded wood volumes in 2021), Congo Basin exports volumes are rapidly increasing – by 173% in Cameroon between 2004 and 2012 (Mahonghol et al, 2016) – with irreversible effects on forest cover. Simultaneously, Congo Basin countries have enacted policies that restrict or prohibit the export of specific forest products, to slow the decline of forest cover and increase value-added. Addressing deforestation in the Congo Basin must therefore include a better understanding of how these flows are shaped. We ask: how do global forest agreements and national policies affect timber flows? And because it takes two to trade, how do national and international actors facilitate or hinder the flows of timber commodities in Cameroon and DRC?

We draw from Ecologically Unequal Exchange, allowing us to critically appraise the mechanisms which sanction asymmetrical transfer of natural resources through trade, and their effects on monetary and socio-ecological aspects. Through critical discourse analysis of the policies that act as these mechanisms, namely the Log Export Ban in Cameroon, and Moratorium on logging concessions in the DRC, we investigate underlying problematizations and assumptions embedded in policy formulation. Through interviews (n = 82), we explore how different actors perceive the role of domestic forest policies in shaping forest governance, and the strategies that they adopt in abiding or bypassing them, by inquiring about preferences in traded wood species, and tactics of resistances.

We show that ecologically unequal exchange remains the guiding principle of international timber trade, where historical trade partners retain a strong influence on policymaking. However, the apparent change in flow trajectory (China and Vietnam being the main destinations) and of preference in wood species, seem to show that Cameroon and the DRC are forming new patterns of trade with different trade partners, thereby bypassing existing policies. This work hopes to provide a more nuanced picture of the mechanisms underlying the unequal flows of timber.

Land Registry Program's Impacts on Land Use Knowledge and Conversion

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Land registration can contribute to sustainable forest use and increase the livelihoods of people who depend on natural resources by establishing and strengthening land titles and property rights. The formalization of access to and rights to use forests through land registration has occurred globally through initiatives such as state-initiated land reforms and programs. While the evidence on the environmental and development impacts of land certification, registration, or titling programs abounds in the literature, less is known about (1) how land registration programs might create perverse incentives to deforest, (2) market formalization channels through which land registration programs might change smallholders' land use, and (3) how those changes might affect smallholders' welfare.

In this paper, we fill these gaps by studying the impacts of one of the most extensive land registration programs, Cadastro Ambiental Rural (CAR), on smallholders' land use change and livelihoods in Bahia and Piauí in Brazil. Using unique primary panel data collected from 1,177 smallholders and by applying various impact evaluation strategies for causal identification, we find that smallholders who complied with the Forest Code by having more than 20-30% of their land as native vegetation at the time of CAR registration have increased conversion of forests/grasslands into agriculture or pasture area by 0.5-0.8 ha more after CAR registration compared with those who were not in compliance with the Forest Code. Our investigation of mechanisms shows that rather than the land use rights shown through CAR, the knowledge about their land area might have driven the increased conversion to agriculture or pasture area. We also find that the production of subsistence crops has increased, which could have contributed to improving smallholders' livelihoods.

These findings contribute to the literature by showing how land certification or registration programs might facilitate a market formalization process that can change smallholders' land use and livelihoods. Our results have policy implications for similar land registration programs for forest conservation, suggesting that land registration programs need to consider factors associated with perverse incentives to increase cultivation area to avoid unintended consequences.

Mixing policies under the umbrella: the case of REDD+

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Many on-the-ground interventions in tropical forests, aiming to address combined, implicitly or explicitly weighted goals of forest conservation and livelihood improvements or other co-benefits, prefer to combine different instruments simultaneously in their applied strategies. Reduced emissions from deforestation, forest degradation, sustainable management and enhancement of forest carbon stocks (REDD+) constitutes one such example of intervention/ policy mix. In a way, REDD+ has been to forest-based carbon mitigation what integrated conservation and development programmes (ICDP) have been to biodiversity conservation: an umbrella concept covering a heterogeneous mix of on-the-ground interventions. Our purpose here is to employ a bigger sample to systematically characterize the composition of REDD+ interventions, including incentives (e.g., payments for environmental services (PES)), disincentives (e.g., forest-law enforcement, protected areas), enabling actions (e.g., land reform, decentralization), and their respective subcategories. We will do so by drawing on quasi-experimental data from 16 local REDD+ sites in Brazil, Peru, Cameroon, Tanzania, Indonesia, and Vietnam, as part of CIFOR's Global Comparative Study on REDD+ (GCS-REDD+), combining data from a comprehensive implementer survey with remote-sensing data and surveys applied in nearly 130 villages to 4,000+ households, in 2010-2011 (pre-intervention) and 2013-2014 (post-intervention I). In 2018, a new round of GCS data was collected, in a subset of the 23 initiatives (post-intervention II). We will characterize the distributive patterns of action, and try to juxtapose our findings to what we know regarding the effectiveness of these forest interventions, trying to respond to the research question: were some combinations or sequences of mixed policy/ intervention instruments apparently more effective in reaching conservation and livelihood objectives? Our results will feed into tentative policy recommendations, and suggestions for the emphasis of future research.

Keywords: tropical deforestation, conservation strategies, climate change, global-comparative study

Role of National Conservation Instruments in Improved Provisioning of Ecosystem Services in the Tropical Andean Forest

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: After the pandemic, the scientific community and decision-makers have recognized with greater emphasis the crucial role of natural capital in generating well-being for the population. Whose binding element between both (natural capital and well-being) are ecosystem services.

To contribute to constructing a more resilient society to disturbances, governments have created national conservation instruments to provide more goods and services from forests, avoid deforestation of forest ecosystems, to increase carbon reserves and sequestration.

The Socio Bosque Program (SBP) is a national conservation instrument of the Ecuadorian government that seeks to generate well-being for communities through the increase and fixation of carbon. The impact assessment method under the theory of change was used to estimate the impact of (PSB) between 2008 to 2014 and 2014 to 2020 on improving a provisioning ecosystem service, such as forest carbon.

The study estimated that the amount of carbon and CO2-eq that the SBP prevented from being released into the atmosphere was 11 and 41 (ton/ha), respectively, between 2008 and 2014; the results for 2014 to 2020 are still under construction. Other research data shows that the protected area in the collective SBP was 39.121 ha, and if the SBP had not been implemented, an area of 1.077 ha would have been lost in 2014. For individual SBP contracts, the protected area was 8.675 ha, and the presence of the SBP prevented the loss of 238 ha by 2014.

These results are critical within the policy of the Government of Ecuador that pursues that ecosystem services can be negotiated within a voluntary or formal market (Art. 74 of the Constitution of Ecuador limits access to a carbon market). Based on the results, it is expected to contribute to the sustainability of the SBP, and both community and private partners have better information to negotiate the sale of carbon credits. Our conclusions are robust, even considering potential hidden biases. Therefore, the present study demonstrated that the SBP mitigates climate change's effects.

Science to support the European Union Deforestation-Free Regulation

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: According to the United Nations Food and Agriculture Organization, the world has lost 420 million hectares of forest through deforestation over the past 30 years. This is significantly affecting vital forest functions such as carbon sequestration to slow climate change, provision of raw materials, serving as biodiversity hotspot. Agricultural expansion accounts for nearly 90% of global deforestation, with seven forest risk commodities representing the largest share of EU-driven deforestation. Much of the tropical forestlands lost are used to produce globally traded goods like palm oil, soy, timber, cocoa, coffee, beef and natural rubber. EU consumption of these goods is responsible for about 10% of global deforestation. To address this issue, the European Commission has introduced the European Union Deforestation-Free Regulation (EUDR) as a legal framework with mandatory due diligence requirements for companies placing forest-risk commodities and their derived products on the EU market. The regulation is ratified in June 2023.

Our project DeFREE is bringing together research institutions and an innovative start-up to develop methodologies in support of EUDR. The first component focuses on tracing: a QR-code based product tag enables consumers to trace the origin of products. The second component utilizes remote sensing to assess deforestation and degradation (D&D) in production areas and their surroundings after December 31, 2020. Previous results demonstrated that certification bodies can leverage these services to enhance the verification of reported timber harvests and identify instances of illegal and unreported logging, particularly in remote forest areas where on-site verification is logistically challenging. Based on the assessment outcomes, products will be flagged with different colors: red for D&D in the production zone, orange for D&D in surrounding areas and green for no detected D&D. Especially in the case of "orange flag" and for the assessment of degradation, in situ-data is needed. Such ground data is – especially in tropical and subtropical countries – not easy to obtain. Therefore, our third component focuses on crowdsourcing. Especially for ambiguous satellite data this additional ground data will increase information value. We will implement test cases for cocoa, rubber and coffee in Cote d'Ivoire and Uganda.

Seeking synergies in a polycentric policy mix: Brazil's priority list for deforestation control

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: In many countries with large remaining areas of tropical forest, governance of those forests is shared across multiple levels of government with varying incentives for conservation and deforestation. In this type of polycentric system with heterogeneous objectives, central governments need ways to translate international and national priorities, such as Nationally Determined Contributions to climate action, to local governments. One mechanism widely recognized as effective was the Brazilian federal government's priority list. Launched in 2008, the priority list identified municipalities responsible for the most deforestation, and then publicized their status, targeted enforcement action to them, and restricted their access to input and output markets for agriculture. This established a collective incentive for municipal governments and local stakeholders to reduce deforestation. The priority list was layered on top of a pre-existing and complex policy landscape. We examine how previous land tenure/land use policy shaped the effectiveness of the priority list. Specifically, we establish a typology of municipalities based on the fractions of their area in protected areas and in agricultural settlements. For each type of municipality, we estimate the causal effect of being added to the priority list, using both traditional matching methods and new approaches to estimating dynamic treatment effects. The new approaches reveal that the priority list had the most impact where protected areas and agricultural settlements cover intermediate fractions of the municipalities. Those municipalities presented the greatest opportunities for synergies between the priority list and land tenure/land use policies, and thus adding a collective incentive into the policy mix was highly effective.

The struggle of conservation territories expansion in the Congo Basin: insights from the Democratic Republic of Congo

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: International actors had and continue to play key role in triggering several policy reforms in Central Africa. A significant international financial incentive to establish new conservation territories or to enlarge existing ones, either through estate-protected areas or other conservation areas (managed by private operators or by forest dependent communities). To date, up to 15% of the Central Africa is officially protected for its biodiversity, with the most imposing restriction use placed on forest dependent communities. The quest of biodiversity conservation in the Central Africa, driven by international actors, has resulted to demarcation of conservation territories in which boundaries are mostly visible on maps. Using the long-term US-funded biodiversity conservation programme in Congo Basin countries known as Central Africa Regional Programme for the Environment (CARPE) as a case study, this paper aims to assess the process in which conservation territories expansion was pursued and to what extend it has affected the power dynamics of diverse and divergent actors' interest within these mapped boundaries. Drawing on the symbolic politics as theoretical and analytical framework, we tested if the conservation territorialisation pursued under CARPE has fallen into symbolic demarcation in which the spatial claim is poorly enforced and overstated to hide inefficiency and ineffectiveness as well as injustice. We collected a mix of qualitative and quantitative data through face-to-face interviews and field observations, triangulated with a review of policy and programmatic documents. We deepened our empirical studies using one of the largest landscape conservations under CARPE which known as Kahuzi Biega-Tayna-Maiko landscape located in the Eastern of Democratic Republic of Congo. Our findings show that conservation territorialisation efforts performed in a fragile state such as DRC have fallen to a symbolic demarcation which have failed to achieve biodiversity conservation and local development objectives.

Transforming forest reserves to national parks: Political economy and governance perspectives on forest policy changes and instruments in Uganda.

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Institutional arrangements to counter forest loss in Africa are rapidly evolving. Gazetting Forest reserves (FR) was a traditional governance arrangement in most countries, initially rooted in the colonial land use administration. Uganda took a bold step in 1993, reforming its forest policy and transforming many FRs to National parks (NP). With a legal notice, six FRs were converted to stronger conservation regime as NPs. In 2023, it announced again such changes, suggesting three areas be transformed. This changed overnight the conditions for forest indigenous and neighbouring communities. Following came application of multiple policy instruments, often bundled within conservation and development projects. These policy instruments, nested in the nature conservation legal and policy frameworks, included issues like collaborative agreements on resources access; revenue sharing systems; access to business, compensation for wildlife losses and different human-wildlife conflict measures.

The study is rooted in theories on natural resources governance and in particular forest governance resources systems. The objective is to examine sustainability outcomes of the transfer from FRs to NPs and how the different policy instruments implemented parallel have delivered differently to the multiple social, economic, and ecological objectives. A political economy lens analyses what priorities have become dominant from the transition. We employ mixed methods of qualitative and quantitative data analysing the governance systems, design, and outcomes from the policy instruments.

The findings show the transition having different implications for the different pillars of sustainability and the policy instruments often not effective or enduring. The outcomes for the livelihoods of neighbouring communities are generally negative. Economically they are worse off, revenues are disproportionally shared and compensation instruments weak. The ecological objectives are however improving like many wildlife populations. That has however amplified wildlife conflicts.

Countering deforestation and enhancing delivery of ecosystem services for tropical forests by transforming FRs to more strict conservation governance systems is challenging. It may have severe political economy implications, allow local neighbours significantly worse off, redirect economical gains and cause new conflicts. That has been the case in many Ugandan parks. This all comes down to identifying the effective and efficient policy instruments to deliver more just outcomes.

Understanding biological conservation governance through campaign-style enforcement in China

T4.8 Effects and effectiveness of forest policies in developing tropical statehoods

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Abstract: Effective management of PAs has been seen as essential for biodiversity conservation and further achieving EC. However, even though the central government has set biodiversity conservation goals and passed related laws and regulations,conservation effectiveness in China has been extensively criticized. In order to improve the implementation, Green Shield Action (GSA) was conducted, which provides critical insights into the nature of environmental politics during a campaign-style inspection under an authoritarian regime. By using qualitative research method, and based on fieldwork in Fujian from 2019 to 2022, the dynamic interactions among stakeholders, the role of campaigns in environmental governance, and the logic behind policy formulation, implementation, and revision were explored. This study finds that in the campaign-style inspection, with the application of new technology and improved management, less room was left for local governments to make trade-offs and dilemmas. The high political pressure caused conflicts. These outcomes were used as a reference for the central government to adjust policy design and turn it into regular enforcement with an improved environmental governance system. The campaign-style enforcement is not the opposite of regular enforcement, but these two are closely connected in the case of GSA.

Selected references

T4.9 Evaluating policy outcomes in complex land-use systems

A framework for assessing climate neutrality and biodiversity conservation in a regenerative forest-based circular economy

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: The provision of one ecosystem service from nature often comes at the expense of another, resulting in trade-offs. There is evidence from the literature that trade-offs between provisioning and regulating or cultural ecosystem services are hard to avoid when managing forests. However, synergies between ecosystem services are also seen.

This study presents a conceptual framework for the analysis of synergies and trade-offs between ecosystem services in the forest-based circular economy. The framework facilitates a dynamic modelling quantification of environmental footprints to evaluate goals towards forest multifunctionality formulated in e.g., the European Green Deal and the New EU Forest Strategy for 2030. Furthermore, the framework allows us to assess the implementation of circularity and cascade utilisation.

Our scope includes changes to the marketed ecosystem service of timber provision and the partially or non-marketed ecosystem services of carbon sequestration and biodiversity conservation. The key question is how to preserve forest biodiversity and ensure carbon sequestration for climate benefits, while maintaining resource extraction sufficient for supplying downstream processing industries and consumers in a growing global bioeconomy.

The framework adopts a holistic systems approach for mapping economic flows and associated flows of resources, energy, greenhouse gas emissions and other relevant environmental impacts from the forest and through industries to final consumption. Our conceptual framework builds on well-established economic and environmental accounting frameworks for national accounting, material flow analysis and life cycle assessment.

Our main contribution to the literature is the design of an operationalisable framework allowing for sustainability assessment of pathways towards regenerative practices in a forest-based circular economy at the macroeconomic level, which includes the identification of modelling requirements, data needs, and knowledge gaps. We apply the framework to model the relationship between forest-based economic activities and the selected ecosystem services from the forest to the end-of-life of wood-based products at a system level. The framework can be applied for an individual country, a region, or the world as a whole.

Analyzing possible reconciliation for policy support – A case study on wood production vs. biodiversity

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: Our case study investigates impacts and feasibility of implementing protection targets of EU Biodiversity Strategy 2030 in Finland. According to the protection targets, 30% of EU's land and sea area should be legally protected by 2030. The strategy aims to increase protection by setting aside forests and extending closer-to-nature forest management practices. Hence, the implementation of the strategy would impact the supply of wood and the forest management practices.

To investigate impacts, we used the European Forestry Dynamics Model (EFDM) to simulate the development of Finland's forest resources considering the protection targets. The EFDM components were estimated from National Forest Inventory (NFI) data and MOTTI forest simulator results. The impacts were analyzed via economic (standing total growing stock, net present value) and ecological (dead wood volume, bilberry and cowberry yields and coverages) indicators.

According to our simulations, the total growing stock and net present value will be lower with the additional protection than by carrying on the business-as-usual management. The additional protection resulted in intensified harvesting in the remaining forest area available for wood supply with the current harvest level. This may weaken the positive ecological impacts of protection. Reducing the harvest level from the current level is not a likely alternative either, because the demand for biomass is predicted to increase in the future, while the supply is insufficient, and EU policies aim to avoid shifting the negative impacts of resource extraction outside the EU.

The analyses were conducted while the actual targets and even terms were still to be define. Still, the strategy's possible impacts can be simulated for policy support purposes, and then reformulated and rerun once the definitions are fixed. Our approach could be used for other countries and further developed to cover more aspects, such as climate change, timber markets and forest owner's behavior.

Beyond Twenty years of Nordic Forest Governance: Key Informants perspectives on Policy changes, Trends, and Future Implications

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: There are increasing demands for robust, legitimate, and evidence-based policy making to tackle present and future sustainability challenges, including the management and governance of Nordic forest systems. This study uses interviews with key informants to evaluate recent forest policy implimented in Sweden, Norway, Finland, and Demark. We identify and assess policies and their outcomes related to forest products, biodiversity, carbon budget, and other socio-ecological consequences. We contribute to the literature by an expert-based assessment of adaptive changes in governance approaches from a comparative perspective in the Nordics. Here, we provide in-depth insights into what factors determine successful policy making. An overarching governance paradigm that has emerged in the Nordics since last century is "freedom with responsibility". In this context, preliminary resuts indicate that there are overall shifts towards i) an increasing consideration of multifunctionality under a continuously strong focus on biomass and harvest production, and ii) a growing use of economic instruments that do not infringe on the principle of freedom of choice. What remains, a somewhat unresolved question is how to integrate responsibility for effective climate change mitigation and biodiversity conservation. We collect and present the most promising developments for present and future policy mixes that facilitate inclusive, multifunctional, and multi-level forest governance.

Keywords: Nordic forest governance; Policy evaluation; Comparative policy analysis; Adaptive governance; Sustainable forest management

Climate targets in European timber-producing countries conflict with goals on forest ecosystem services and biodiversity

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: The European Union (EU) set clear climate change mitigation targets to reach climate neutrality, accounting for forests and their woody biomass resources. Increased forest resource demands might lead to increased timber harvests in forests escalating pressures on forest ecosystem services and biodiversity (FESB). The climate change mitigation policies may thus interact with goals from other policy domains, such as the EU Biodiversity Strategy or the EU Forest Strategy, both operationalized nationally reflecting the countries' priorities placed on forests.

Using three Nordic countries (Finland, Sweden and Norway) and Germany as study regions, we investigated the consequences of increased harvest demands resulting from EU climate targets. Further, we analyzed the impacts on national policy objectives for FESB through forest simulation and multi-objective optimization methods. We first used empirical models to simulated forest dynamics and management under climate change and to gain information on the future provision of FESB. Second, we modelled the future harvest demands related to EU mitigation targets using the global forest sector model GLOBIOM. Third, we elaborated the demands for FESB of three national policy domains. Fourth, we resolved the optimal forest management programs for national policy targets (bottom-up) and for EU mitigation targets (top-down) by using the method of multi-objective optimization. Finally, we analysed the cross-scale policy coherence between national- and EU-level policies by comparing the outcomes of the two optimization approaches

We show that key European timber-producing countries (Finland, Sweden, Germany) may not be able to cover the increased timber demands for material and bioenergy usage arsing under the

ambitious 1.5°C target. Focusing on EU mitigation targets further conflicts with national sectoral policies and cause adverse effects on multiple forest ecosystem services and biodiversity. We argue that the role of forests and its timber resources for achieving targets on climate change mitigation and societal decarbonization should not be overstated. Our study provides a comprehensive analysis on the potential consequences of future harvest demands required for achieving EU climate change mitigation targets. For the first time, forests are assessed to determine if multifunctional benefits can be provided while transitioning to a climate-neutral economy.

Could the Sloping Land Conversion Program Promote Farmers' Income in Rocky Desertification Areas?—Evidence from China

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: The Sloping Land Conversion Program (SLCP) is a significant measure to achieve the Sustainable Development Goals (SDGs) proposed by the United Nations in 2015. SLCP plays an important
role in poverty alleviation and income increase for farmers in poor areas. The purpose of this study is to analyze whether the income of farmers has increased after participating in SLCP, and whether SLCP has released the agricultural labor force to obtain non-agricultural income by participating in non-agricultural work. Based on the field investigation in Luocheng County and Longsheng County of Guangxi, Libo County, and Dushan county of Guizhou, this paper uses the method of propensity score matching (PSM) to explore the impact of SLCP on the income of farmers in rocky desertification
areas. According to our research, it is found that: (1) SLCP has a positive effect of 5.2% on the average annual net income of farmers, a positive effect of 43.2% on agricultural income, and a negative effect of 9.8% on non-agricultural income, but all of the effects are insignificant. Selective deviation will overestimate the impact of SLCP on farmers' total income and agricultural income and underestimatethe impact on non-agricultural income. SLCP failed to promote the transformation of farmers into secondary and tertiary industries. The mechanism of SLCP to increase farmers' income is complex. (2) Farmers' participation in SLCP is influenced by work experience and education level in human capital, participation in skills training in social capital, and owning durable consumer goods in physical capital. Although SLCP will promote economic development under the condition of improving the ecological environment in the future, it is not advisable to exchange farmers' livelihood for ecological construction at present. The implementation of SLCP should consider not only the overall ecological benefits, but also the short-term social and economic benefits.

Evaluating the impact of 20 years of forest policy for endangered fish habitat in the Pacific Northwest, USA. Using multiple methods to inform policy.

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: The legislature in the State of Washington commissioned the University of Washington to conduct a policy impact assessment after 20 years of the "forests and fish" policies intended to protect endangered salmon habitat. This paper situates the resulting policy report in the broader context of policy impact assessments in a forest governance context. We identify a common goal among all stakeholders of protecting small forest lands from development pressures and maintaining the environmental services they provide. The central trade-off the report analyzes is the net outcome of regulations and policies intended to secure riparian function against the complaint of forest owners that the same regulations are an incentive to divest from forest stewardship thereby driving the conversion of forest lands to non-resource uses and reducing riparian functions. Evaluating the impact of forest policy in the State of Washington was facilitated using the Forestland Database to account for the relatively dynamic land use change patterns in the state, including: lands that go in and out of forest land use, conversions between different kinds of resource land use categories, changes between family forest ownership and industrial ownership status, parcelization and agglomeration, and changes to riparian zones themselves.

In addition to social-ecological complexities, the policy environment includes a mix of regulations, an easement program for partial compensation of foregone timber revenues in riparian zones, an alternative management program, and a landowner assistance office. We outline how a combination of stakeholder interviews, policy document and budgetary reviews, two new forest owner surveys, a previous forest owner survey, and causal inference techniques using parcel data were employed to analyze the impact of the policy mix and derive policy recommendations. The report identifies policy leverage points to help sustain forestry in a complex land use environment and support riparian functions, yet after 20 years of policy implementation and ongoing conflicts most policy suggestions were not novel to policymakers. We close by discussing the challenges of distilling a 400+ page policy report into recommendations for practitioners as well as the outcomes the report has had on state policy, such as increased funding for public stewardship foresters.

Forests in systemic transition (ForTran): Bringing solutions to balancing efficiency with fairness and resilience in the forest system

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: Global changes in the forest sector accentuate the conflicts among views on how to use forests. Forests are an important source of intangible and material well-being , but their resilience is being challenged by climate change and biodiversity loss. In response to these challenges, policies at EU and national levels are being designed to facilitate a green and just transition in how we perceive and use forests. To promote effectiveness and coherence among forest-related policies and actions, we need a system-level approach. To explore the importance of utilizing a system-level approach we focus on the Finnish forest system, which is affected by global phenomena such as climate change, and the increasingly polarized and politicized debates on national and international policies. Through this approach, we address the challenges faced by private sector enterprises and society in finding increasingly resilient and sustainable ways to use the forest. We combine participant observations, semi-structured interviews and facilitated workshops with forest stakeholders and governance actors to produce qualitative information to maps the rich diversity of views, values and practices regarding forests and plausible future paths towards resilient forests (JUST). To define how much forest resources can be used without compromising the natural capital of forest ecosystems (GREEN), we combine those views and needs with ecological knowledge and state-of-the-art forest simulation and optimization methods interactively with stakeholders. Simultaneously, we find solutions for business, forest management and governance to enable systemic change (TRANSITION). These findings are summarized into a new and flexible coupled human–environment systems method to bring together the social and ecological solutions for resilient forests and just green transition. The knowledge created will enrich our understanding of the interconnectedness of the social, economic and ecological dimensions of the coupled human-environment forest system and will allow for better mixes of policies and other mechanisms to unlock novel opportunities that strengthen the resilience of forest use.

How to improve the evaluation of forest outcomes under complexity – insights from large-scale deforestation assessments in the Neotropics

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: To support decision-making, robust assessments are needed that determine how forest outcomes are affected by environmental policies and management interventions, and by the properties of the social-ecological systems in which they are embedded. The inherent complexity of forest systems makes it particularly challenging to disentangle, attribute, and quantify effects on forest change. Based on complex adaptive systems theory, we developed an approach to causal inference that allows assessing the effects of policies, interventions, and system attributes in a spatially explicit way, while addressing issues of confounding and non-linear relationships. Given that ongoing deforestation in the Neotropics continues to fuel biodiversity loss and climate change, we provide two examples of how a complex adaptive systems view can enhance our understanding of forest outcomes. The first example addresses the effect of different (and overlapping) types of protected areas governance and indigenous tenure regimes on deforestation patterns. To this end we formulated spatially explicit models based on 20 million point observations in the Amazon region and Central America. Our method allowed us to separate the effects of governance and tenure regimes both from each other and from confounding variables that are known to affect deforestation (such as distance to roads, topography, population density, and others). Our results indicate that, overall, indigenous tenure and protected areas are equally effective at reducing deforestation, but also that the effectiveness shows pronounced variation at the country scale and below. As a second example, we assessed the affect of the COVID-19 pandemic on deforestation rates in the Neotropics, again controlling for known deforestation drivers. We observed that there is a pronounced spatio-temporal variation of this effect, which suggests that the pandemic has affected deforestation through multiple pathways. Based on these examples we explain how the approach can be used to assess other forest outcomes (such as ecosystem services and biodiversity indicators) and how the results can be used to support decision-making and adaptive management.

Implementation of Public Policies in High-Risk Fire Areas: The Case of Mação, in central Portugal

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: Rural fires in Portugal annually devastate thousands of hectares of forest areas. High-risk fire areas experience more frequent occurrences compared to other regions of the country. Public policies are intended to play an important role in preventing these occurrences, acting at the level of forest and landscape management. This study examines the implementation of public policies in areas with high-risk fire, focusing on the case of Mação, in central Portugal. Semi-structured interviews were conducted with key institutions and political actors involved in the implementation process. This research aimed to understand the factors that determine the success and failure of public forest policies implementation. The findings revealed that coordination between institutions and stakeholders is crucial for policy implementation, highlighting the role of local political actors in carrying out political measures. The results allow us to understand the need for inter-institutional coordination strategies and mechanisms are important to mitigate these frequent fire occurrences.

Integrative governance, multi-actors, and power relationships to human-elephant conflict: The case of elephants in Xishuangbanna, China

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: The conservation of nature is critical for the preservation of biodiversity. However, it can also lead to conflicts and challenges for communities who rely on natural resources. This paper focuses on the Human-Elephant conflict (HEC) in Xishuangbanna National Nature Reserve, China, and examines the causal linkages between governance systems and HEC. Drawing on integrated governance (IG) theory and actor-centered power (ACP), we analyze the influence and interaction of three policy systems, namely Asian elephant conservation policy, agricultural development policy, and forestry policy, on the governance of HECs. We also explore the power dynamics among multiple actors involved in policy formulation and those affected by policies to identify the drivers that influence the performance of governance. Our findings suggest that the interaction within policy systems significantly impacts the transition of land use and human-elephant relationship at different governance stages, with farmers playing a crucial role in shaping conflict management. Specifically, we document a 30-year evolution of human-elephant relationship in a tropical rainforest community and provide recommendations for future conflict management from the perspective of integrated governance. Overall, our research contributes to a better understanding of the complex dynamics of wildlife conservation and its impacts on local communities, emphasizing the importance of adopting an integrated governance approach in managing conflicts.

Research on the Profit Contribution of Forest Ecological Benefits—Based on Policy and Market-Tools Compensation Projects in Nanping

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: Abstract: Measuring the profit contribution of ecological benefits is an important prerequisite for the operation of the value-realization mechanism of ecological products. Based on the theory of ecological benefits and ecosystem services, combined with system dynamics and the project cost benefit method, a forest-ecosystem-service capitalization of the resources and assets value and the realization of an ecological product-benefit system is constructed. The value-realization project of the national reserve-forest ecological products in Nan-ping City, Fujian Province, the National Ecological Civilization Pilot Zone, was selected to calculate the cost and income during the 30-year operational period of the project, and to calculate the profitability of the forest-ecosystem ecological benefits in the project, using different scenarios. Scenario 1: The project income will only be enough to cover the costs of the project operation, and the cost will be recovered at the end of the project operation. Scenario 2: With policy-based ecological compensation, compared with scenario 1, the total project-input line-of-revenue breakthrough and total project-cost line were advanced by 3 years and 2.5 years, respectively. Scenario 3: With the additive effect of the ecological benefit of the ecosystem, compared with scenario 2, the total project-input line-of-revenue breakthrough and total project-cost line were advanced by 3.5 years and 6 years, respectively. It is suggested that the guiding role should be that of policy-based ecological compensation, expanding the scope of ecological-market access, and attracting social investors to participate in the development of ecological products by means of diversified ecological compensation such as market-oriented tools, so as to fully realize the profit contribution of ecological benefits to the project through the realization of the value of ecological products.

Structural Leverage Points for Sustainability Transitions in Polycentric Forest Governance: The Case of Forest Genetic Resources Policies in Europe

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: To tackle deforestation, biodiversity loss, and climate change, Europe is taking a lead role by adopting numerous policies (e.g., the Green Deal) related to access, management, and use of natural resources, aiming at transitions towards a sustainable, green, and just society. Thus, we are facing significantly increasing policy complexity that implies high possibilities of incoherence within domain-specific policies and among policy domains and policy levels. Multiple effects, as substantial trade-offs and spillovers can be further observed in further transposing of the EU policies to regional, national, sub-national, and consequently local levels. While on the decision-making level transition efforts might result in uncoordinated policies and ill-designed policy instruments, on the implementation level, this might manifest in inefficient and poor implementation that reflects in the unsatisfactory state of forests and other natural resources. Starting from the premise that forest genetic resources (FGR) are a basic constitutive unit of forest trees and ecosystems underpinning biodiversity, adaptation, and resilience, our contribution illustrates the complexity of polycentric forest governance by identifying social/system-level leverage points and potential strategic policy interventions, based on the case of FGR in Europe. Building on the literature review, expert

interviews, and policy gap analysis within Horizon Europe project OptFORESTS (101081774), we analyzed policy gaps pertaining to FGR. We explored policy domains that both directly and indirectly relate to FGR in Europe, mapped current and forthcoming European policies, and identified types of policy instruments. Our results indicate that there are at least four policy domains to consider based on their *sensu* relation, as the manner by which they address FGR *(sensu eminenti, stricto, lato, and amplo*). By focusing on *sensu* relationships of policies at the intersection of different policy domains, we identified synergies and tradeoffs between policy instruments and pointed leverage points in policy areas that will be the key for future actions in facilitating sustainability transitions. To guide future policy reforms and adjustments for unlocking the potential of FGR for a more resilient environment and sustainable society, we provide a better understanding of policy (in)coherence among and within policy domains such as agriculture, environment, health, and technology.

Synergistic Approaches to Sectoral Policy Coordination: A Case Study of North Korea

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: This research delves into the intricacies of forest governance and policy coordination with a focus on promoting sustainable forest management in North Korea. The study investigates the complex land-use systems that involve conflicts over forest resources and competing interests in rural development, economic growth, agriculture, landscape management, and environmental protection. By conducting a meticulous analysis of 56 forest-related laws and their provisions, this research sheds light on the synergistic contributions of diverse sectors to the dynamics of forest management. An analytical framework is employed to categorize forest-related articles based on their respective ecosystem services, allowing for a comprehensive assessment of sectoral coordination and the diverse functions fulfilled by forests.

The findings of this study underscore the significance of provisioning services in fostering coordination between the forest and agricultural sectors, highlight the role of cultural services in facilitating coordination between the forest and urban sectors, and emphasize the foundational importance of supporting and regulating services in achieving coordination across the forest, environmental, and energy sectors. This enhanced understanding of sectoral coordination emphasizes the distinct functions fulfilled by each ecosystem service, paving the way for effective forest management strategies.

This study provides a comprehensive overview of the complexities inherent in decision-making processes, trade-offs, and the multifaceted policies required to effectively combat deforestation and promote sustainable forest management. Considering diverse interests and the varied utilization of forest resources, the result offers insights into transforming trade-offs and conflicts into opportunities for synergistic cooperation. Moreover, the research identifies crucial leverage points within ecosystem services to facilitate sectoral coordination of forest and non-forest sectors. The findings of this study propose a constructive option, highlighting the benefits of shared management through coordinated efforts among sectors, as informed by the comprehensive legal analysis conducted. This research contributes to the body of knowledge on forest governance, providing valuable insights for policymakers, practitioners, and scholars working towards sustainable forest management and the conservation of forest resources.

Synthesizing the evidence of anticipatory forest use behaviours under policy introduction

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: Sound forest conservation policy is needed to tackle the combined challenges of climate change and biodiversity decline. However, policy introduction might potentially trigger unexpected outcomes, such as displacement effects, where avoided deforestation is spatially displaced elsewhere, or rebound effects, where gains in resource use efficiency leads to increased extraction of the resource. The implications of these unintended policy outcomes are well understood and considered by policy makers. However, a set of unintended outcomes of forest conservation policy that has so far escaped detailed scrutiny is that of anticipatory behaviours, where forest edge residents or landowners change behaviour in advance of policy implementation.

Anticipatory forest use behaviours have been detected under a range of policies. A classic example are nation-wide conservation policies, like the Endangered Species Act in the United States, with several cases reported where landowners pre-emptively destroyed endangered species' forest habitat within their property. Terrestrial protected areas establishment also led to pre-emptive forest clearings by forest edge populations in Madagascar, to secure land that would be out of reach once the conservation scheme would be in place. Even if not directly aimed at forest conservation, land titling programmes may also encourage related behaviours, such increased conversion of forest to agricultural land, in the hope farmers will acquire a formal title for the land just cleared through the forthcoming programme, which was found in Cambodia and Madagascar. Such behaviours might also emerge in the case of voluntary participation to programmes, like sustainability certification of agricultural commodities production, which found with palm oil in Indonesia.

In this talk we will present results from an evidence synthesis we are conducting to compile and describe the evidence on anticipatory forest use behaviours under the introduction of policy around the globe. The synthesis is being conducted as a systematic map, and the database resulting from this work, which contains all relevant studies and their attributes, will be freely available to interested users. The database will serve as repository of cases to help increase decision-maker's awareness of the risk of policies triggering such unintended behaviours, and hopefully, will stimulate more formal study of the phenomenon.

The burden of multifunctionality: balancing timber provisioning, carbon sequestration and biodiversity targets in Swedish forests

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: In recent decades, public awareness regarding the vital role forests play in providing a wide range of services to human society has been steadily increasing. This is reflected in targets of EU policies such as the Biodiversity Strategy for 2030 and the New EU Forest Strategy for 2030, which recognize the multifunctional nature of forests and advocate for increasing the share of protected land area. However, concurrently, in the Fennoscandian region there are evidences of an increase in harvest levels. Hence, forests in Europe appear to be subject to divergent policy objectives, and questions arise on their ability of simultaneously fulfil all the expectations that policy-makers and stakeholders have placed on them.

In this context, it is crucial to obtain an understanding of the trade-offs and synergies among forest ecosystem services at the national scale. It is equally important to consider the potential consequences that the EU forest policies may have on the provision of ecosystem services in the short, medium, and long term and hence the feasibility of their objectives. In the present work, we conduct such analysis of the Swedish forests.

The backbone of our work is a comprehensive century-long nationwide forest simulation that incorporates over 100 management alternatives, utilizing data from national forest inventory plots. For each of these alternatives, we estimated the expected harvest levels, functional biodiversity and climate benefits provided based on a life-cycle analysis assessment. Lastly, by employing multi-objective optimization we select the optimal set of management alternatives to achieve the different goals set by EU policies and investigate the consequences that these could have on the future of Swedish forests.

Our analysis suggest that while forests certainly do play a central role in reaching the ambitious Green Deal targets they cannot simultaneously meet all of them targets posed by EU policies. Therefore, to avoid suboptimal forest use and management, realistic quantitative targets of forest biodiversity and ecosystem services should be urgently proposed and implemented.

“Which strategies should we use?” - Modelling actors’ decision-making to forest policy interventions

T4.9 Evaluating policy outcomes in complex land-use systems

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Abstract: Recent forest policy debates have highlighted an increased recognition of the diverse values that different actors see in forest ecosystems. In combination with evidence of the importance that resilient forest ecosystems have in relation to climate change mitigation, livelihoods and biodiversity, there is an urgent need for methods that take broader perspectives into account to understand the complexity of governing forest systems.

In this study, we combine a social-ecological system understanding of forests with policy feedback theory for seeing how policy interventions are received by forest actors, and how their interactions and decisions in turn affect forest use. A mixed methods approach is applied, using the spatially explicit agent-based modelling framework CRAFTY. Agents’ decision-making is informed by historical land use data and interviews with Swedish forest actors. The case is focused on Swedish forest policy interventions, with the purpose to explore the mechanisms between forest actors and the environment, and whether and how these interactions are driving changes in the forest landscape.

The results indicate that while objectives and beliefs are important dimensions for distinguishing forest actors’ decision-making, actors’ time, and resources for seeking advice and accessing new practices have a major impact on how policy interventions play out. The study shows promising results for using agent-based model as a tool for capturing trade-offs in complex governance problems, by integrating qualitative data from participatory processes in combination with social simulations and a dynamic vegetation model. In this way, the study contributes to methodological development on how integration of quantitative and qualitative data representing different types of knowledge production can broaden our understanding of complexity within forest governance.

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

Climate vulnerability and the politics of forest restoration in India

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

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Abstract: Global climate agreements have required national government to pledge contributions for emissions reduction and commit to net zero emissions targets. India's NDCs present a threefold strategy to reduce emissions, offset the emissions reduction gap and increase climate finance to achieve these outcomes. In this paper we examine policy and legal apparatus adopted by national and sub national governments in India to achieve "additional carbon sink of 2.5 to 3 billion tonnes of CO2 equivalent through additional forest and tree cover by 2030." The paper will use the recently proposed amendments to India's forest conservation legislation to understand the national government's persuasion to legally recognise the role of forests in achieving emissions mitigation targets. Does this proposed amendment reorganise the federal structure of India forest restoration practices? Does it facilitate title holding indigenous and forest dwelling communities in being partners in climate mitigation? The paper will draw upon an historical understanding of forest restoration practices in India and examine their role in India's climate policy discourse.

Everyday struggles to transform tree rights: The decentralization and recentralization of state and corporate power through community-based management

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

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Abstract: Community Resource Management Areas (CREMAs) have come to play a central role in Ghana's climate mitigation and adaptation strategies in the cocoa growing regions of southern Ghana. Initially formed as institutions to facilitate community-based wildlife management and habitat protection in a manner that is 'socially just' – i.e., locally empowering and beneficial – they have more recently been elevated to a central role in Ghana's Reducing Emissions from Deforestation and Degradation (REDD+) strategy. This paper draws on case studies in two different cocoa forest landscapes, with different histories of external interventions, to unpack how this 'climatization' of CREMAs as mechanisms for social justice has generated everyday struggles across multiple scales, from local actors to the Ghanaian Wildlife and Forestry Departments, Non-Governmental Organizations (NGOs) and cocoa companies.

Based on 44 key informant interviews, participant observation and 32 focus group discussions, we find evidence of both decentralization and recentralization of decision-making power in REDD+ processes among communities and higher levels of state and corporate actors. Evidence of decentralization is strongest in CREMAs that receive relatively strong and sustained local and NGO support, though in all cases farmers' lack of tree tenure rights favors state control over tree resources. Meanwhile, power struggles between government agencies and/or between cocoa companies sourcing in the same area have led to competing social justice claims, with destabilizing and variable effects on power across scales. These findings highlight the importance of everyday forest relations across all scales and how the social justice claims of community-based management may be variably harnessed to decentralize or recentralize forest and climate governance.

Geopolitics and everyday forest conservation in North Karelia and Finnmark: the case of the Greenbelt of Fennoscandia Initiative

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

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Abstract: This presentation aims to communicate to practitioners and researchers the results of a research conducted in Scandinavia and published in 2023 in the journal Sociologia Ruralis.

It investigates how the framing of forest conservation in terms of sustainable development both enables and constrains participation in conservation initiatives. The Green Belt of Fennoscandia, an initiative to develop a transnational ecological network of old forests between Finland, Russia and Norway, is used as a case study.

A desk study and 40 interviews with participants of two regional working groups from this initiative show how the mobilisation of the concept of sustainability encourages actors living in and near high conservation value areas to become leaders of projects in favour of both nature conservation and economic development. This research also describes how the lack of state engagement and potential conflicts between regional and national levels can discourage these actors to commit to the initiative.

This research refines previous work on the reduction of the role of the state in conservation, illustrating the scalar dynamics of sustainable development implementation in a European rural context. It provides material to inform the governance of conservation projects, by highlighting how an approach that aims to boost local participation can in fact discourage it, if the reduction of the role of the state is not accompanied by resources, formal rights to democratic representation or/and an acknowledgement of past work.

Green transition vs local realities in forestry: Finland and Sweden

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

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Abstract: For more than a century, forest industry has been an integral part of the regional economy in Northern Finland and Northern Sweden as well as the main contributor to the net export value. Consequently, national forest strategies have promoted the use of forest for industrial expansion and economic growth. However, sustainability concerns and more recently expectations on green transition, highlights the competing land use interest in the region. As the latter brings about an extensive increase in the mining industry and wind power production and distribution, it becomes essential to examine, at multiple levels, how green transition is understood in relation to forest use and what are the trade-offs and synergies realized in the localities. Through the analysis of national and regional strategies, and semi structures interviews with local experts in two forest industry dependent municipality Kemi in northern Finland and Malå in northern Sweden. Ensuing, we problematize the complexity of long-term competing land use interests amplified by the green transition movement. Results show that for both municipalities, there is an expansion of the forest industry's wood procurement area brought about by the increase in demand of wood within and outside the municipality. Such expansion means encroachment to the existing land use which is reindeer husbandry, tourism, hunting and gathering of natural products as every man's right in both countries. Reconciliation is needed between the actors to sustainably manage the forests and have a better understanding of the different actors' perspectives.

Guiding principles for Romanian Forest Strategy: stakeholders perceptions

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

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Abstract: An important step in promoting a strategic direction to ensure a sustainable way of managing forests in Romania was the elaboration of the National Forest Strategy for 2030. This strategy contributes to the desired integration of European level objectives into national strategic plans by referring to the objectives contained in the New European Forest Strategy for 2030. The strategic options for the development of forest policies proposed in the strategy were formulated based on several guiding principles of forest management, reiterated from the perspective of validating the strategic assumptions at the European level. The guiding principles that should guide public policy in the forestry field and the main recommendations for their operationalization were subjected to a public consultation process with the stakeholders in the forestry sector. This research presents and qualitatively analyzes the opinions expressed by the participants regarding the proposed guiding principles for forest policy. The analysis is based on 146 responses received from those enrolled in the process (response rate 68%). The results showed that different degrees of consensus were highlighted during the consultation. Principles with a high consensus, reflected in firm strategic desires, and principles that create controversy among respondents, reflected in contradictory strategic options, were identified. Also, 74 responses corresponding to the formulation of new principles were recorded within the consultative process, their relevance being analyzed within this research. The guiding principles, as emerged from the opinions expressed by stakeholders, are: a) related to forest management: the principle of ensuring the continuity of ecosystem services, the principle of ensuring the stability of forest ecosystems, the principle of representativeness in biodiversity conservation, the principle of economic viability and competitiveness; b) principles of good governance: the principle of scientific substantiation, the principle of legislative coherence, the principle of administrative efficiency, the principle of respect for property, the principle of intersectoral integration, the principle of participatory politics and the principle of transparency. The importance of analyzing these principles results from the fact that they must provide the basis for the creation of a forest governance framework adapted to the structural changes of the national forestry sector.

Inclusive multi-use forestry adoption in Sweden through social learning networks

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

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Abstract: Forest management practices in Sweden are embedded in an established industrial structure in which forests are managed for industrial timber supply, yet this structure has been criticized for hindering the adoption of sustainable forest management practices. Multi-use of forests holds the potential to leverage alternative and more sustainable forest management methods. Adopting alternative forest stewardship methods can contribute to diversifying primary production and provide a wider variety of income opportunities in rural regions while also improving a wide range of environmental benefits and social inclusion. The aim of the study is to explore how social learning for adopting multi-use forestry can be facilitated and negotiated by social networks and build an inclusive forest management. These relations were investigated by following family forest owners who already are adopting multi-use forestry and alternative forest management practices, and their micro-level social networks in three geographic regions in Sweden. This was done by using qualitative methods such as semi-structured interviews, structured observations and group discussions. The study investigates how institutional structures and intersectional social dynamics impact the adoption of multi-use forestry by family forest owners. The study pays attention to the power dynamics and social relations between forest owners and the social networks and other actors within the forestry sector and how these dynamics impact the adoption of multi-use practices. The insights from this study have the potential to improve policy interventions that enable and accelerate the processes of inclusive and just social learning and forest innovation between key actors to accelerate the implementation of more sustainable forest use and management.

Struggles and limits for territorial sovereignty in the context of forest extractivism: cases in Galicia, Spain and Araucania Region in Southern Chile

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

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Abstract: In recent years, the concept of sovereignty has been key to centering the power of communities and peoples who are unequally affected by environmental changes, conflicts and disasters. Concepts such as "Food Sovereignty" and "Energy Sovereignty" are currently key in the work of social movements (such as La Vía Campesina) to put the rights of peoples at the center above the economic interests of the agro-industry, and related to the generation, distribution and consumption of energy, respectively. However, and despite being highly contested spaces, a specific debate of the term "sovereignty" in forest contexts has not yet been discussed in detail, or beyond its connections with territorial sovereignty. In this communication, we first present the concept of forest sovereignty as a term where environmental justice and decolonial ambitions meet in defining the future of forested areas for the people living in the territories. Further on, we analyse preliminary interviews with local communities, urban and rural activists who live in forest territories in conflict in North-West Spain and Southern Chile in order to discuss the struggles and limits of forest sovereignty in such contexts.

Sustainability and justice in Northern forests? Exploring intersecting and cumulative land-use conflicts in Swedish Sápmi

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

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Abstract: It is often claimed that climate mitigation and, more broadly, a transition to a sustainable future, is heavily reliant on renewable and non-renewable resources. Forests are expected to contribute to climate mitigation, while being managed and subject to different kinds of resource exploitation. Massive investments are currently directed towards northern Sweden to increase fossil free production of electricity (including batteries) and steel. This transition towards green technologies involves increased demands for biomass, timber, minerals and wind for power production. These resources are available in the forests of Sápmi, the traditional territory of the Indigenous Swedish Sámi. However, the cumulative land use implications of ongoing and planned industrial activities and investments are substantial and contentious. Resource extraction has not least far-reaching impacts on rural environments and local and indigenous communities. Indigenous Sámi reindeer herding communities (RHCs) depend on access to forests while encountering increasingly intensified forestry practices. Deeply concerned about the cumulative effects of forestry, mineral exploitation, and energy production, they call for alternative visions of a transition to a fossil-free and just society.

This paper explores the prospects of new collaborative planning solutions to intersecting forest- and mineral-related land use conflicts in Swedish Sápmi. Based on interviews with Sámi RHCs, other key actors and an analysis of relevant policies, it explores the intersection of different knowledge systems and understandings of justice in the context of forests and collaborative land use planning. The paper specifically addresses the importance of landscapes and institutions conditioning the collaborative system, trade-offs and claims to justice. Two questions are addressed: how do rights- and stakeholders make claims to justice and connect these to forest landscapes and institutions; and how can collaborative planning, claims to justice, and supporting institutions be coordinated to facilitate trade-offs that are perceived as fair and legitimate? While the empirical focus of this project is on forest management and mining in northern Sweden, the conceptual approach and planning solutions may be applied to other contexts and support transition to a sustainable future.

Traditional Sámi knowledge, Árbbediehto in collaborative land use planning

T4.10 Finding paths in everyday forest negotiations – towards sustainability and justice in climate transitions

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Abstract: The Sámi culture and economic activities have revolved around the forest for thousands of years. Reindeer husbandry has been a central Sámi livelihood and is conducted on almost 50 % of the land area in Sweden. Reindeer husbandry depends on having a large grazing area and a range of forest in different ages. As reindeer primarily graze lichen under the snow during winter and terrestrial lichens growing in old pine forest, a varied landscape is an important factor for husbandry. In Sápmi fragmentation and competition in the reindeer grazing areas from infrastructure, mining, wind power, forestry and effects of climate change causes stress upon reindeer herders. Sámi critical voices highlight the unquestioned rush to support renewable energy production without taking the Sámi rights into recognition.

By looking how Sámi reindeer herders understand and conceptualise land use conflict in reindeer grazing land, ways to adapt to these challenges are discussed. Reindeer herder´s close relationship with the forest and their traditional Sámi knowledge, *árbbediehto* are some key factors in their adaption strategies. *Árbbediehto* has evolved over long period of time and is transferred from generation to generation. However, unpredictably changing environment and climate poses new circumstances for husbandry and challenges the value and the usefulness of *árbbediehto*. The adaptive capacity of reindeer herders today is also hampered by lack of political power and lack of supporting legislation. This restrains reindeer herders' opportunities to practice their livelihood as preferred.

From an ethnological perspective, this case study has through interviews with experienced reindeer herders from different Sámi reindeer herding communities in Norrbotten and Västerbotten County explored herders' strategies to meet land use conflicts and climate transition. The interviews have focused on the role of *árbbediehto* in adaptation and its possible use in collaborative land use planning to handle land use conflicts. Further, the intersection of different knowledge systems in planning has been explored. For future, better appreciation for and understanding of reindeer husbandry and use of *árbbediehto* in ways that are fair and ethical appropriate in the society would improve life for reindeer herders. Also regulations that strengthen Sámi rights in land use conflicts.

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

Biocultural Treescapes: Exploring the Feedback between Values of and Care for Trees

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: The ways that people value trees influences how they act toward the trees in their care in complex and nuanced ways. Our study investigates the reciprocal relationship between people and trees in the Mont Saint Hilaire Biosphere Reserve, near Montreal, Canada. This study provides valuable insights into the feedback between trees and tree managers. Our findings highlight the importance of people's values, in addition to ecology, in shaping forests.

Using a mixed method approach, we illustrate that specific values, particularly values relating to the provisioning and cultural contributions of trees, shape the care work of land managers and ultimately the biophysical structure of trees in the Mont Saint Hilaire Biosphere Reserve in ways that are often not captured in models of ecosystem services or similar concepts. We identify ways in which these values influence forest management practices like promoting the growth of certain species or pruning to promote or reduce fruit production.

We used a combination of random ecological plots to assess the biophysical attributes of trees and forests within the mixed land uses of the Mont Saint Hilaire Biosphere Reserve, followed by semi-structured interviews to understand the ways in which land managers value and manage those specific randomly selected trees. Our results show that people are shaping trees and forests based on their values in addition to other factors like resources and knowledge.

Our results also emphasize the intrinsic value of care work for trees. Land managers expressed the act of managing trees (planting, pruning, cutting) as a mutual benefit to trees and themselves. By probing the feedbacks between value and management, our understanding of the role of land managers in nature's contributions to people through management or care work can be enhanced, contributing to a more complete understanding of how people shape forests. We hope our results will be of interest to those seeking to understand the governance of trees, promoting a holistic approach that recognizes the diversity of values associated with trees and fostering a sense of responsibility for their care and our mutual wellbeing.

Building community and individual RESilience thrOugh NATurE based therapies (RESONATE)

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: We present an overview of an ongoing Horizon Europe funded project (RESONATE, 2023-2027) which is exploring the impact of nature-based therapies on human health and well-being. The talk will begin with an overview of a new theoretical framework developed especially for the project which argues that many of the positive associations between contact with the natural world, especially forests, and health and well-being can be explained via nature's ability to build and maintain biological, psychological and social (i.e. biopsychosocial) resources that make people more resilient to everyday and chronic stressors. We call this new approach Nature-based Biopsychosocial Resilience Theory (NBRT). Building on this novel theoretical approach we will explain how the RESONATE project is exploring nature's role in building biopsychosocial resilience through: 1) a systematic mapping review of existing nature-based therapies globally; and 2) nine original Case Studies each of which are evaluating health, environmental, economic and social outcomes. In addition to discussing how we are measuring the effectiveness of the interventions, we will explain how we are paying particular attention to the mechanisms underpinning successful project implementation and expansion by integrating Social Innovation Action approaches with Process Evaluation methodologies developed to assess complex interventions in public health. Our aim is to provide a clear set of What Works Guidelines tailored to different stakeholders' needs (e.g. health practitioners, land owners, forestry organisations, local planners, resident bodies etc.) which can be used to develop and sustain wider uptake of nature-based therapies to promote health and prevent disease in populations across Europe and beyond.

Creation of socially sustainable conditions for nature stays of preschool children in public care

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: In the past decades, numerous nature children's groups have been founded in Austria, which hereby make an essential contribution to more nature knowledge transfer to preschool children.

Due to the physical underload and psychological overload (lack of exercise, digitalization, ...), to which preschool children are now exposed, the urgency of nature education in the context of public care at preschool age increases.

Furthermore, there is the circumstance that preschool children before the mandatory kindergarten year cannot spend several times per year, legally insured against accidents in the natural environment. In order to obtain insurance coverage, the public insurance carriers consider the fulfillment of minimum requirements for the natural area similar to existing in the public sector.

The first necessary step is the survey of the current situation in nature children groups, in order to be able to derive minimum requirements for the natural space as well as existing built infrastructure.

Cycling in different environments: mental well-being in South American and European contexts - preliminary results

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: The connection between well-being, physical activity, and contact with nature is an emerging topic in academic research, particularly given its pertinence to planetary health. This study investigates potential correlations between the frequency of bicycle use in different environments and mental well-being, employing a comparative approach between Brazil and Portugal. Using an online questionnaire, established psychometric scales were applied, including the Perceived Stress Scale-4 (PSS-4), the 5-item World Health Organization Well-Being Scale (WHO-5), and the Positive and Negative Affect Schedule (PANAS). Additionally, questions about bicycle use and sociodemographic information were included. The Brazilian sample (n=405, average age 46.94, 28.7% female, 71.3% male) showed significant differences with higher levels of negative affect and lower well-being on the WHO-5 scale compared to the Portuguese sample (n=95, average age 43.41, 9.5% female, 90.5% male). Preliminary analyses using Spearman's correlation showed, in the Brazilian sample, bicycle use in rural areas negatively correlated ($p < 0.05$) with perceived stress ($r=-0.247$) and negative affect ($r=-0.263$) and positively with WHO well-being ($r= 0.264$) and positive affect ($r=0.309$). Similarly, trail use showed a correlation with perceived stress ($r=-0.232$), negative affect ($r=-0.202$), well-being ($r=0.257$), and positive affect ($r=0.342$). However, no significant correlations were found on the parameter evaluated in urban contexts and highways. In Portugal, leisure park usage presented the sole significant correlation, positively aligning with positive affect ($r= 0.404$). Though not significant, rural and trail environments correlated positively with positive affect and well-being and negatively with negative affect and PSS. Similar to Brazil, urban contexts and highways showed no significant correlations. Despite these correlations being less intense than those in Brazil, they pointed in the same direction, indicating similar patterns between the two countries. In summary, while this study is ongoing and the results are preliminary, data suggest that cycling in environments with more natural elements in Brazil and Portugal may be associated with improved mental well-being. However, it is crucial to underline that correlation does not imply causality. Further research is necessary to deepen these findings and explore potential causal mechanisms.

Economic Valuation of Cultural Ecosystem Services: A Review of the Methods with a Focus on Green Care

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: Green Care (GC) is a catch-all term summarising initiatives that primarily address human physical and psychological health, wellbeing, and social inclusion with human-nature interactions at its core. To date, most studies have focused on the therapeutic effectiveness of GC interventions, while systematic research evaluating the economic value of GC benefits is still limited. Such intangible benefits from nature can be conceptualised within the ecosystem services framework as cultural ecosystem services (CES). Although methods are available for the monetary valuation of CES, they are complex and results are often context-specific; hence CES, in general, are undervalued and understudied, and the total economic value of GC still largely unexplored. The aim of this study, is to undertake a comprehensive analysis of the literature on the monetary valuation of CES with the intention of identifying and evaluating suitable methods for a subsequent valuation of the health and wellbeing benefits delivered by GC. Using a systematic approach, this study conducts a global literature review of peer-reviewed studies identified by applying a pre-determined search protocol in the Scopus database. Search keywords were selected based on a rigorous testing and refining process by the authors. Inclusion/exclusion criteria were defined to select relevant papers for further detailed analysis. The selected studies are categorised and analysed for commonalities, methods employed, and evaluated considering our overall focus on the economic value of GC.
Our results show a variety of different methods are applied to the valuation of CES, such as the travel cost method (TCM) and choice experiments. Most of the studies focus on use values by employing the TCM and/or valuing recreational services while less studies address non-use values. Many studies combined several methods, frequently integrating non-market valuation with qualitative methods. Few studies address the benefits of GC, however those identified employed direct market valuation approaches, such as the avoided cost method. In light of our research objective, and our results indicating a lack of studies focusing on the valuation of the benefits of GC, we identify several relevant methods for this task such as cost-based approaches and choice experiments and critically evaluate their suitability.

Exploring the factors related to eco-tour guides toward sustainable ecotourism in Amami-Oshima Island, Japan

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: Ecotourism is a sustainable form of tourism that aims to balance environmental protection and tourism use, and ecotour guides are increasingly attracting the attention of stakeholders as key coordinators of this effort. We conducted a case study focusing on eco tour guides on Amami Oshima Island, Japan, to determine the factors for environmental exploitation and protection in a sustainable manner. The findings indicated, through a chronological analysis of local attitudes that prior to the 1990s, that there was a conflict between environmental protection and use in the wake of large-scale development projects. However, since the 2000s, there was increased momentum for the designation of national parks and world heritage sites, and an increased focus on stage-wise changes in protection and use, rather than opposition to them.

A system employing eco-tour guides was established, along with the designation of national parks and world heritage sites. These guides led the creation of the system, and a consensus on environmental use was obtained through engagement with residents and the government. The increased number of guides contributed to a certain level of success in these attempts at effective ecotourism.

However, the recognition of ecotour guides by tourists and compliance with voluntarily established rules were cited as problems. Thus, we found that developing a system is insufficient, and acknowledgement of how the environment has been accepted and interpreted locally is essential to balance nature conservation and tourism.

Green Care Innovation System Framework. An analytical tool to understand leverages for advancing nature-based health and well-being in Europe

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: In the Anthropocene, the climate crisis, biodiversity loss, and urbanization have profound effects on health and well-being. Decoupling humans from nature in the current economic system also leads to the loss of stewardship, cultural identity, and sense of place. It manifests as rural outmigration, weakened social ties, reduced value-generating activities, exacerbated social inequalities, and increased socioeconomic instabilities. Green Care has emerged searching for solutions that focus on the interconnectedness between nature and human resilience. In this research, we take Green Care as an umbrella concept that recognises the nature-human interdependence and focuses on designing opportunities for contact and connection with natural environments to address individual and societal needs, with special attention to reduced impact on nature. In this definition, Green Care spans across diverse knowledge and value systems, disciplines, sectors, land tenure, and management practices. It also offers a unique social field for experimentation, innovation, and entrepreneurial activities. It is a field where technological, sectoral, organizational, institutional, and social innovation become intertwined, creating new and sustainable attitudes and relationships with natural environments. Taking the innovation systems approach, we developed a conceptual and analytical tool for understanding the complexity of the Green Care innovation system in Europe to formulate potential policy responses as levers for advancing nature-based health and well-being. Using a stepwise and iterative approach, we developed a preliminary conceptual framework of the Green Care Innovation System that guided us in the data collection through surveys and in-depth interviews with 20 selected case studies. We revised the framework after the data analysis and as a result, identified the actors, system functions, and blocking mechanisms in the form of challenges and adequate policy responses as levers in Green Care innovation processes. To focus multi-sectoral attention on the health, well-being, and social inclusion benefits of nature, we formulated potential policy responses for the decision-makers and key action points for practitioners.

Integrating Green Care Initiatives into Traditional Health System: a literature review focused on governance dimensions

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: The umbrella term Green Care (GC) includes a spectrum of interventions supporting health promotion, disease prevention, and rehabilitation. GC can potentially improve public healthcare provision, responding to modern increases in demand for healthcare in the general population and the specific needs of vulnerable groups. Actions aimed at expanding care provision are often undertaken by the government justified on public economic grounds to reduce the impact of market and information failures that undermine people's ability to maximize their welfare. Despite this, public health organizations and institutions have not yet recognized GC's potential in supporting innovative health practices. Green Care Initiatives (GCIs) are organized interventions involving professionals of different legal entities (e.g., private, public) and various fields (e.g., forestry, healthcare, agriculture) representing diverse environmental, economic, social, and health-related stakes. Therefore, the issue is strictly connected to the partnership composition, decision-making processes, and rules implemented by GC actors and, thus, embedded in a governance framework. Given this, our aim is to comprehend which conditions could enable GCIs to be recognized within the public health system by adopting an analytical understanding of governance. Therefore, we conducted a systematic literature review of international studies on integrating GCIs into healthcare systems by exploring the conditions observed for this to happen and through which specific governance arrangements. By following the PRISMA guidelines, search strings of keywords were combined concerning the themes of "Green Care," "Healthcare," and "Governance" in Scopus and Web of Science databases. Then, pre-defined criteria were applied to refine the selection of relevant documents. Finally, findings were categorized under the main dimensions to facilitate qualitative analysis. Results from our research indicate that the discourses around governance are more developed in Social Farming, while contrastingly, Forest-based initiatives remain little explored. Our governance analytical framework could facilitate institutional awareness and evidence-based decision-making to support the integration of GCIs into healthcare practices. Furthermore, it could help determine relevant aspects for the success of GCIs by paving the way for developing an evaluation framework based on different health and environmental governance dimensions.

Relationship between Visitors Motivations in Canadian and Brazilian's Parks

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: Several studies indicate benefits promoted to human well-being after having frequent contact with nature. Understanding the motivations that lead people to leave the comfort of their homes and visit natural areas more frequently can help to establish public policies that enhance the benefits already known in the medical field. The study by Lemieux et al. (2012) addressed the perceived importance of well-being related to motivations for visiting two parks in the autumn of 2011 in Canada (n=166).Using the same methodology, we addressed the perceived well-being indicators that motivated the visit to an urban park in the autumn of 2023 in Brazil (n=150).

The well-being indicators evaluated include physical, psychological, social, intellectual, spiritual, ecological, environmental, cultural, occupational and economic. Of these indicators, the Brazilians who participated in the survey considered psychological well-being (71.33%), physical well-being (66.66%), environmental well-being (64.00%) and social well-being (63.33%) as "very important", with all indicators considered "very important" by at least 45% of the Brazilian participants. As "not important", only psychological, spiritual and occupational well-being were scored by Brazilians, with a minimal portion (0.66%).

Comparing the results obtained in Brazil and Canada, it was observed that Brazilians tend to consider well-being indicators related to motivations for visiting parks more important than Canadians. When averaging the indicators identified as "very important", we obtained 59.20% for Brazilians and 27.32% for Canadians. A difference of more than 30%. While Canadians consider such perceptions as "not important", on average 5% more than Brazilians.

The data obtained show that the motivations for visiting parks are related to human well-being, being an important value for people. However, it is observed that there is a difference in the two contexts, which indicates that there are other factors that can collaborate in motivating the promotion of well-being, in addition to contact with nature. This study is still in progress and in the near future we will obtain results from the same indicators in other Brazilian protected areas.

The case for a relational turn in forestry

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: Forests are central to some of today's greatest ecological challenges, including climate change, biodiversity loss and many environmental justice issues. The discipline of forestry can make key contributions to helping address those problems, but it has also contributed to them. We suggest that the institution of forestry must transform to be more relational and inclusive for it to consistently be part of the solutions and not a contribution to the great ecological and societal challenges we face. In this presentation, we identify and articulate four core principles of forestry drawing from textbooks, university curriculum, the Society of American Foresters code of ethics, policy documents, peer reviewed literature, and the writings of prominent foresters who influenced the codification of the discipline. These principles are: 1) Forests should be managed; 2) Forests should be owned; 3) Decisions about forests should be based on western science; 4) Forest should sustainably provision goods and services for human ends. We explore how these institutionalized principles limit the inclusivity of the field of forestry and keep it from being compatible with diverse worldviews and values. Further, we suggest such limitations hamstring the discipline's utility in combatting climate change, biodiversity loss, and environmental injustice. To overcome these limitations and make forestry a more diverse and inviting field capable of addressing 21st century challenges, we propose revising these four principles so that they reflect relational values and relational worldviews. The new relational principles of forestry we propose are: 1) Care for and respect the forest; 2) Timber can be owned, but other aspects of forests cannot; 3) Traditional Ecological Knowledge and other ways of knowing can complement western science in determining forest practices; 4) Forests should sustainably support people's diverse values of and about forests. Revising these principles in print is easy but revising them in practices requires an institutional transformation of the discipline including shifts in the way forestry is taught and expanding what approaches to forest management and policy are acceptable.

The Role of Community Faith Based Organization in Enhancing Forest Governance: Comparative Study of Gwasii and Kibiri Forest, Kenya

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: Globally, regionally, and locally, most forests are managed by the state with minimal community involvement resulting in high levels of degradation. In Kenya, the forestry sector has experienced poor governance in the past and still faces challenges in ensuring sustainable conservation and management of forest ecosystems. Effective forest governance requires empirical evidence on how different forest governance structures and systems contribute to improved forest conditions and management. The study conducted a comparative analysis of forests managed under different faith-based institutions including traditional, church and government-managed forests and among the Tiriki and Abasuba Tribes of Kenya. The study sites engaged 40 participants from Kibiri forest and Gwasii forest in Kenya. The approaches applied in the study included an ecological approach and social assessment of governance in the management of forests under different management regimes such as state, faith-managed and community-managed forests. Focus group discussions, and scoring of governance system using the 3 pillars of forest governance frameworks developed and applied widely by FAO. Community shrines and church-managed forests appeared to be in a much better condition than the gazetted (state-managed) forests which were in the worst condition. The stem density of woody plants in community shrines (450 stems ha^{-1}) and church-managed forests (675 stems ha^{-1}) was within the expected range for well-managed natural forests of 300 to 1,000 stems ha^{-1}. The scores on governanace showed notable differences with strong scores for concordance of sector level policies having a higher score in Kibiri gazetted forest (2.4) and Gwasii gazetted forest (2.3), legal framework and forest related policies within gazetted forests in Gwasii was 1.3) while in Kibiri the gazetted forest (1.0). There are weak community forest governance systems leading to the high degradation of government forests. The culture and local belief systems of the local communities have also contributed greatly to the conservation of the forest. We recommend that traditional and faith-based forest management practices be integrated into forests managed by the state and that such practices be piloted in sections of the forest before wider application in other forests in the country.

Towards mainstreaming the use of forests for health through multi-actor collaboration

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: Frequent contact with and exposure to forest environments are shown to have positive effects through different pathways on human health and wellbeing. During the past 20 years the research in Finland has primarily focused on urban and peri-urban forests looking at the associations between self-reported and clinical manifestations of health and the accessibility and use of nature spaces, key patways of health outcomes in various local contexts and, how different users may response to forest exposure. More recently there is increasing number of studies looking at how nature contact can boost human immune function and decrease the risks for non-communicable diseases.

The forest-based care research has been conducted in interdisciplinary collaboration across outdoor recreation, sports, health sciences, psychology, ecology, environmental health and medical scientist involving wide range of universities and research institutes to contribute to the current knowledge base. Natural Resources Institute Finland has been a leading national institute to initiate studies and research collaboration focusing on the health benefits of forests. During the past years the cumulated scientific knowledge has been increasingly acklowledged in forest and environmental policies such as the first Finnish Outdoor Recreation Strategy 2030, in urban planning as well as social and public health services. The improved knowledge has also supported the expansion of Green Care practices in Finland, offering nature-based activities targeting well-being, social inclusion, pedagogy, recreation and tourism. More recently, medical sector has been more actively initiating scientific studies and promoting preventive health care practises and long term health promotion programs such as The Finnish allergy & asthma -programme (2008-2018) and the Nature step towards health -program (2022-2032) in Päijät-Häme health care district grounding its key actions on the Planetary Health -concept and initiative.

This presentation describes briefly the current status and scientific development of forests for health -research in Finland and its future prospects. Moreover, already established or most promising forest-based care practices will be presented and analysed how they can support transformative change toward sustainable, responsible, and just societies. Finally, the potential and key challeges of mainstreaming forest-based care practises will be discussed.

Which trends and socio-economic opportunities of forest-based care initiatives?

T4.11 Forest-based care as an innovative pathway to shifting values, uses and governance of forests

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Abstract: We are witnessing a growing number and typologies of forest-based care initiatives (FBC), from forest bathing and healing forests in Asia, these initiatives are expanding throughout Europe providing a wide set of cultural ecosystem services. While this diversity provides a lot of potential business opportunities, the market is relatively young and not always fully recognized. Further the research on the economic impact of this emerging sector is still lacking. Nevertheless, market is relatively young and not always fully recognize and the lack of a clear overview of these two aspects, may result in gaps regarding the full understanding of potentials and benefits and widespread implementation of FBC.

To contribute to fill these gaps, our research group developed a first FBC market outlook, within the framework of the Erasmus + GREEN4C project founded by European Union. We used an online survey (n=40), to obtain an overview of the FBC sector in Europe, and through focus group discussion and interviews with six experts in the field we explored success factors, challenges, and next steps. What emerged is a widespread need to increase the acceptance of FBC, together with the need to be recognized by health sector and insurance and the need to diversify the sources of funding. Being able to demonstrate the economic effectiveness and positive impacts of FBC along with the effectiveness for health purposes, might unlock future opportunities for wider adoption of such practices. Building also on these results, within the Horizon Europe funded project (RESONATE, 2023-2027), using 9 EU case studies we will assess the saving potential for health and social-related costs, the cost-effectiveness, and the quantification of hypothetical impact of a generalized adoption of nature-based therapies, and particularly FBC.

In this talk we will start by framing the main trends in FBC initiatives to have a general overview of what's happening in Europe, then building on the results of the GREEN4C market outlook on FBC, we will have the opportunity to share the first results towards the economic impact assessment of nature-based therapies (RESONATE).

T4.12 Forests in Cities: Ecology, management, and silviculture.

A cross-continent study on the relationship between microhabitats and organismic diversity between native and exotic species in city trees

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Urban forests play a critical role in the healthy functioning of cities and those who occupy them through various ecosystem services, such as supporting biodiversity and creating habitats. Solitary trees are a vital component of urban forests. As cities worldwide undertake greening initiatives, we must understand the relationships that utilize these services to their fullest potential. This study aims to understand how the difference in the native status of two tree species between two continents influences their ability to support biodiversity in the urban environment. Additionally, this study attempts to understand the role of the enemy release hypothesis in the microhabitat production between native and non-native trees. This was achieved through a survey of microhabitats and tree health of *Acer platanoides*, a tree species native to central Europe, and *Quercus rubra*, native to the northeast United States, in Karlsruhe, Germany and New Haven, USA. 160 trees equally comprised of both species with a DBH greater than 20 cm in parks and along streets were selected in both cities for a total of 320 surveyed trees. Variables relating to tree and site conditions, such as tree height, DBH, crown dimensions, crown light exposure, crown transparency, competition, and distance to buildings and streets, were collected in conjunction with tree health and microhabitat surveys. An environmental DNA analysis using the meta barcoding technique on leaf, bark swabs, and soil samples has been conducted to detect fungi, invertebrates, and vertebrates diversity on sub-sample of selected trees in Germany and USA. Currently, data collection and laboratory analyses are going on, and we will present the findings of our study at the IUFRO world congress. We expect to get our first results by spring of 2024. Our findings from the surveys and eDNA analysis will illuminate the relationships between native status, tree heath and biodiversity in cities. Our cross-continent approach and focus on microhabitats, organismic diversity, and pathogens will contribute to our understanding of urban ecological processes and the native vs. exotic species debate in tree species selection for planting inside cities.

Biodiversity indicators in urban and peri-urban forests in central Italy

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Invertebrates are central to structuring and maintaining the functioning of urban forests, which provide critical ecosystem services. Identifying the role of invertebrates in urban forests help reveal their importance to practitioners and the public, not only to preserve biodiversity but also to make the public aware of their functional importance in maintaining healthy greenspaces. In urban environments, intense land management, pollution, and the removal of dead or decaying wood often pose threats to numerous species and ecosystem functioning.

The aim of this work was to examine interrelated biodiversity indicators (forest structure, tree-related microhabitat, beetles, and birds) in urban environments in three Italian cities, differing in spatial, environmental, and social dimensions (Campobasso, Florence, and Rome).

In each city, four forest sites were selected were selected along an urban-to-rural gradient. In each area, field works were carried out into 15 circular plots with a radius of 13 m. In each plot, we collected data to derive biodiversity indicators related to stand structure, deadwood, tree-related microhabitats, beetles, and birds. Two types of traps were used for monitoring the beetles, window flight traps and pitfall traps, to capture both flying and ground beetles. The traps were checked approximately every 30 days for a total of 4 samplings, from June to October.

We analyzed the stand structural indicators, the amount and types of deadwood components, and the microhabitat occurrence, evaluating their impact on the abundance, distribution, and diversification of saproxylic and non-saproxylic beetles, and the bird fauna.

Results were discussed to compare the three city types in relation to the complexity features of the examined sites and the different levels of biodiversity present in the studied plots.

The study was carried out within the Project "National Biodiversity Future Center - NBFC".

Designing legible forests for an urban silviculture

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Silviculture is the art and science of growing trees. Although commonly associated with non-urban forest landscapes, the principles of silviculture may help guide the design and management of urban forests as well, whether those forests represent remnant forests, spontaneous urban woodlands, large forest parks, or designed natural areas. But the application of silviculture to these kinds of forests in cities, at least in the U.S., in uncommon, and has long been met with resistance—as far back as Frederick Law Olmsted's Central Park experiments with “planting thick and thinning quick,” public sentiment has been protective of trees, even when forest health would have benefitted from such treatments. As complex social-ecological assemblages, forests in cities need to respond to the expectations and desires of people and communities, and their institutions and cultural systems.

Landscape architecture, meanwhile, is the art and science of designing cultural landscapes, but rarely stays engaged with the long-term management of designed spaces after initial planting, nor typically participates in the design of sites for ecological experiments. Yet landscape architects help to shape cultural attitudes about nature in cities, and their design skills could be used to improve the public literacy of urban forest ecological dynamics and forest management. How might urban silviculture, drawing on techniques of both landscape architecture as well as forestry and urban ecological science, increase the public literacy of beneficial forest management? Existing spatial prototypes and design interventions offer promising ways forward towards increasing the public legibility of forests, and could be leveraged to increase the public acceptance of the emerging principles and techniques of urban silviculture for forests in cities. Examples of such spatial principles, drawn from precedents of successful designed landscapes, demonstration forests, and ecological experiments will be shown, in order to suggest ways that such techniques can be deployed in for advancing the legibility of urban silviculture. The design of legible forest landscapes and demonstration forests in cities can utilize techniques from both landscape design and ecological science—in line with the interdisciplinary framework of urban silviculture; we will explore what the design of more legible forests in cities could look like.

Development of silvicultural concepts for forests around urban areas to mitigate the urban heat island

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Particularly in urban areas, global warming is leading to an increasing heat load on the residents living there. The urban heat island effect causes cities to cool down less at night than their surrounding areas. The positive cooling properties of trees and parks in urban areas are widely known. To date hardly known, however, are the effects of peri-urban forests on the urban climate. Silvicultural factors in their interaction with landscape structure have not yet been sufficiently investigated to guide forest management in practice towards the goal of mitigating urban heat.

In a sensitivity study, forestry factors are investigated with regard to their influence on the cooling effect of an urban area using the micro-scale urban climate model MUKLIMO_3 TD of the German Weather Service. In different scenarios, the factors tree species, stand density and forest structure, as well as the forest-open land ratio are systematically changed and resulting cooling effects are evaluated. Based on the results of the sensitivity study, silvicultural measures for peri-urban forests to mitigate urban warming will be developed.

The study is part of the project "Optimized forest management around urban areas for improved cooling and air exchange" which is kindly funded by the Hessian Climate Plan. The project is a cooperation of the LCRS (Laboratory for Climatology and Remote Sensing) of the University of Marburg and HessenForst.

Ecology and Management of Forests ---- in Cities

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Forests in cities, which are sometimes referred to as urban forested natural areas or woodlands, are an important component of the total urban forest and tree canopy. Although forests in cities are like rural forests in structure, composition, and function, these habitats are threatened by multiple, co-occurring, and often exacerbated urban and climate stressors. Furthermore, forests in cities often lack a formal silvicultural framework and there is a need for evidence-based forest management strategies. At the most basic level, we suggest that cities can benefit from the existing body of knowledge established for nonurban forested ecosystems; put more simply, forestry has a place in the management of urban forests. However, given the complex set of drivers that are either unique to or exacerbated in urban systems, we take this argument a step further and suggest that managing forests in the city demands innovative strategies be added to the silviculturists' toolbox. By rigorously applying silviculture science within cities, we advance applied ecological knowledge that may extend beyond cities and inform forest management across the urban–rural continuum. From climate change to invasion of exotic species, urban ecosystems provide a window into conditions that nonurban ecosystems will face in the future. Advancing an urban silviculture may therefore not only help to conserve ecologically and culturally valuable habitats in cities, but may also serve as a proactive step in advancing nonurban forest conservation practices in an increasingly human-impacted and uncertain future.

In the United States, networks of municipal forest managers, community groups, university and federal scientists have been formed. The Forests in Cities (FIC) network was formed in 2019 and includes 17 cities from across the United States. The FIC is a national network dedicated to promoting, and advancing health forested natural areas across America through science, management, partnerships, and communications. The Northeast Urban Silviculture Network was formed in 2020 and is focused on cities in the northeastern U.S. (Baltimore, MD to Springfield, MA). This network is focused on knowledge co-production and has implemented multi-city applied management studies leveraging local and scientific knowledge to explore climate-adapted forest management strategies.

FLORAL COMPOSITION AND STRUCTURE OF REMNANT SEMI-DECIDUOUS FOREST IN URBAN LANDSCAPE: A CASE STUDY OF NAIROBI CITY PARK IN KENYA

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Nairobi City Park Forest (NCP) is a semi-deciduous forest within an urban landscape in Kenya. Due to the growing urban population, there is increasing pressure on the available green space, which may negatively impact the forest ecosystem and its ecological integrity. Therefore, monitoring the forest is essential. This study aimed to achieve three objectives: (1) determine the diversity and composition of plant species, (2) assess the structure of woody plant species, and (3) evaluate the regeneration status of the dominant woody plant species in NCP. Twenty four nested-plots of size 625 m2 (25 m X 25 m) were used to collect vegetation data. The plants were categorized into three groups; seedlings, saplings, and mature based on DBH classes then the floral composition, population structure and status of natural regeneration determined. A total of 58 plant species belonging to 48 genera and 28 families were documented. The dominant mature tree species were *Craibia brownii* (17%), *Drypetes gerrardii* (8%) and *Strychnos mitis* (7%) while the saplings were dominated by *Craibia brownii* (15%), *Rawsonia lucida* (10%), *Vepris simplicifolia* (10%) and *Rothmania urcelliformis* (8%). The mean density for trees with dbh ≥10 cm was 584±431.1 stems/ha whereas the basal area was 12.9±9.6 m^2/ha. Shannon-Wiener index had a range of 2.3 - 2.9 implying high diversity in NCP. There was a significant difference in the storeys in the vertical structure ($F_{(2,437)} = 456.756$, $p=0.0001$); species in the storeys ($F_{(47,355)} = 1.537$, $p=0.017$). There was a significant difference in height between the upper and lower storey whereas there was no significant difference in height between the upper and middle storey and also between the middle and lower storeys. The top ten dominant species comprised 54.6% of the total Importance Value Index (IVI). The woody plants with poor and no regeneration comprised of 40% of all species. It is recommended that species with a low Importance Value Index and poor regeneration status should urgently be prioritized for conservation. The results of this study provide valuable information for the development of sustainable management strategies for the NCP, with a focus on urban green space and biodiversity conservation.

keywords: urban, forest-conservation

FRAME: Building a Dispersed Research Network In FoRests Among Managed Ecosystems

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: The temperate deciduous forest biome has been subject to more anthropogenic development than any other on earth. It covers less than 5% of the Earth's habitable land area, yet holds approximately 25% of the human population. Destruction and fragmentation of temperate deciduous forest is accelerating as more people move to cities and urban and peri-urban areas expand. Our focal study area of the Boston-Washington (BosWash) Megalopolis of eastern North America is an excellent region in which to study this phenomenon and what it means for modern forest function and biodiversity: most development and alteration has occurred here within the past 400 years, unlike Europe and Asia.

Our analyses show that there are approximately 250,000 deciduous forests in the BosWash Megalopolis of 1 ha or greater size, 92% of which are less than 50 ha and are surrounded by human development. Those surrounded by the densest human populations are also among the smallest, so that the daily "forest experience" of most people is that of a relatively small woodland. We will present a summary of the various trophic levels and abiotic conditions across a latitudinal and urbanization gradient in the form of an "average and idealized" Megalopolitan forest. We will also present synthesis providing an understanding of the current and future ecosystem services that these forests may, or may not, provide. Finally, the authors will outline possible paths toward improvement and protection of forest in the Anthropocene.

Heritage urban trees in public spaces. Case Aburra Valley-Antioquia-Colombia

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Urban Forest and trees have evolved to adapt to the local urban environment in which they grow. Such local adaptations lead to genetically differentiated populations, with traits that enable them to adapt to local biotic and abiotic stress factors in urban space. Many tree species can't stand up with rapidly changing climate, resulting in maladapted forests with reduced capacity to provide multiple ecosystem services. Some human-facilitated into the urban environment is necessary to match or realign the populations to the environment to which they are best adapted. An example of these are old and tall trees that in the urban context of Aburra Valley (Antioquia - Colombia) are identified most of them as Heritage trees.

With a local efforts, investigation, visibilitation, new policies ,economic resources and forest inventories for 2006, ten urban areas in Aburra Valley (Colombia) reported 420,750 trees in their public space (trees, palms or shrubs more than one (1) meter tall), these trees inventoried belonging to 367 species. By the year of 2022, 543,135 trees were reported belonging to 794 species

Into these community of urban trees almost 100 heritage urban trees were identified in 12 species in 2006. After that, other trees are incorporated in the list of the heritage trees until 2022. The list in 2023 of heritage trees is incremented with new species and trees with almost 900 trees in 170 species. That means a forest community into urban areas hath need an urban contemporary silviculture towards ecologically-based practices and natural regeneration. These metropolitan valley actions towards ecologically-based silviculture is going on mainly in conservation of these heritage trees.

The objective is show and to discuss close-to-nature silviculture as a tool for climate change mitigation in urban forestry areas. Following a comparation in 2 moments (2006-2022) of urban heritage trees ecologically-based management and their actual state in 10 urban territories (Metropolitan Aburra valley) will showcase current trends and developments in forestry practice and research for management and care.

Managing urban woodlands conservation for a better balance of their socio-ecological roles

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Conservation efforts regarding natural woodlands in cities are increasing more than ever due to the rising awareness of the benefits they provide. They are valuable biodiversity hotspots and participate in the connectedness of surrounding natural areas and migration corridors, but they also participate in numerous human-oriented services, such as the mitigation of heat islands, general well-being and recreational opportunities. However, up until now, the conservation prioritization of urban woodlands has for the most part solely been driven by the ecological roles they fulfill. Practitioners usually consider their ecological integrity or connectivity as an indicator of their value and to select where conservation actions should be conducted. By doing so, we might be contributing to separating woodlands ecological and social roles and overlooking environmental inequities, compromising long term city resilience.

The aim of this study is thus to compare the outcome of different methods of prioritizing the conservation of urban woodlands in order to highlight the existence of spatial intersections or trade-offs between them. We will evaluate the (i) ecological integrity, (ii) connectivity, (iii) multifunctionality of ecosystem services, and (iv) population vulnerability of a network of 50 woodlands located in Montreal. Soil water retention, temperature regulation and carbon sequestration will be used to compute a single metric of multifunctionality. Different prioritizing scenarios considering the four above-mentioned methods taken separately and combined will be generated and compared to each other to highlight if they point to similar or different conservation priorities. Data treatment and analysis are presently being conducted and results are yet to come. The outcome of this research is expected to help practitioners build management plans that will ensure a sustainable balance of the complex socio-ecological systems that cities are.

Operationalizing silviculture in the city: novel approaches to forest assessment and management in Philadelphia, PA

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Forests in cities are an important greenspace for urban dwellers and regional biodiversity. Urban silviculture is a systematic framework for developing knowledge-based management approaches for forests in cities. Urban silviculture is based on an understanding that the social and ecological context of forests in cities alters these ecosystems, and as such, traditional management approaches, including forest mapping, inventory, and operational activities may need to be modified and in some cases, novel strategies developed.

In this presentation, we examine how the city of Philadelphia, PA, USA is leading the way to develop, test, and integrate urban silviculture approaches in order to conserve, sustain, and grow forests. Within Philadelphia, there are ~10,000 acres of city-owned parkland, of which, more than 6,000 acres are natural land and primarily forested. We present case studies that include novel methods in forest mapping, an urban-adapted inventory that defines urban management units (e.g. canopy gaps, edge), and planting and management strategies for these different stand conditions. The latter includes long-term studies designed to test pre-planting treatments (e.g. mechanical removal vs. herbicide) and planting techniques designed to re-establish native canopy species (e.g. appropriate tree density; nurse tree methods). In doing so we discuss how these management approaches may be scaled up and/or replicated elsewhere. Finally, we present the need for research, and in particular long-term studies, to build and expand an urban silviculture toolbox for forest managers in cities.

RESTORING FUTURE FORESTS: DRIVERS OF URBAN TREE RECRUITMENT DIFFER BY SPECIES' SUCCESSIONAL STATUS AND JUVENILE GROWTH STAGE

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Projects restoring forests from scratch in cities using native species are increasing in frequency throughout Aotearoa New Zealand. While early-successional tree species establishment and formation of a canopy is often successful, the long-term existence of forests depends on their capacity to regenerate and persist. This entails germination and recruitment of seedlings into the sapling growth stage, especially for middle and late successional species. Here we investigated drivers promoting recruitment of species in two successional categories (early vs. mid-late) in 79 restored urban forests spanning 4 to 58 years since planting across nine cities. Negative binomial generalised linear models were used to determine relationships between abundance of early and mid-late successional native woody juveniles across three growth stages as related to the predictors forest age, patch size, herbaceous ground cover, canopy openness, and site microclimate (air and soil temperatures). We found as forests age, canopy openness decreases and the understory microclimate cools and stabilises. This cooler microclimate promotes increased abundance of only the mid-late juvenile trees, even though canopy closure promotes an increase of both early and mid-late native tree seedling germination and recruitment. This effect's strength decreases as seedlings grow taller, and is not important for juveniles of either successional status once in the sapling stage. These findings indicate that seedlings and saplings have different light requirements. Herbaceous cover plays an early role as it is inversely related to short seedling abundance, but once seedlings reach sapling height there is no relationship. Increased restored forest age is the most important predictor of greater seedling abundance, although larger forest patch size is similarly important for just the mid-late successional woody species. These results indicate that to promote restored urban forest succession (juvenile tree recruitment), management should vary depending on forest age, site conditions, and developmental stage of the restored forest.

Silviculture in the City: Urban and Climate Adaptation Management

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Forests in cities are dynamic, living structures vital for local-to-global biodiversity conservation and climate change adaptation. Assisted forest migration studies enhance forest resilience to current and future changing climate regimes. In 2020, we established the USA Northeast Urban Silviculture Network, along with urban forest practitioners and city land managers, to co-produce urban- and climate-adaptation management strategies. Our primary goal is to build resilience in urban forests in response to myriad environmental challenges, such as invasive plants and pests, deer herbivory, and climate change. The Urban Silviculture Network co-produced an assisted population migration study in five cities along the USA Atlantic coast to study climate adaptation management strategies in urban forests.

In fall 2021, we collected over 100,000 acorns across six provenances (seed zones) of the USA Atlantic coast and southern states (KY, TN). In spring 2023, we planted 6000 chestnut and white oak seedlings in forest canopy gaps across four cities (Springfield, MA, New Haven, CT, Philadelphia, PA, Baltimore, MD). In addition, we planted over 2000 oak seedlings across three common garden experiments in Springfield, MA, Katonah, NY, and Baltimore, MD. In each forest canopy gap and common garden, we planted seedlings from six provenances in a full transplant experiment. Our research design will provide insight on how: 1) oak seedlings from northern provenances withstand warmer climatic conditions in southern latitudes predicting whether local resilience to future climate scenarios is possible, and 2) oak seedlings from southern provenances withstand northern latitude stresses, such as late frost, predicting whether assisted migration can provide resilience to climate change. In addition, our research informs how above- and below-ground (e.g., apical dominance, root:shoot biomass, root architecture) oak traits relate to tree survival and growth. In our southern most city, we observed foliar green-up in 98% of our oak seedlings in the early growing season. At the end of the 2023 growing season, above- and below-ground traits will be related to seedling survival and growth. Our findings will identify fundamental traits and provenance that determine oak seedling resilience to changing climate regimes, further informing management strategies for climate adaptation in urban forests.

Structure, composition, and tree health of the urban forest in Kumasi, Ghana: Implications for climate change adaptation and urban forest management

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Past and ongoing rapid urbanization led to an immense degradation of the urban forest in Kumasi, Ghana. Additionally, increasing heat waves, droughts, and extreme weather events pose challenges to the urban forest in the more than 3-million-inhabitants city in West Africa. A prerequisite for the sustainable management of urban forests is a comprehensive knowledge of the composition of the vegetation and its spatial distribution in urban and peri-urban areas. However, such knowledge of the natural and anthropogenic factors affecting the current state of urban forests needs to be improved in Ghana and other West African countries.

A tree inventory was conducted in 238 plots distributed all over the Greater Kumasi area between August and December 2022. We found and measured 647 trees in our plots and evaluated numerous liana, shrub, banana trees, and palms. We systematically observed and documented tree health indicators. The plots were installed following the guideline of *i-Tree-Eco* from the US Forest Service. The Simpson Index provided information about the diversity of the urban forest. In addition, statistical analyses were used to study patterns and limitations of natural succession in the urban forest in Kumasi. We analyzed the age structure of the urban forest in different land use classes to distinguish the natural and man-made recruitment and mortality patterns. Using non-metric multidimensional scaling (NMDS), we investigated the similarity of urban forest composition in different land uses.

We found that anthropogenic and management activities in Kumasi heavily impacted the urban forest. Those impacts increased with an increasing degree of densification, leading to increased degradation. We are still analyzing our field data, and we will present the first results of the study regarding the structure, composition, and health of urban forests in Kumasi, Ghana in the conference. We will discuss the impact of the findings on the sustainability of Ghana's urban forests and their ecosystem services provision. Further, we will discuss implications for climate change adaptation and urban forest management in West African cities such as Kumasi in Ghana.

Tree cover increases bird predation on insects and enhances biotic resistance of urban trees

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: Bird predation on insects can improve growth conditions for plants and help control invasive insect populations. This ecosystem service can be enhanced by environmental conditions that promote bird diversity and abundance and, consequently, their predation rate on insects. We investigated bird diversity and abundance along a gradient of urban tree cover to understand how much tree cover promotes insectivorous birds. We also investigated predation rates of birds on artificial caterpillars to understand how much tree cover contributes to predator control of insects. Birds were surveyed in the cities of Zurich, Basel, and Lugano (Switzerland) using point counts along replicated transects placed in city areas with different tree cover: < 20%, 20-40%, 40-60%, and in the peri-urban forests. To measure insect predation rates, artificial caterpillars were deployed at the same locations. Attack rates of birds were counted from the artificial caterpillars and related to bird diversity and abundance at each site. To refine the predation rate assessment, we also considered the predation rate experienced by larvae of the horse chestnut leaf miner (*Cameraria ohridella*), a widespread invasive moth commonly found on horse chestnuts (*Aesculus hippocastanum*). For this, 10 leaves of horse chestnut trees were collected at several study sites, and caterpillar mines on leaves inspected under a stereomicroscope to identify mines opened by birds to feed on the larvae. We found that tree cover had a positive effect on bird diversity and increased the share of insectivorous birds in the local bird assemblage. Similarly, predation rate on artificial caterpillars was higher at sites with higher tree cover. This finding was also confirmed by the predation rates experienced by the horse chestnut leaf miner. However, high tree cover areas were rather rare in the studied cities, leaving most of the urban trees exposed to potentially high herbivory and with low biotic resistance. In addition, bird predation on insects could be enhanced by increasing diversity of native trees in the urban tree assemblages.

Tree Ring Analysis of Dominant Species from Variable Urban Forests in the Mid-Atlantic United States

T4.12 Forests in Cities: Ecology, management, and silviculture.

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Abstract: The majority of temperate forest in the eastern U.S. exists as a patchwork of small, isolated, urban forests. Often these forests have a history of deforestation followed by regrowth under surrounding urbanization. Due to their history and location, urban forests experience altered environmental conditions which mimic global change, such as increased temperatures. These urban effects could be beneficial or detrimental to tree growth, and may vary between forests due to variable city structure and urban heat island (UHI) intensity. Because urban forests exist in highly populated areas, humans rely on them to provide physical and mental health benefits. Additionally, we increasingly rely on the carbon (C) storage potential of forests as nature-based solutions for climate change. If tree growth declines in a forest it may not be able to provide all of the necessary ecosystem services.

Here, I present an analysis of tree cores from 15 mid-Atlantic forests, spanning an urban intensity gradient in Newark DE, Baltimore MD, and Philadelphia PA. I collected tree cores from 4 dominant species; *Acer rubrum, Liriodendron tulipifera, Fagus grandifolia, and Quercus spp*., and from multiple plots within each forest. The trees were selected based on their distance to the forest edge and their size, so as to include a range of sizes and therefore a range of ages. The cores were measured and chronologies were constructed using software programs CooRecorder and CDendro. The resulting chronologies reveal the growth rate throughout time for each species, across multiple cities and varying degrees of urban intensity. Smaller and therefore younger trees show a different growth rate than older trees due to differences in their life stage. This observation could have implications for managing forest growth in the typically mixed-age forests of this region. Future research will investigate whether these patterns in tree growth rate are reflective of temperature variations across different cities and urban intensities.

Urban forest seed bank composition and invasion varies across the developed east coast of the United States

T4.12 Forests in Cities: Ecology, management, and silviculture.

Jack Levy-Diedrich
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Abstract: Urban forests are increasingly receiving attention for their potential to both provide ecosystem service benefits to human population centers and habitat for non-human populations within an otherwise developed and urban landscape. However, in contrast to rural forests within the same ecoregions, urban forests typically contain higher richness and abundance of non-native plants, which may pose a threat to the existing native plant community. While the dynamics of soil seed banks have long been studied within temperate deciduous forests, we know relatively little about how seed bank composition varies within and across urban forests in the same areas.

Invaded seed banks may compromise biodiversity in these forests by replacing the native canopy with quick-growing non-native trees following large disturbances. Furthermore, recruitment from the seedbank by non-native understory species may prevent the growth and establishment of any canopy individuals, fundamentally altering the structure of these ecosystems. Consequently, a better understanding of which landscape and patch variables correlate with highly invaded seed banks can help practitioners and cities more strategically intervene to secure the future biodiversity of urban ecosystems.

In order to discern how urban forest seed bank composition changes across the developed landscape, we sampled soil seed banks from 25 forest patches across five cities along the urban east coast of the United States. Soil samples were collected from multiple locations in each forest, allowing us to assess how seed bank composition varies within forests, between forests, and across cities. Seedling emergence trials were then conducted in greenhouses to characterize the community composition of seed banks. While our findings suggest that the non-native composition of urban seed banks varies greatly from forest to forest, urban forest seed banks within our largest cities, Philadelphia and Baltimore, were much more invaded overall. While upwards of 60% of emergents from some of these forests were from non-native species, other forests within the same cities had a much stronger native character. Our results suggest that urban forest seed bank composition varies greatly across the urban landscape and provides a potential roadmap for practitioners on how best to restore and maintain urban forests.

T4.13 Gender sensitive leadership in research

Addressing Sexual Harassment in the Lab & Field

T4.13 Gender sensitive leadership in research

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Abstract: Sexual harassment is a persistent problem in academia, including the biosciences. The field of forestry poses unique challenges to the management of sexual harassment. Contextual factors, such as remote isolated work locations in the field and small spaces in laboratories, and social factors, such as masculinity contesting norms (e.g., competing to be the most masculine/dominate) in STEM fields, pose the risk of sexual harassment opportunities, especially for those with intersecting marginalized identities (e.g., women, people of color, LGBTQ folks). Even when unrealized, these risks can still affect women and marginalized people in the workplace, who may engage in career-damaging "trajectory guarding" behaviors (e.g., avoiding certain coworkers or work spaces) to protect themselves from potential sexual harassment. This presentation will review what is known about sexual harassment from the social science literature (e.g., psychology, sociology, management), focusing on specific evidence from STEM fields and academia. Multiple forms of sexual harassment (e.g., "come on" harassment, or unwanted sexual attention, and the far more common "push out" harassment, or gender harassment) will be defined and clarified for the audience. Common myths about sexual harassment will be dispelled with research evidence (e.g., the myth that only women are targets, the myth that sexual harassment is primarily motivated by sexual desire, the myth that false allegations are common). The harms of sexual harassment for targets, bystanders, and organizations will also be reviewed. Finally, the presentation will focus on potential actions to both prevent and respond to sexual harassment based on the three levels of allyship behavior (i.e., self, interpersonal, and organizational) and prior research on bystander intervention (i.e., types of interpersonal responses, barriers to intervention). The presentation will conclude with resources for the audience to continue learning more about sexual harassment and how to address it in forestry contexts.

Breaking barriers: Promoting gender equality in forestry research through supportive student environments in developing countries

T4.13 Gender sensitive leadership in research

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Abstract: The forestry sector in developing countries, especially in the Southern Hemisphere, experienced significant growth and development during the 1970s. However, during the same period, women were advocating for education and equal rights. The progress of women's inclusion and participation in this sector has been notably slow, with many countries still monopolizing the industry and decision-making only for males. The main focus is on highlighting the importance of creating a student environment that fosters support for women in developing countries, specifically the significance of gender-sensitive leadership in research. By creating an inclusive and supportive environment, it becomes possible to empower and encourage women to actively participate in the forestry sector and enhance women's participation and representation. By employing gender-sensitive approaches, such as ensuring equal opportunities, providing mentorship, and fostering a supportive network, barriers can be overcome, and the potential of women in the sector can be fully realized. There are many challenges faced by women in developing countries and the need for collaborative efforts involving academia, industry, and policymakers to create a conducive environment that supports women's development and success in the forestry sector. Ultimately, to contribute to the wider conversation surrounding gender equality and women’s empowerment in environments where voices are heard.

Death by a thousand cuts: Gender microaggressions, their impact and the way forward

T4.13 Gender sensitive leadership in research

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Abstract: Scholars propose that sexism, just like other forms of discrimination, is not as blatant as it used to be a few decades ago. Rather, sexism is expressed more subtly through what they call microaggressions. The term is defined as intentional or unintentional verbal, behavioural and environmental indignities exhibited by people, groups of people or organisations that communicate a biased or prejudiced view of a marginalised group. Men cutting me off, not paying attention when I speak, telling me to smile more, looking at and speaking to me as if I were physically or emotionally fragile, or not respecting my authority as a team leader are only a few examples of the many microaggressions I have experienced as a woman in science. These daily slights threaten women's identity because they create a lack of alignment between how they see themselves (i.e., capable, and qualified leaders and scientists) and the way their coworkers see them. Additionally, they burden women with the task of decoding the microaggression, and emotionally regulating to respond to the situation in a way that is socially acceptable. While this more modern form of discrimination might be less conspicuous, studies have shown that it is as capable as its predecessors to cause burn out, depression, anxiety, or trauma, and as such, impact women's mental and physical health. The talk will review the concept of microaggression by giving examples encountered by women in the field of forest research. The talk will also cover the impact that gender microaggressions have on women. It will provide a concrete guide to responding to microaggression either as a victim, bystander, or team leader, and to responding to accusations of microaggression if the audience were to become perpetrators. Finally, the presentation will provide advice for team leaders to reduce the potential for microaggression within their team by actively cultivating a culture that promotes safe communication and reflection.

Fostering inclusive development to maintain a stable work-life balance for female forestry researchers

T4.13 Gender sensitive leadership in research

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Abstract: Professional female researchers often face unique challenges when it comes to balancing work and personal life. Some of these challenges include; long and extra working hours resulting from demanding fieldwork (data collection, analysis, and writing. Secondly, juggling family commitments and work responsibilities often create conflicts; gender bias, and discrimination in terms of decision-making and practice. Thirdly, they encounter a limited support system in accessing resources that are tailored to their needs and demands for career growth and psychological well-being. This leads to increased stress, burnout, implicit expectations, self-imposed pressure, and feelings of overwhelm while struggling to maintain a balanced healthy work-life.

Forestry research organizations and institutions should strive to create inclusive and supportive environments that address these challenges and promote a healthy work-life balance for all researchers. This is crucial for reducing gender inequality and ensuring the active participation and empowerment of female forestry researchers globally.

Through a participatory virtual group discussion with 15 fellow female forestry researchers from various expertise, age groups, and regions of Kenya, it has been suggested that crucial strategies should be enforced to improve work-life balance for female researchers in order to support their overall well-being and productivity. Majority indicated the need for setting clear boundaries between work and personal life in order to organize and manage the two differently and at their designated time. The need to utilize technology and remote working, teleconferencing, or having flexible working hours can offer more flexibility and control over work schedules. Prioritizing self-care through engagement in activities that promote physical and mental well-being such as exercises, hobbies, spending time with loved ones, and having more breaks and vacations to help maintain energy levels and reduce stress. The need to delegate tasks to junior researchers in a sense of mentorship and focusing on more collaborative research and networks with low, mid, and high-level career researchers whilst practicing open communication to meet individual objectives and expectations set.

In conclusion, achieving a work-life balance requires regular evaluation and adjustments for self and work prioritization and advocacy for workplace policies for promoting flexible work hours, family-friendly environments, and support programs for caregivers.

Lead with your heart: A case study of women leaders in the only forestry state-owned enterprise in Indonesia

T4.13 Gender sensitive leadership in research

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Abstract: With respect to gender diversity, forestry is generally regarded as a men dominated sector. This viewpoint is corroborated by global forestry workforce statistics. As a workplace, forestry has traditionally been associated with a macho-masculinity culture. The masculine image and the notion of manual work and physical strength have resulted in more men workers in forestry. This gender imbalance has influenced its leadership environment. Although there is considerable research about women in forestry, to the best of our knowledge, there are few comprehensive gender and leadership studies in forestry in less developed countries. Studies specifically researching gender and leadership in the forestry sector are mostly conducted in North America and Nordic countries. This study aims to investigate women's leadership dynamics in *Perhutani*, the only state-owned enterprise who is responsible for managing the forest resources in Indonesia, one of countries with the largest forest area in the world. For years, *Perhutani* workers' gender composition is relatively static with 93% of men employees, compared to only 7% of women employees. Eleven women leaders from middle to top management level were interviewed with four themes questions: (1) gender and forestry industry, (2) career path of the women leaders, (3) impacts and benefits of women leadership, and (4) future of forestry sector. Utilizing inductive thematic analysis, we found that our respondents showcase heart and mother leadership. The styles are resulted from being raised in patriarchy culture with theological narrative. The heart-led leaders draw on the qualities of empathy, love, and vulnerability while mother leadership means not only leading with the heart of mother, but also with the mission, vision, and actions of mother. Future research can be directed to investigate the recently established women's network in *Perhutani*, as a result of the top-down approach from the Government of Indonesia. Can this network provide an inclusive environment for *Perhutani*'s women employees as well as potential mentorship for advancing their careers?

Scientific Masculinization of Community Forestry

T4.13 Gender sensitive leadership in research

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Abstract: Community forestry is widely recognized as a decentralized forestry program empowering women to participate in decision making in their forestry actions. Establishing women in vital leadership positions in community forestry institutions is not only a process or means, but also an outcome toward creating gender-equal society at large. Overlooking gender inequality for higher productivity of goods and services from forest ecosystems cannot be justified if sustainable forest management is considered a vehicle for community forestry to prosper. This study examines Nepal's scientific forest management program particularly in community forestry within the framework of feminist institutionalism. Key informants' interviews were carried out to collect primary information. Formal and informal institutions, structure-agency, power relations and continuation and change in community forestry institutions were analyzed. Excessive emphasis on timber production, introduction of silviculture without rolling out it to community people, trivialization of social and gender issues by highlighting higher production of goods and services, paying low attention to forest benefits that were valued by women and sidelining women in timber sale and financial activities were found to further marginalization of women in community forestry. The community forestry that is considered a model for women empowerment and gender-responsive forestry regime seemed to more masculinized due to scientific forest management. Although scientific forest management sensitized forestry stakeholders toward actualizing the full potential of forest goods and services through silviculture intervention, it failed to continue and strengthen women leadership and decision making by putting men back in *de facto* decision-making roles. Scientific forestry contributed to masculinizing community forestry and continuing unequal power relations between men and women in forestry sector institutions. Some recommendations are made to enhance

Who is your supervisor? Dealing with unconscious bias in forestry academic leadership

T4.13 Gender sensitive leadership in research

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Abstract: “Who is your supervisor?” This is a question I get all the time. Similarly to being ID’d in the supermarket when you want to purchase an 18+ item, this question could be welcomed by some people as temporarily, it makes you think “I must look young”. However, in an academic context, is a poisoned question as it is completely linked to the assumption that for one reason or another, I do not fit the characteristics of an Associate Professor but I “look” like a student. This question may be asked specifically to me due to different factors such as gender, nationality, age or physical characteristics, which all have been associated to unconscious bias. Other characteristics linked to unconscious bias are race, ethnicity, religion, sexual orientation, economic background, political affiliation and disability. Unconscious bias can impact our decisions, perceptions, set baselines and expectations of someone or something. Whereas there is nothing wrong about being a student (we have all been one at some point!), at a professorial level, unconscious bias resulting in that perception can affect the careers of researchers in those specific groups. It has been shown that unconscious bias is one of the factors to hinder gender balance representation at research institutions, research impact or race/gender balance on grant funding success, resulting in fewer women professors, fewer citations on women-led publications and more research funding allocated to white male researchers, respectively. There is therefore a need to enhance awareness on inequalities and bias within research institutions. However, a study demonstrated that perception of bias in research institutions differs between men and women, with women perceiving greater degree of inequality. Considering the male-dominated representation in professorial positions in forestry, it is of vital importance to improve awareness and training on inequality and unconscious bias to minimise their consequences. In my presentation, I will cover from a personal perspective, different strategies that women (and men) researchers could implement to increase awareness and reduce unconscious bias in their research institutions. Moreover, I will briefly provide some examples of institutional strategies which are being developed at the Birmingham Institute of Forest Research.

T4.14 Governing EU's forests: policy narratives, perception and power

Transposing EUTR Requirements in the Western Balkans: multiple case study of Slovenia, Croatia, Serbia, Bosnia and Herzegovina, and Montenegro

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: Although between 2015 and 2020 the deforestation rate had a 40% global decrease compared to 1990s values, deforestation and forest degradation remain major concerns. The size, trends and impacts of these processes are emphasized by illegal practices. To halt them, the European Union (EU) is taking a lead regulatory role through flagship policies, e.g., the Forest Law Enforcement Governance and Trade (FLEGT) program, including the EU Timber Regulation (EUTR), and the newly adopted European Regulation on Deforestation-free Products (EUDR). While the EUDR is not yet implemented, evaluation reports of EUTR and FLEGT implementation present inconclusive results, highly dependent on the national context of EU member states or exporting countries. Among high-risk exporting countries are also some Balkan countries, considered as a corridor of illegal timber and timber products from Eastern to Western Europe. Although some scholars focused on forest and timber trade legality in the Balkans, existing studies are patchy and there is limited research on how Balkan countries are adapting national forest policies to the EUTR. This study aims to contribute to filling this gap by identifying the main actors involved in the adaptation of national forest policies to the EUTR and EUDR within selected Balkan countries (Slovenia, Croatia, Serbia, Montenegro and the Republic of Srpska - BH), as well as investigating their roles and relations. Using multiple embedded case study designs, we conducted a qualitative content analysis of policy documents and 30 key stakeholder interviews in selected countries. We used network analysis to map the actors involved and influenced by the adaptation of national policies, as well as to examine the resource and information flows between them. Our results indicate that in all targeted countries state actors are the key stakeholders: they form small elite communities representing policy networks characterized by rather formal patterns of information exchange and resource dependency. This indicates the persistence of strong state authority and weak shifts towards innovative 'soft' forest governance. Our research contributes to a better understanding of forest policy adaptation and highlights power relations paving the way for improving measures in combating deforestation and promoting sustainable forest management in the Balkans.

Dismiss, ignore or integrate – the Swedish parliamentary parties' arguments on the new EU forest strategy for 2030

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: To address the critical consequences of climate change, and achieve the environmental goals in Agenda 2030, the European Commission has drawn up an agreement for the member states, the Green Deal. The focus of our study was the EU commission's flagship initiative – the new EU forest strategy for 2030 – which addresses the role of forests to mitigate climate change and halt biodiversity loss across Europe. Sweden is one of Europe's most extensively forested countries and the forest strategy will create avenues for enhancing the sustainable use of Sweden's forests. In this paper, we examine how the Swedish parliamentary parties represented in the national parliament argue regarding this strategy and upcoming regulations, with a particular focus on the themes 'supporting the socio-economic functions of forests' and 'protecting and restoring EU forests and large forest areas'. The arguments are analysed using an argumentative analysis targeting three main strategies that are frequently used by political parties in general, including the adversarial strategy, the dismissive strategy, and the accommodative strategy, showing that a political party either ignore, dismiss, or integrate the political issue into their political agenda. The results show that a clear majority of Sweden's parliamentary parties express explicit negative concerns towards the forest strategy and the Commission's involvement in Swedish forest policy. Most of the parties argue that there is too much focus on biodiversity protection in the strategy, and that it poses threats to national sovereignty and current Swedish forest management practices. Current management and harvesting are generally considered key actions in Sweden's ambitions to achieve climate neutrality by 2045. It turned out that all parliamentary parties used one or more of the three main strategies in their argumentation, implying that some ignored the political issue, dismissed it, or integrated it into their political agenda. These results have implications for current and upcoming regulatory discussions, in which the Swedish government may choose to delay the progress of EU polices.

EU policy effects on Finnish non-industrial private forest owners

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: Multiple pieces of legislation that affect forestry have been proposed during the tenure of the current European Commission. When introduced this legislation will change the operational environment of the forest sector. Most of the legislation is still in preparation, so the overall effect on the forest sector is still unknown.

The project aims at improving the non-industrial forest owners' understanding of the overall effect the EU legislation will have on them and their forest management. This will be achieved by providing a concise and descriptive synthesis based on the information available in autumn 2023 on the content and effects of the legislation. The EU legislation under closer assessment includes most notably the nature restoration act, the LULUCF revision, the EU Taxonomy act and its' technical criteria, and the revision of the renewable energy directive.

The synthesis will be formed in the autumn of 2023 with the cooperation of Finnish stakeholders, both in the public and private sector, that follow closely the legislative process of the EU. Aided by their insights, an overview can be formed on how the various pieces of legislation may affect non-industrial private forestry and forest owners. The project will produce a policy brief presenting the synthesis of the effects of the new or revised EU legislation. To conclude the project, a public workshop or panel discussion will be organized on how the EU forest related legislation should be influenced in their opinion. This will be organized in November or December 2023.

Fighting for Forests and Watching the Woods: Conflicting Use Interests and Sustainability Regulations in Europe's Forest Policy

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: In recent years, the European Union introduced numerous new forest-related policies and targets. In these policies and the accompanying political and scientific debates, conflicting use interests become clear: Forests play a central role for biodiversity protection, as they provide a habitat for many kinds of species. Furthermore, they serve as a space for recreation for humans. In recent debates, forests are also understood as important carbon sinks in climate policy, and they are important for the regional climate and water management.

In addition to these rather nature and climate protection oriented and recreational use interests, forests can be used commercially in many ways. Forest biomass is a material that has been used as a building material, for the production of goods and the generation of energy for centuries and it is seen as a central resource in the bioeconomy, which aims at a shift from fossil resources to bio-based resources. Within this economic dimension of forest use, conflicting use interest come up between material and energetic use routes of wood and concepts of efficient and sustainable circular systems are currently debated.

Forests are part of the global, regional and local carbon cycles and there are European policies that regulate different parts of the forest carbon cycle. This contribution analyzes European regulations that relate to different kinds of forest use, climate policy and sustainability regulations. A focus lies on the role of forests and woody biomass for the energy transition in the heat sector and corresponding regulations. The contribution is based on a qualitative interview study on European bioeconomy and bioenergy policy, on the results of a quantitative survey (N = 1,427 participants) and a literature and document analysis. It identifies important political conflicts arising from different forest-related use interests, points out critical points in recent political debates and discusses implications for the regulation of forest use and sustainable wood use in Europe's multilevel governance system.

Forest Governance in the Baltic Region - Sustainability Pathways for Adaptive and Inclusive Forest Governance.

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: The Baltic region, with its central role in international trade, the diverse forest functions and variety of actors involved, is the ideal location to test a new nexus approach. The proposed WEFF nexus (Water-Energy-Food-Forest) highlights the interdependence of resource security and sectors that underpin these securities. Combined with adaptive management, the newly developed nexus could enable new pathways for sustainability. The aim of the project is to map, analyse and propose a governance system where water, food, energy and forest synergies are highlighted and enhance each other through strategies that build on the scientific evidence of the involved actors and groups, and aims for long term cooperation and sustainability. Adaptive management and participatory governance are going to be used aiming effective stakeholder engagement at different scale leading to informed decision-making processes. Forest governance increasingly require combinations of different methodologies, as implications of production and protection of forest resources and management impact all aspects of society: a combination of qualitative and quantitative methods ranging from interviews to experts to statistical analysis are required to reach the aims of the research. Practices and polices related to water, food and energy security are scrutinised to identify synergies and trade offs, and results would guide towards potential solutions and set conditions of emergence for cooperation between security division for long term sustainable development. As global pressures such as climate change, rising global population and consequent demand for resources, forest are increasingly considered a viable and sustainable way to meet those demands. Setting up an efficient and collaborative agenda for governance is then necessary to avoid additional thresholds and define a safe operational space for human activities in the long term. The conceptualisation of this sustainable governance combining water, energy, food and forest sector is the overall aim of this proposed project.

From sectoral policy change to cross-sectoral (dis)integration? A longitudinal analysis of the EU's Forest and Rural Development Policy

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: Policy integration (PI) is critical to address cross-cutting challenges like climate change and biodiversity loss holistically. In the European Union, forests are confronting increasingly adverse climatic conditions and numerous stressors that impact their vitality and biodiversity. Political efforts to counteract these trends are mainly channeled through funding from the Rural Development Policy (RDP) as a pivotal part of the Common Agricultural Policy (CAP). In contrast, forest policy is hardly institutionalized at EU level. This study employs longitudinal qualitative content analysis and examines the development of sectoral policy change and its implication for the cross-sectoral integration of forest policy into agricultural policy at the EU level. Results suggest that adopting the new Forest Strategy (EU-FS) for 2030 in 2021 represented a provisional paradigm shift in EU forest policy. This shift is characterized by a substantial reprioritization of policy objectives, transitioning from an emphasis on economic aspects to a more climate- and biodiversity-centric approach, alterations in supported policy instrument types and the introduction of various new (legislative) instruments. This development was facilitated by changes in government leadership along with political reorientations introduced under the EU Green Deal and an intensification of forest damages in many parts of Europe in recent years. On the other hand, the CAP and its RDP, remain largely characterized by an ideational and policy path dependence, and the latest reforms hardly reflect ambitious forest policy objectives both from budgetary and content perspectives. Findings imply that the latest seemingly decoupled developments within both policy areas resulted in a resurgence of policy silos and an increase in forest policy fragmentation at the EU level.

Governing EU's forests on the route to Paris: an examination of how EU's policy goals translate to the national context of the member states

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: Following the Paris Agreement and the European Parliament's declaration of a climate emergency, the EU has developed multiple directives and strategies, including the European Green Deal, the EU Biodiversity Strategy, and the fit for 55 package, which describe EU's forests as a key contributing sector to the aimed for sustainability transition and agreed climate goals. In addition, the EU has made commitments that these transition processes are conducted in a just manner. We examine how the EU's ideas around forests' role in reaching the climate goals translate to the national contexts of the member states. We aim to gain deeper understanding of potential differences in framings of the forest at different levels, potential synergies and trade-offs between different prescribed roles to forests at different levels, what policy instruments are proposed to motivate forest owners to manage their forests so as to contribute to the fulfilment of these roles, and in what way just transition considerations are incorporated in these policy instruments. We conduct a case study in which we analyse and compare the Paris Agreement, EU climate and biodiversity directives and strategies, and Swedish government bills, strategies, and action plans for the forest sector. We find that, whilst there are many roles and goals ascribed to EU's forests, there is no clarity in governance on how to fulfil these both at the EU and nationally in Sweden. The current setup provides opportunities for synergies in the short-term, but risks goal conflicts and trade-offs in the long-term. In addition, there is a divergence in focus of policy instruments, where EU climate policy builds on rules and regulations and economic instruments, whilst the Swedish forestry policy focusses on social and information-based instruments. Neither include rights-based instruments and the EU's commitment to create just transitions has no prominence in the proposed policy instruments and national level policy documents. We conclude that the current translation of EU goals to the national level in Sweden provides insufficient clarity and incentives for forest owners to engage with the sustainability transition and risks a lack of perceived legitimacy through its limited attention to considerations of justice.

Legitimacy of EU forest-related policies in digital media discussions: linking theories and empirical findings

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: The new strategic EU guidelines and legal regulations that partially override the competence of member states will increasingly affect the legitimacy of forest-related policies, also at the national levels. The implementation of new policies requires reasonable public support and willingness to cooperate, especially in countries like Finland, where more than 10% of the population are private forest owners and many others engage in forest-related recreational activities.

The research series examined the perceived legitimacy of the EU forest policy, social values used in the evaluations, identification with political communities, and the support of politicians in public discussions on social media platforms and discussion forums of news media. Theoretical basis and methods for the analysis of textual data were employed from political science and social psychology.

Most evaluations regarding the legitimacy of the EU forest policies and the exercise of power by the EU were negative across all data sets. In this context, trust in the competence of the EU concerning forest issues was predominantly low and self-identification as European was also weak. The evaluations of politicians involved in EU-induced forest policy decision-making were also mostly very unfavorable.

The fair distribution of benefits and burdens among both European nations and domestic citizen groups was the most common social value used to assess forest policies. Legitimate policy was also deemed to require fair compensation for both one´s own nation and private forest owners for their conservation measures. Following concerns about distributive justice, the preservation of national sovereignty and the right to autonomous decision-making emerged as the second most frequently mentioned social values. The next highest emphasis was placed on economic objectives and private ownership. The values related to nature protection and climate protection were brought up much less frequently than in the previous studies on national level policies and the same applies to values related to democracy, good governance, and fair markets.

The comprehensive theoretical framework developed in this study is useful for the analyses of various public policy discussions; however, the text-analytical methodology is not only limited to fixed categories and therefore it can be flexibly applied in different contexts and countries.

Meeting the European Unions' Forest strategy goals: a comparative European Assessment

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: The new Forest Strategy for the 2023 for the European Union was adopted in July 2021, creating a new policy drive for policymaking. While the implementation of the EU Forest Strategy is accompanied by debates around the principle of subsidiarity and competencies for forest policy, until now no systematic scientific assessment has been conducted which looks at to what extent countries meet these goals. This study aims at: i) assess to what extent the national and sub-national forest policies of European countries align with the EU's goals; and ii) identify opportunities and challenges for enhanced implementation.

This study refers to 15 countries and 3 regional cases ensuring a variety of socio-economic contexts and forest related conditions. We applied mixed methods based on comparative content analysis. Specifically, a total of 221 policy documents were analyzed through a content analysis, and a vast number of semi-structured expert interviews (69) conducted based on a common interview guideline that was translated into national languages were conducted.

The results of this comparative assessment show that the level of alignment of national implementation with the new EU forest Strategy depends on each country implementation trajectories. In most of the countries significant policy efforts are devoted to defining sustainable limits and practices for forestry whist advancing at the same time new measures on protecting, restoring, and enlarging EU forests. Climate change and their impacts are acting as trigger for putting forest higher in the policy agenda and getting more attention of public opinion and media. However, there is a general lack of mechanisms and participatory planning addressing different ecosystem trade-offs and involving concerned societal groups and scientists systematically in goal formulation. Moreover, there is an increased polarization between conservation and forestry, which results in multiple level and regional governance structures that are not well coordinated. A lack of human and economic resources constrains, in some cases, the ability of public administrations to conduct public management of forest goods and services, and to achieve ambitious goals - embedded

in more complex policy frameworks. We conclude with 9 policy recommendations to overcome these challenges and strenghen EU forest governance.

Overlaps and tensions within actor networks and EU policies towards the implementation of the Biodiversity Strategy and the Nature Restoration Law

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: The Earth systems are faced with multiple crises, of which the biodiversity crisis is recognised as perhaps the most severe and complex, in combination with the climate and pollution crisis. The 2019 EU Green Deal (EGD) represents an ambitious plan for a more radical response to such challenges towards transforming the EU into a more sustainable and yet prosperous society, in a just and inclusive way. In the context of the Green Deal, the new EU Biodiversity Strategy for 2030 (BDS2030) aims at protecting, conserving and enhancing European biodiversity and associated ecosystem services, as central elements to transformative change.

The effective implementation of the BDS2030 is challenged, among other things, by the heterogenous landscape of actors involved in the co-creation of knowledge and in decision-making processes related to biodiversity, as well as by horizontal policy incoherence, which involves policies beyond biodiversity, such as agriculture and forestry.

In this study we further explore such challenges by examining the biodiversity science-policy arena at the EU level, and look at overlaps and tensions in roles and responsibilities within actor networks, as well as within existing policies, relevant to biodiversity, including in relation to forest. We base our analysis on social network analysis of key organizations operating in the EU science-policy interface (n=100) as well as a document analysis of EU policy documents (such as EU forest strategy) from key sectors relating to biodiversity and forests. We particularly focus on the Nature Restoration Law as an example of cross-cutting policy process that provokes different knowledge needs within the science-policy arena. The preliminary findings show that the EU science-policy interface hosts several actors with overlapping and conflicting positions and interests, and such diversity is similarly reflected in the policies analysed.

Policy change and learning related to forests and climate change in Germany between 2000-2022

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: Policy process research has shown that both power and learning matter for explaining policy change or stasis over time. However, we still do not have sufficient knowledge about how learning contributes to policy change, through which mechanisms it works and how it interacts with power related factors. Learning is particularly relevant for forest related policy, which deals with highly complex ecosystems and wicked problems concerning the supply of wood, climate change adaptation and mitigation, and biodiversity conservation. The use of scientific and other types of information are thus an essential part of forest related policy processes.

Forest related policy in Germany represents a relevant case study in this regard. Within the EU, Germany has the fourth largest forest area as well as the biggest population, greenhouse gas emissions and GDP. Linked to an increase in the average air temperature by 1.6°C between 1881 and 2021, extreme weather events have become more common since the 1990s. Recent heat waves and droughts, storms and bark beetle outbreaks have led to significant forest damages and increased public attention.

The research paper deals with the question to what extent and why forest related policy in Germany has changed or remained stable between 2000 and 2022 and how policy learning has contributed to it. The paper focuses on a longitudinal analysis of forest and climate policy at federal level and in two selected states with particular attention to regulation and public funding for forest related climate change mitigation and adaptation.

The Advocacy Coalition Framework serves as analytical framework, which assumes four pathways to policy change, including external and internal events, negotiated agreements and policy learning. Theory on policy learning helps to shed light on the updating of policy related beliefs by multiple actors such as in parliaments, ministries, business associations, environmental organisations, and scientific advisory boards. Methodologically, the paper draws from qualitative content analysis of policy documents and statements by actors with a process tracing approach. It thereby contributes to empirical and theoretical research on policy learning as independent variable and policy change as dependent variable with a focus on forests and climate change.

Politicization of the EU Forest Strategy at the Member State Level: Implications for forest management

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: The forest can take a central role in the efforts to mitigate climate change. Several factors, however, inhibit a clear delineation as to what this role entails. One set of factors includes the large variation of interests, legal frameworks and forest policy paradigms with related forest management practices of EU Member States. Another set of factors relates to the potentially conflicting goals of sequestering carbon in wood products and sequestering carbon in standing forests (sinks), all while providing other forest ecosystem services. This latter potential antagonism is also reflected in the EU Forest Strategy which aims to enhance the multifunctionality of forests, promote long-lived wood-based products as well as non-wood based products such as ecotourism and other aspects linked to multifunctionality. Depending on Member States' interests, priorities and forest policy paradigms, these potential goal conflicts or trade-offs within the EU Forest Strategy may lead to politicization at the national level and to very different forest management strategies. In a systematic literature review, we zoom in on the forest management practices across Europe, map them and analyze them according to their contribution to mitigate climate change, be it in wood sinks or wood products.

Promoting effective forest Payments for Ecosystem Services through the EU financial and state-aid programs: the ProForPES project

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: In the context of European and national legislation and financial programs, Payments for Ecosystem Services (PES) are gaining momentum as innovative solutions for meeting societal demand for ecosystem services from forests in Europe. In particular, the EU Forest Strategy 2030 encourages Member States to develop payment schemes for ecosystem services to compensate additional costs met by forest owners and managers in the provision of several regulation and cultural services, such as forest biodiversity, carbon storage, recreation. This calls for increased coordination and coherence amongst the existing EU policies, financial instruments, and state-aid programs towards the common goal of designing payment schemes, as well as for understanding potentialities and limitations of such innovative tools with respect to more traditional environmental policy instruments. The paper will present the first results of the ongoing LIFE21-ProForPES project, which aims to investigate the readiness, possibilities, and barriers to mainstreaming PES and PES-like schemes within the EU policy framework currently under development. The existing gaps and potentialities for PES and the synergies across different EU policy tools are assessed through an in-depth institutional analysis of existing programmes undertaken with the help of policymakers and experts in PES design and policy integration. This is followed by a scenario-based policy assessment achieved through a robust stakeholder consultation process, involving national public administrations and agencies, policy makers, protected area managers, forest owners and their associations, research institutions, private companies, investors. The project will provide recommendations for future funding programmes targeting appropriate forest ecosystem services (or their bundles), actors, institutional and financial models, temporal and spatial scales.

So Many Principles, So Much Policy Confusion

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: Striving for policy coherence aims at the careful harmonization of diverse goals. The governance literature suggests "policy coherence" is an important strategy for addressing potential conflicts between divergent goals, and for mitigating policy tradeoffs and unintended consequences. Indeed, regarding forest policy goals, the Member States of the EU have very different interests.

The forest-related policy terrain and potential policy pathways are rapidly proliferating into ever newer areas. For some time, *multifunctional* and *multi-purpose* forestry described forest policy frameworks with both pluralistic objectives and largely unified (congruent) goals. However, as the principal top-down objective, "*climate change mitigation*" has rapidly replaced multifunctional/multi-purpose forestry as the organizing principle around which policy coherence has been promoted. Thus, for example, "*climate smart forestry*", and the promotion of the renewable circular bioeconomy have become one of the principal goals of future forest management strategies. In turn, in addition to climate change mitigation, goals such as biodiversity protection and increased nature conservation are quickly becoming the principal topics and policy orientations of the day.

Alone, concepts such as climate change mitigation, sustainable land resource use, or biodiversity protection provide organizing principles around which cohesive policy objectives can be coherently organized. Organizing principles lend a much-needed degree of coherence to the practice of policymaking, and, as such, may well contribute to more successful policy outcomes. However, the proliferation of climate change mitigation strategies, bioeconomy interests, biodiversity goals and conservation objectives have increasingly rendered the policy arena more complex, creating powerful interest divisions both within and across states and actors. In particular, the *EU Green Deal* and the *Biodiversity Strategy for 2030* exemplify this shift in policy orientations and the proliferation of policy pathways. And, to some extent, biodiversity and conservation goals have eclipsed policy orientations such as the bioeconomy strategy, though perhaps less so with respect to climate change mitigation.

Taking this development of EU policy into account, this paper analyzes EU forest policy by means of a policy document analysis. It assesses whether and how the prioritization of new and potentially divergent policy goals affects policy coherence, and in doing so favors some interests over others.

Taxomania! Shaping EU forest policy through financial regulation?

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: The EU taxonomy has made headlines in recent years due to major concerns mainly from member states and their prime ministers but also of environmental groups over the question of what should be considered a sustainable investment including in forests and forestry. While supposedly "science based", this new classification system has raised fears of resetting existing EU and member state sectoral policies through the "back door" of financial regulation and/or greenwashing unsustainable activities. Building on 46 expert interviews conducted in three interview rounds in 2019, 2021 and 2022 as well as process tracing, we investigate the evolution of advocacy coalitions and strategies used to influence the development of the forestry criteria for the taxonomy regulation and its climate and environmental delegated acts. Our findings illustrate a very complex process that is connected to a diversity of sectoral policies including EU forest and nature policies and that translates into cross-sectoral alliances, highlighting strikingly different worldviews and economic and bureaucratic/political interests connected to it. Due to the rich set of strategies and deals made at different levels as well the overall lack of transparency, "science-based" decision-making is challenged to the impossible. While the forestry criteria have been excluded for the time being for parts of the regulation, fossil gas is included, pointing towards a disbalance in favour of certain economic and political interests and despite the EU Commission's goal to enhance private finance for achieving its climate commitments and the Green Deal. The taxonomies ambiguity as well as the political struggle including for the development of the forestry criteria, question its potential as a gold standard to be copied by other countries overall.

The EU de facto Forest Policy: Insights from Finland, Slovakia and Slovenia

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: The European Union (EU) founding treaties do not establish a common forest policy. However, several bodies within the EU implicitly, and some of them explicitly, deal with the issue of forests. The latest major strategic document focused on forests is the EU Forest Strategy to 2030. Despite the fact that the document aims to integrate different objectives related to forests, it is perceived as controversial on several points. Member States argue for insufficient involvement during the adoption process, conflicting goals and vague definitions. The poster aims to point out the perceptions on uploading as well as downloading the EU de facto forest policy, with a focus on the New EU Forest Strategy in Finland, Slovakia, and Slovenia. A total of thirty interviews were conducted in three countries to explore the perceptions of key domestic forest policy actors from forestry and environmental administrations as well as non-governmental policy arena, e.g. forest owners, industry, research, and environmental NGOs. Finland is the most active in uploading its policy to the EU within selected countries. It forms a national joint position that includes the positions of various domestic actors. Slovakia and Slovenia are represented by governmental forest experts and create interest coalitions with strong forestry-like-minded countries. In addition, Slovenia is active in informal groupings with fewer members. All three countries have been active in commenting on the New EU Forest Strategy, but they believed that their positions were not sufficiently taken into account. These three countries perceive a strong influence of the EU forest policy despite the fact, it is formally the exclusive competence of the Member States. A turn towards an ecological orientation of the EU in relation to forest policy, confirmed by the New Strategy, may have further consequences for domestic policy-making and financing of the forestry sector.

Understanding forest related conflicts and solutions based on local realities: the case of Gällivare Sweden

T4.14 Governing EU's forests: policy narratives, perception and power

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Abstract: With the EU's green transition, bioeconomy and sustainability goals being pursued, coupled with the impacts of the war in Ukraine, the demand for forest land and resources is increasing which causes conflicts with mining, energy and traditional activities like reindeer husbandry and hunting. Our study aims at understanding the landuse conflicts using a constructivist lens and conducting a holistic analysis by including multiple sectors. Constructivism offers insights for conflict analysis and conflict resolution because it directs our attention on the historically contingent and constitutive nature of the social structures, agents of conflicts, the social construction of identity, history, culture and the reproduction of conflict. We apply this approach in Gällivare, Northern Sweden which is a small Arctic town undergoing social transformation to accommodate varying demands from multiple sectors. In line with our approach, we therefore ask: How do local stakeholders perceive the conflicting demands from various sectors and what are the conditions wherein these sectors can exist side by side? Using discursive analyses, and looking at the three main elements of conflict: actors, discourses and identity, we analyzed national policy documents and semi-structured interviews with local experts from different sectors including indigenous people. Initial results show that alliances between sectors are created and sectors adapt a 'solution-oriented' thinking that reformulates the conflict into a positive situation where solutions are preferably discussed instead of causes, ignoring the root cause of the conflict and applying Band-Aid solutions. We also found that sectors are aware of the 'cumulative effects' of their operations in addition to the effects of other sectors on the environment, which promotes collective action and inaction. Lastly, green transition is used as a discursive weapon to marginalize and delegitimize traditional livelihoods such as reindeer husbandry and hunting, thereby facilitating industrial exploitation of indigenous lands including forests. On the one hand, solutions are hard to come by as stakeholders are skeptical and can only depend on negotiations and active representation as a way to move forward.

“We need to give up something” - Readiness of Finland to adopt and accept the New EU Forest Strategy for 2030

T4.14 Governing EU’s forests: policy narratives, perception and power

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Abstract: Environmental policymaking has shifted from largely state-dominated, to a multi-level, shared responsibility of national and transnational actors alike (Arts & Leroy, 2006). Finland, with comparatively high forest cover and contribution of forest industry to national GDP, faces the challenge of ongoing biodiversity loss despite a long history of national forest legislation and programmes. When the European Commission published “the New EU Forest Strategy for 2030” in 2021, emphasizing environmental outcomes, it was welcomed by the Member States with varying reactions; the traditionally timber-oriented countries, including Finland, resisting the strategy.

This study analyzes Finland’s readiness to *adopt* and *accept* the EUFS by assessing primary and secondary data through a critical institutional policy analysis lens and policy integration framework (Nilsson & Persson, 2010; Di Gregorio, 2016). Readiness to adopt EUFS is assessed by analyzing objectives of national forest-related policies, action plans, and legislation in relation to the objectives set out in EUFS. To capture a full understanding of the readiness, the study considers policy documents from fields of forest, biodiversity, climate change (adaptation and mitigation), energy, bioeconomy, and rural development. The readiness to accept the EUFS is examined through semi-structured expert interviews that aim to increase understanding on actors’ views on national forest-related priorities and factors affecting those.

The initial findings indicate that the existing policy documents seem to primarily align with the EUFS through goals supporting the economic functions of forests. However, a lack of coherence and communication amongst actors in Finland suggests the absence of a unified forest vision. Other gaps are related to lacking political will for adopting and accepting the EUFS, partly legitimized by concerns that Nordic forestry expertise and needs are ignored in the EU. Among most forestry actors, “the productivity reflex” – more production and extraction as a solution - is a dominating response to climate, energy, and biodiversity crises. Meanwhile, environmentally oriented forest actors suggest strengthening forest carbon sink and socio-cultural uses of forests. These findings imply several challenges for the implementation of the EUFS. Meanwhile, opportunities might arise due to changing preferences of private forest owners, and national climate and biodiversity ambitions.

T4.15 Healing Power of Nature: Forest Therapy in Action

Trees, Nature & Health Economics: Putting a Value on What Counts

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Extensive and rigorous research indicates that urban natural systems, including urban forestry, contribute to residents' health and wellness. Thousands of studies link public health outcomes with green space experiences, including therapeutic effects for cardiovascular diseases and mental health disorders, positive immune system response, stress reduction, improved gestational and infant health, and reduced mortality rates. Natural experiments during the COVID-19 pandemic further document the importance of green space access and wellness. Evidence of nature and health effects range in scale from small groups of treatment patients to entire nations. These outcomes represent significant potential economic value, as most nations face high, and ever-increasing healthcare costs. Yet few natural resource or public health economic analyses have included nature-influenced human health outcomes in comprehensive valuation approaches. This absence is impactful as economic analysis helps support policy development and solidifies consistent budgets. However, political and civic support, including budgeting and funding to sustain resilient urban nature and urban forest systems, falls far short of what is necessary to maintain ecosystem health, and associated human health benefits. Public health policies, plans, and insurance incentives rarely acknowledge health and green experience outcomes, which include improvement in quality of life and ubiquitous morbidities. The evidence indicates that green experience can mitigate health disparities and cost-effectively decrease the burden of disease and improve health equity. Our presentation will offer a conceptual framework for nature and health benefits economics. We first make the case for nature and health as critical to issues of global concern. Then we summarize the links between nature integration within built landscapes and resulting biophysical services and salutogenic benefits. We outline how both the health and environmental disciplines use similar decision-making tools based on economic analysis of costs and benefits. Emphasizing cost-effectiveness analysis, the conceptual framework explores potential community-based urban greening and urban forestry interventions that promote human health. Studies of nature and health economics are sparse. Our examples of potential applications will demonstrate nature and health valuations and provide suggestions for future analysis that can promote community-level wellness and support green space and forest therapy investment.

A Multi-Country Study Assessing the Mechanisms of Natural Elements and Sociodemographics behind the Impact of Forest Bathing on Well-Being

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Iterventions such as forest bathing (slow, mindful nature walks) have been shown to increase our connection to nature and be an effective intervention for improving health and well-being.
However, there is variation in the activities delivered during forest bathing and the guidance given. Few researchers have evaluated which activities, elements of nature, and senses are responsible for improvements in well-being. The current evaluation addresses this gap and also monitors the emotional state and nature connection following guided forest bathing walks. Participants (N = 1142) across 35 countries completed post-walk evaluation surveys online. Results suggest that well-being and nature connection were rated very highly following forest bathing activities. Experiencing happy feelings and trusting emotions were especially highly rated. The natural elements perceived as contributing the most to well-being were sound-related elements. In terms of sociodemographics, women had higher well-being and nature connection ratings than men; ratings were higher in specialised nature resort areas, with little difference between natural and urban park areas; higher scores were seen in the southern hemisphere and during hot or long-day seasons. This has implications for forest bathing, forest therapy, and nature-based training organisations and their guides who want to improve their method of intervention delivery, maximise well-being, and enhance nature connection

Co therapist forest: the IWSI method brings forest therapy into health care and rehabilitation

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Climate crisis, heat stress, water scarcity, pest plagues, pandemics, increasing life-style related diseases, demographic change, rising health care costs, digitalization, flood of information, ever accelerating everyday work, stress and excessive demands - keywords showing that forests and humans face similar existential challenges.

But while the forest might be even better off without humans, human existence is hardly conceivable without forests. So, for a good reason, societies around the world are seeking new concepts to integrate the forest into the value chain in innovative ways.

Forest therapy offers excellent opportunities for this in health care contexts. The bond between humans and the forest and the multifactorial effects that the forest as a natural space exerts on body, mind and soul of humans are now so well researched that they can form the basis for an experimental model of forest therapy.

In the field of individual preventative health care, this model must admittedly meet different standards than in the field of medical rehabilitation of (chronic) diseases.

The presentation highlights two projects with which the Im-Wald-Sein Institute intends to bring more forest and nature into people's everyday life and medical care and how it is contributing to the further development of a target group specific, living world-related and effectiveness proven model of forest therapy and forest medicine.

Comparison of the Mindfulness Therapy Interventions on University Students' Emotions and Attention in Different Environments

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: After COVID-19, university students experienced stress-related health conditions due to restrictive measures that limited face-to-face communication. These measures have led to feelings of isolation and stress among students. Additionally, the transformation from in-person teaching classes to online classes had adverse effects on academic quality, happiness, and overall life satisfaction. Mindfulness therapy has been proven by scholars to improve people's health and manage stress and negative thoughts. However, traditional therapy meditation is typically conducted indoors. The primary purpose of this study was to identify: 1) whether mindfulness therapy intervention in forest and indoor environments can affect the health of university students; 2) whether the forest therapeutic effect differs depending on the environment.

We recruited 109 university students to participate in a two-week long study and divided them into three groups: the forest group, the indoor group, and the control group. The forest and indoor groups received one hour of mindfulness therapy intervention every day in the corresponding environment, while the control group received no intervention. Physiological and psychological indicators were used in this study. Physiological indicators included heart rate variability (HRV), heart rate (HR), and blood pressure (BP), while psychological indicators included the Profile of Mood States (POMS) and the Five Facet Mindfulness Questionnaire (FFMQ).

The results indicated that participants who received mindfulness therapy in both forest and indoor environments experienced positive effects on their emotions and self-attention compared to those in the control group. However, concentration of self-attention was more significant in the indoor environment than in the forest, possibly due to the absence of noise and distractions in an indoor room. On the other hand, participants in forest environments exhibited greater reductions in stress, depression, and anxiety symptoms, as well as an increase in positive emotions compared to those who were in indoor.

Finally, this study showed that in the post-COVID-19 era, a two-week mindfulness therapy intervention can benefit contemporary people with limited time. Further studies are needed to examine the long-term effects of mindfulness interventions in different environments and their potential applications in promoting mental health.

Keywords: Mindfulness intervention, Physiological and psychological indicators, Stress reduction, post-COVID-19 era.

Developing an Islamic-Inspired Forest Therapy Module for Senior Citizens: A Pilot Study

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: This pilot study aims to develop an Islamic-inspired forest therapy module specifically designed for senior citizens. The research will be conducted in August 2023 at Bukit Bakar Forest Eco Park, Machang, Kelantan. A total of 20 senior citizens will participate in a three-day, two-night forest therapy program, which will incorporate various activities including Ancient Malay Exercise and Religious Lectures.

The primary objective of this study is to investigate the effects of the Islamic-inspired forest therapy module on the mental and physical well-being of senior citizens. The participants' blood pressure will be recorded, and they will complete the Positive and Negative Affect Schedule (PANAS) scale and Depression, Anxiety, and Stress Scale (DASS-21) before and after the program. These assessments will enable the measurement of changes in participants' emotional states and stress levels resulting from the forest therapy intervention.

Additionally, qualitative interviews will be conducted with the participants to gather their perspectives on the activities that had the most significant impact on them. This qualitative data will provide valuable insights into the specific elements of the program that resonated with the participants and contributed to their overall well-being.

The findings from this pilot study will serve as a foundation for further research and the development of evidence-based forest therapy programs tailored to the needs of senior citizens, particularly Muslims. By understanding the impact of forest therapy on the mental and physical health of senior citizens, healthcare professionals and practitioners can better support the well-being of this population.

This study contributes to the emerging field of nature-based interventions by exploring the integration of Islamic values into forest therapy modules for senior citizens. The results of this research have the potential to inform the development of culturally appropriate and effective interventions that promote the health and well-being of older adults in a holistic manner.

Evaluation of the restorative potential of urban forest through a forest therapy program

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: More proof is needed to understand the underlying restorative potential of urban and peri-urban forest and how to plan, design, and manage urban forest to optimize their restorative impact. Also, there is a great need to identify and describe specific qualities of urban forest that may support health processes guided by a professional forest therapist. Forest therapy bases have been established in many countries in the world. However, there is a lack of research on forest therapy in Serbia, especially in urban forests. The forest therapy program was designed and implemented to evaluate the perceived psychological benefits of spending structured time at two urban forests in Belgrade. The participants in this study were voluntary students from the fourth year of the Faculty of Forestry (n=18) randomly selected for the study group (n=9) and the control group (n=9). The study group had two hours walk with a forest therapist and control group had a walk without forest therapy program. Participants in both groups were assessed pre- and post intervention using the questionnaire consisting of the Profile of Mood States (POMS) and after the walk, they filled out the questionnaire regarding Perceived Sensory Dimension (PSD). This study indicates that forest therapy in urban forests has clear benefits for human health and well-being.

Exploring the potential of a guided forest bathing programme as a nature-based intervention for well-being, restoration, and nature connection

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Stress-related mental illness is a growing public health challenge worldwide, and Sweden is no exception. Shinrin-yoku (forest bathing) is a nature-based intervention developed in Japan during the 1980s to curb growing incidences of stress-related illness in society. Shinrin-yoku has spread across the world since the 1980s. In Sweden, the Scandinavian Nature and Forest Therapy Institute (SNFTI) provide guided forest baths in accordance with the Eco-Forest Therapy theory, method and guiding skills. The aim of this study was to evaluate how participants experienced a guided Eco-Forest Therapy intervention programme (one a week/3 week) and if participation increased perceived well-being, restoration, and nature connection and decreased perceived fatigue. A sequential mixed methods design was adopted to strengthen the study's results. The intervention was conducted by certified SNFTI guides in a variety of forest settings from the northernmost- to the southernmost parts of Sweden. 124 participants from the general public were enrolled in the intervention programme from the start, and 75 answered all surveys in a correct manner. The results show that the intervention programme had significant positive effects on the participant's perceived well-being, fatigue, restoration, and nature connection and that feelings of well-being, restoration and nature connection seem to be mutually reinforcing. The positive effects are confirmed by the pre-and post-measurements of the whole intervention programme, by the pre-and post-measurements of each forest bathing session and by the results of the interviews. There is particularly strong evidence for the beneficial health effects perceived directly after each forest bathing session, where the standardized mean difference (effect size) is above one standard deviation for all three baths. The beneficial short-term effects are also confirmed in the interviews. The most valued experiences are; finding rest, and reminders of personal needs; the guided group sessions became a safe haven and fascinating nature experiences. The least valued experiences are; feeling pressured to share – and reflect on others´ experiences, disturbing sounds and emotional turmoil when slowing down. The results indicate that forest bathing can be important for supporting human health and well-being. Randomised controlled trials are warranted to confirm this.

Findings from a Mindfulness-based Forest Therapy Intervention for Supporting Individuals with Substance Use Disorder

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Forest therapy has been shown to reduce depression, anxiety and improve overall physical health. However, little is known about the potential of forest therapy for supporting recovery from substance use disorder. Non-profit organization Nature Worx, and a university researcher, measured the effects of forest therapy on individuals in addiction treatment. Our goal is to establish findings regarding the effectiveness of Nature Worx sessions for reducing anxiety, depression, and substance cravings.

Methods

We used a one-group post-test only design to measure attitudes towards nature, and perceived anxiety, depression, and substance cravings before and after a 90-minute session. Sessions were facilitated by trained guides who lead experiential activities promoting connection with nature. After each session, participants complete a survey assessing levels of anxiety, depression, and substance cravings. All participants (N=821) were enrolled in an inpatient or extended residential program, between March 2020 and April 2022. All descriptive and bivariate analyses were conducted using STATA 16.

Results

Respondents experienced a mean 1.15-point reduction in anxiety (on a 1 to 5 scale) from pre- to post-intervention. Similarly, respondents reported reductions in depression (M=.74) and substance cravings (M=.43) after one session. A comparison of average change scores by baseline cravings indicates that respondents who reported “somewhat high” to “very high” cravings before the session experienced a significantly greater reduction in cravings compared to those with “very low” to “moderate” baseline cravings ($t(786)=-11.31$, $p < .00$). For those with high cravings at baseline, the average change from pre- to post-intervention was 1.4 points (SD=.16). Additionally, 89% of participants reported feeling more connected to the natural world, and 95% learned ways that nature could support their recovery.

Conclusions and Implications

These findings indicate the average participant experienced reduced anxiety, depression, and substance cravings after participating in a session. Additionally, the greatest reductions in cravings were found among the highest risk group, suggesting Nature Worx sessions may curb strong cravings. The majority of participants understood how nature could support their recovery, demonstrating the sessions give participants tools to use. Nature Worx sessions are affordable, accessible, and could be a sustainable supplement to traditional forms of substance use treatment.

Forest Bathing in Canada: A Randomized Controlled Trial Investigating Environmental Influence on Health

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Forest bathing, a nature-based therapeutic practice originating in Japan, has gained recognition for its significant mental and physical health benefits. However, the influence of environmental factors and the effectiveness of different forest bathing techniques on health outcomes remains understudied, particularly in North America. To address this research gap, we led a year-long randomized controlled trial in Vancouver, British Columbia, a city characterized by abundant, diverse urban green spaces and biodiversity.

While respectfully acknowledging the enduring connection of Indigenous Peoples connection to the land and their historical practices that resonate with forest bathing, our study focused on the health outcomes of two contemporary forest bathing techniques: guided and self-guided multisensory immersion. Interventions took place across four diverse urban forests in Vancouver, spanning all four seasons, and health impacts were evaluated using physiological and psychological measurements.

This study sheds light on the intricate relationship between individuals and their environment, providing insights into how it shapes health outcomes in the context of forest bathing in Canada. The findings have far-reaching implications for public health policy, urban planning, and forest management, particularly in cities rich in green spaces like Vancouver. Furthermore, our findings can inform the development of more personalized forest bathing interventions.

By highlighting the critical role of urban forests in promoting health and well-being, this study contributes to interdisciplinary research bridging forest science and health. It adds to the growing body of knowledge on forest bathing while underscoring the importance of considering environmental factors for designing effective nature-based interventions.

Forest Therapy for Women with Gynaecological Cancer—A Feasibility Study to Find New Alternatives in Cancer Rehabilitation

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Psychosocial support during cancer rehabilitation has proven to be insufficient and nature-based treatment is one of the alternatives mentioned as the way forward. In an ongoing study we offer women suffering or recovering from gynaecological cancer participation in a ten-week forest bathing intervention, as an add-on to the standard care. Our aim is to evaluate the patient's experience of the intervention, and whether it can improve general health and well-being.

The study started in the autumn of 2022 and is planned to continue until the end of 2023. It is a prospective single-case study, including quantitative and qualitative approaches using validated self-administered instruments (pre–post measurements) and semi-structured interviews (post) on women's lived experience of the intervention. The quantitative outcome measurements will be the quality of life, fatigue and depression/anxiety. There is also a questionnaire on perceived sensory dimensions experienced in the forest environment. The study will include 24 participants, divided into four groups of 6 participants. Once a week for ten weeks, the participants will be offered a session of a 2.5-hour stay in the forest with breathing exercises, slow movement, time in silence and privacy and a social gathering to conclude each session.

Up to this date one group of participants is completed, one group is ongoing and two more groups are planned to start in the late summer and autumn of 2023. Spontaneous feed-back from the participants has been encouraging. Data will be analysed in the spring of 2024 and presented at the congress.

To our knowledge, this is the first study on forest bathing for cancer survivors in Sweden.

Healing Power of Nature: Forest Therapy in the Modern Era

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: In our modern, fast-paced, urbanized world, we often find ourselves overwhelmed by stress, anxiety, and various mental health challenges. The healing power of nature has long been recognized as a potent remedy for these afflictions. This talk delves into the transformative effects of immersing oneself in nature, particularly the therapeutic benefits of forest environments. The presentation will explore how forest therapy can positively impact our physical, mental, and emotional well-being: 1) the physiological effects of spending time in forests, such as reduced blood pressure, decreased stress hormone levels, and enhanced immune system functioning; and 2) the psychological benefits from forest bathing, including improved mood, increased attention span, and boosted creativity resulting from immersing oneself in a forest's calming and awe-inspiring environment. While exploring the practice of forest therapy, we delve into various techniques and mindfulness exercises that can be employed to engage with the forest environment fully. We discuss the importance of sensory awareness, deep breathing, and mindful walking for cultivating a mindful and enriching forest bathing experience. The talk also highlights how to integrate these techniques into their own lives, allowing them to harness the healing power of nature for their well-being.

How forest social prescribing can provide opportunities and benefits to participants and providers of nature based interventions

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Social prescribing has risen up the agenda in Britain in recent years. In England the National Health Service employed one thousand link workers to match people with a range of problems (psychological and physiological) to community-based activities that can benefit their health when medication is not needed or not the complete answer to the issues they face. Nature based interventions that consider the health needs of individuals who need support have increased in recent years as well. Forestry England and Sport England (both government bodies) developed a partnership programme called Active Forests in 2014. In 2019 as part of the programme a green social prescribing pilot project called 'Feel Good in the Forest' was developed focused on two forest sites in urban areas. A range of activities were developed as part of the pilot project from seated exercise, Nordic walking, reading ramblers, archery, to walking football. An evaluation of the pilot project involved focus group and interviews (n=52) with participants, organisation representatives and exercise providers, and surveys were completed by participants (n=103). There was a total of 6,183 visits during the pilot project by 265 people. The qualitative data revealed some significant impacts for participants particularly in terms of their mental wellbeing, social connections, self-confidence, and self-esteem. The survey results show that participants in the pilot were less happy and more anxious than the general population in England and therefore these were the type of participants that the project was aiming to engage with. Interviews with NHS referral agents and providers of activities such as Age UK highlighted the calming atmosphere of the forest as an important element of the project and as a space in which people felt more comfortable being active as they viewed the forest as a non-judgemental place. There are lessons to be learnt on the use of questionnaires that explore mental wellbeing as these can seem intrusive to participants when they first participate in the project. The findings reveal the benefits and challenges of the intervention for both participants and those involved and delivering the project, providing insights for future improvements of similar interventions.

Managing stress among middle-aged working women through forest therapy approach

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: This study aims to determine the effects of forest therapy on the stress levels of middle-aged working women. Nineteen middle-aged working women (54.80 ± 0.68 years old) participated in a half-day forest therapy program conducted at Bukit Ekspo; A tree-dominated urban park located at the centre of Universiti Putra Malaysia. For the physiological indices, the systolic blood pressure (SBP), diastolic blood pressure (DBP) and pulse rate of the participants were evaluated three times a day; Before breakfast, lunch and dinner. The readings were obtained two days before, during and three days after the forest therapy program. The physiological readings obtained two days before the study served as the baseline reading, as it represented the normal, everyday physiological condition of the participants. The baseline SBP (124.16 ± 0.79mmHG) and the baseline DBP (81.89 ± 0.50 mmHg) of the participants were beyond healthy levels, falling into Stage 1 hypertension. The mean SBP of the participants significantly reduced during the forest therapy day (118.72 ± 0.67mmHG) and three days after the forest therapy day (119.51 ± 0.79mmHG). This reduction was also observed for the DBP readings, whereby the mean DBP readings for the forest therapy day (78.65 ± 0.44mmHG) and three days after (78.47 ± 0.48mmHG) were lower than the baseline values. There were no significant changes in the pulse rate. For the psychosocial perspective, the participants self-evaluated themselves to determine the effects of forest therapy on their mental wellbeing. Only 16% of the participants believed that they successfully performed self-regulation when faced with stressful situations, although 74% of the participants admitted to experiencing stress on a daily basis. After participating in forest therapy, the majority of the participants felt rejuvenated and more at ease at work. In conclusion, forest therapy is an effective stress management tool for middle-aged female employees.

Natural Forest, Cultural Forest, or Urban Landscape? Effects of Different Environment Types on Stress Recovery in Virtual Reality

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Despite a number of studies have demonstrated the benefits of forest therapy on people's health, few have focused on the potentially different effects between natural and cultural elements in forest therapy sites. Therefore, a laboratory-based study was conducted to explore whether environmental types in forest therapy sites could produce different stress recovery effects. The environmental types of Chinese national forest therapy sites were classified into two types, forest natural landscape and forest cultural landscape, based on the Chinese "National Forest Therapy Site Quality Assessment Standards (LY/T2934—2018)" and the landscape characteristics of forest therapy sites, with urban landscape as the control group.

172 university students took part in a stress induction task before being randomly assigned to view a video in virtual reality (VR) environment for 6 min: (a) forest natural landscape video; (b) forest cultural landscape video; (c) urban landscape video. Heart rate (HR) and electrodermal activity (EDA) were selected as physiological indicators while Visual Analogue Scale (VAS) and Short State Anxiety Inventory (SSAI) were selected as psychological indicators.

Results showed that all three environment videos can significantly reduce stress, with HR, EDA, VAS, and SSAI all significantly lower than before the exposure. Meanwhile, forest natural landscape and forest cultural landscape had better improvement in nature connectedness and greater perceived environmental restorativeness than urban landscape. Although there was no significant difference between the three groups on physiological indicators, forest natural landscape and forest cultural landscape had better stress recovery benefits in VAS and SSAI than urban landscape, which were mediated by increasement in nature connectedness and greater perceived environmental restorativeness.

Our findings provide evidence for the construction of forest therapy sites as well as the stress management utilizing virtual reality device.

Keywords: Forest therapy, Forest therapy sites, Virtual reality, Restorative effects, Stress recovery

Natural Resource Management and Livelihood Change in National Park Communities in China

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: A national park based protected area (PA) management system has been set up in China, with a policy target of biodiversity security and providing ecological services to the public, while fully securing the conservation of natural ecosystems.In the past, the management of China's PA system focused on eliminating human impacts and achieving biodiversity security. However, China has a large number of local residents within PAs. In some regions, the disagreements between local residents and conservation management agencies were intensified into conflicts under the high-pressure environmental inspections from the central government since in 2018. How to reduce the conflicts between biodiversity conservation and economic development in and around PAs has become an important issue for the government, the local residents and the public. With the establishment of national parks, the intense conflicts between the PA management agencies and local residents have gradually been released in some areas. By using a qualitative research method, this study explores the factors for this shift with multiple national park cases in China. It is found that except the changes of conservation policy, the dramatic economic and social changes taking place in China also played a significant role.

NURTURING WELLNESS: UNVEILING THE HEALING POWER OF FORESTS ON MENTAL HEALTH AMIDST POST-PANDEMIC CHALLENGES

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: The Himalayas have long captivated individuals with their majestic peaks, lush forests, and serene natural beauty, providing solace and inspiration. As urbanized societies continue to seek refuge in these mountainous landscapes, recognizing the potential of the Himalayas to enhance human well-being becomes crucial, especially in the aftermath of the COVID-19 pandemic resulting in stress, depression, and other mental health disorders. This study investigates the transformative potential of forest therapy as a tool for post-pandemic well-being and sustainable tourism in the Kumaon Region of Uttarakhand Himalayas in India.

The study aimed to gain insights into the experiences and perceptions of tourists who participated in forest therapy programs following prolonged periods of lockdown, social distancing and isolation. By employing surveys, interviews, and psychological assessments, the research examined the effectiveness of forest therapy in mitigating the psychological burdens caused by the pandemic and subsequent stressors. Specifically, the study explored the impact of forest therapy as a key approach to reduce **pandemic-related anxieties, depression,** and **post-traumatic stress disorders (PTSD)** within the unique context of the Mystic Himalayan Woodlands.

The results indicate that forest therapy in the Himalayas emerges as a powerful intervention for post-pandemic well-being, with significant **reductions in stress levels, alleviation of depressive symptoms,** and **enhanced psychological resilience.** The picturesque landscapes and serene natural beauty of the Himalayan forests provided participants with a restorative sanctuary to reconnect with nature, facilitating a sense of tranquillity, relaxation, and rejuvenation. Bridging **forest therapy and medical tourism** can play a crucial role in providing sustainable **livelihood opportunities to the communities** by harnessing the benefits of the therapeutic qualities of nature.

As a major outcome of this study presents that by harnessing the healing power of the Himalayas and promoting forest therapy as a **transformative approach** to well-being and **sustainable tourism**; policymakers, practitioners, and tourism stakeholders can foster a harmonious relationship between nature, and well-being. Incorporating forest therapy into sustainable tourism practices and **public health frameworks** can create a balanced and resilient future, promoting the well-being of both visitors and the **Himalayan ecosystem.**

Keywords: Himalayas, forest therapy, well-being, sustainable tourism, COVID-19, post-pandemic, mental health.

Shinrinyoku (forest bathing) followed by the Japanese tea ceremony

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: This study examines the integration of shinrinyoku and the Japanese tea ceremony to promote well-being in daily life.

"Shinrinyoku" is a term coined by the Forestry Agency of the Government of Japan in 1982, aligning with existing terms such as "seawater bathing" and "sunbathing." It has become rooted in Japan due to its historical and cultural association with forests. Shinrinyoku practice has extended beyond Japan. For instance, in Wisconsin, USA, Kate Bast, an Association of Nature and Forest Therapy (ANFT) guide, initiated Shinrin-yoku Madison in early 2019, conducting private and group walks through forests. Additionally, the Natural Resources Foundation in Wisconsin, a non-profit organization, included shinrin-yoku fundraising field trips annually. The ANFT approach to forest therapy often concludes with tea brewed from wild herbs collected by the guide.

The Japanese tea ceremony originated from China and was initially employed for medicinal and ritual purposes by Buddhist monks. By the 16th century, the ceremony underwent a transition, with utensils being replaced by simpler Japanese items, including bamboo and wood. The traditional tea-making procedures, which emphasize mindfulness, have been handed down through generations and have naturally integrated into everyday life activities. In a formal tea ceremony, which includes a light meal, guests can enjoy a forest garden leading to the tea room.

In 2021, the authors initiated the combination of shinrinyoku and the Japanese tea ceremony. These practices, originating from Japan, share similarities.

1. Being present: Both practices emphasize full presence in the moment, immersing oneself in the surroundings and engaging the senses to become aware of the natural environment.
2. Increasing sensitivity: Both practices aim to enhance well-being through the connection with nature. Shinrin-yoku directly provides an opportunity for individuals to reconnect with nature.
3. Inner calm: The slow walking in shinrinyoku and the deliberate movements of the tea ceremony can induce a state of tranquility and mindfulness.

We anticipate that the integration of shinrinyoku and the Japanese tea ceremony will serve as an effective practice for fostering a deep connection to nature, allowing participants to closely observe and interact with the natural wooden items used in the tea ceremony.

The contribution of green pharmacy towards cancer management: Case study of Zanthoxylum paracanthum Kokwaro (Rutaceae) in Kenya

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: *Zanthoxylum paracanthum* Kokwaro (Rutaceae) is an endemic Kenyan and Tanzanian plant used in folk medicine by local populations. Although other *Zanthoxylum* species have been studied, only *Z. paracanthum* stem extracts have been profiled, even though the roots are also used as herbal remedies. The dichloromethane/methanol (1:1) root bark extract was studied in this report. Eight root bark compounds were isolated and their structural identities were confirmed by mass spectrometry (MS) and nuclear magnetic resonance (NMR) (using COSY, HSQC, NOESY and HMBC) analyses. The structural identities were determined as follows: the fatty acid, myristic acid (**1**); the sterol, stigmasterol (**2**); the lignin-sesamin (**3**); two carboline alkaloids, 10-methoxycanthin-6-one (**6**) and canthin-6-one (**7**); and three phenanthridine alkaloids, 8-acetonyldihydrochelerythrine (**4**), arnottianamide (**5**) and 8-oxochelerythrine (**8**). Some of these compounds were identified in the species for the first time. These compounds and the extract were then tested in vitro for antiproliferative activity against the human breast cancer (HCC 1395), human prostate cancer (DU 145) and normal (Vero E6) cell lines. The root extract and some of the compounds had antiproliferative activity against the HCC 1395 cell line. Stigmasterol and canthin-6-one had IC_{50} values of 7.2 and 0.42 indicating the high potential present in these chemicals in cancer management. The root bark extract also showed activity, at 8.12 g/mL, against the HCC 1395 cells. Out of the chemical isolates, 10-methoxycanthin-6-one and canthin-6-one showed the strongest inhibition of the DU 145 cells. The root extract had significant antiproliferative activities, supporting the traditional use of this plant in treating cancer-related ailments.

Keywords: *Zanthoxylum paracanthum*, anticancer activity, medicinal plant, phytochemistry, traditional medicine

The Effects Of Forest Therapy On The Cognitive Performance Of University Students

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: This study examined whether short weekly forest therapy sessions could enhance the cognitive performance of university students. Twenty undergraduate students participated in the study, which took place at an urban forest in the University Putra Malaysia Bintulu Sarawak Campus. Participants were randomly assigned to either a forest therapy group (FTG) or a control group (CG), with ten students in each group. The FTG received 30-minute forest therapy sessions twice a week (eight sessions in total), while the CG continued with their regular daily activities during the study.

During each session, the FTG engaged in one forest therapy activity, such as sensory enjoyment, leisurely walking, or breathing exercises. The QuantifiedMind web-based cognitive test was used to measure participants' executive function, working memory, and reaction time before and after the study. Two tasks were assigned for each cognitive function, and paired T-tests were used to analyze the results. Additionally, an exit survey was conducted to gather FTG participants' feedback on their forest therapy experience.

No significant changes in cognitive performance were observed in the CG. However, after four weeks of forest therapy sessions, the FTG demonstrated significant improvements ($p \leq 0.05$) in executive function and working memory. Both executive function tasks showed significant improvement: sorting (377.94±94.89, $p = 0.022$) and coding (364.86±141.42, $p = 0.042$). Similarly, both working memory tasks improved: design copy (473.28±59.71, $p = 0.040$) and visual back digit (386.49±102.72, $p = 0.007$). However, there were no significant differences in both reaction time task.

FTG participants reported that the earlier forest therapy sessions had little impact on their mental health, but as they became more familiar with the practice, they experienced an improvement in their ability to manage everyday stress.

In conclusion, this study shows that one hour of weekly forest therapy sessions can positively impact the cognitive performance of university students. The results suggest that universities should consider incorporating forest therapy into their wellness programs to provide students with an enjoyable, low-cost, and effective method of managing stress and improving cognitive performance.

The emerging global network of forest therapy guides

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Over the past 12 years a global network of trained forest therapy guides has emerged. Inspired by Japanese and Korean practices, a wide range of variations on forest therapy have been developed and deployed, largely by entreprenurial companies and leaders in the field. The goals of forest therapy practitioners range from enhancing the health- and well-being of individuals affected by stressful lifestyles, to developing relationships between forests and humans for the purpose of promoting global health. This session is aimed at promoting dialogue between forest management professionals and forest therapy researchers and practitioners.

Using Campus Forest for Students' Psychological Well-being

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: University students are in a transitional period of transition from adolescence to adulthood and s face problems such as adaptation to new environments, intense interpersonal competition, academic difficulties, and uncertain future, etc. Forest therapy is considered an effective way to improve students' mental health. Many researchers have investigated the effectiveness of forest therapy programs for diversed target populations. However, very few study has been conducted forest therapy effectiveness for university students. This study performed to investigate students' psychological benefits, such as academic stress and self-esteem, from forest therapy program using campus forests.

The study employed a randomized 3 × 3 crossover study. Twenty-three university students were randomly assigned into three groups to eliminate the order effect. Twenty-three university students were randomly exposed to three conditions: a self-guided forest therapy program, a guided forest-therapy program, and routine activities. All participants participated in all interventions once a week for three weeks, and each intervention was conducted over a one-week washout period to eliminate the carryover effect of the intervention. Measures included the Positive and Negative Affect Schedule (PANAS), the Rosenberg Self-esteem Scale (RSES), and the Connectedness to Nature Scale (CNS).

As a result, forest-therapy programs significantly improved participants' negative emotions and self-esteem. This study also shows that not only guided forest therapy programs but also self-guided forest therapy programs have a positive effect on psychological health. Therefore, these findings suggest that running guided forest therapy programs and self-guided forest therapy programs as university in-campus programs will significantly help university students' mental health.

What is A Better Way to Achieve Recovery in A Forest? An Experimental Comparison of Forest Therapy Activities and Forest Walks

T4.15 Healing Power of Nature: Forest Therapy in Action

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Abstract: Forest therapy has been recognised as a preventive therapy with a restorative effect. In China, forest therapy activities in forests by forest therapists are now a popular form, and the profession of forest therapist has been included in the Chinese Professional Register. However, it is a question of whether the restorative effect of the forest is a result of the activity or of the environment itself. To this end, the aim of this study was to investigate the difference between the physical and psychological restorative effects of forest therapist-led activities and forest walks, and the possible causes of the restorative effects.

A pre-post field experimental design was used to assess restorative effects by measuring physiological indicators (blood pressure, heart rate variability) and psychological states (nature connectedness, perceived restorativeness, positive emotions, state anxiety) produced during different types of forest therapy programs. Mediation was also used to analyse the possible causes of the restorative effects. 247 university students were randomly assigned to spend 1.5 hours on an approximately 1.5 km long forest path in two groups: a) the activity group was led by a forest therapist with activities focusing on the five sensory experiences; b) the walking group was given a free walk.

The results showed a significant decrease in systolic blood pressure and state anxiety, and a significant increase in sympathetic nervous activity, nature connectedness and positive mood in both groups. There were no significant differences between the two groups on any of the indicators. We found that nature connectedness significantly predicts the reduction of state anxiety, and that this prediction was also mediated by perceived restorativeness and positive mood.

We suggest that the restorative effects of forest therapy are significant regardless of the type of program. It is also recommended that forest therapy activities should be designed to increase participants' sense of nature connectedness and positive mood. For those who are unable to participate in forest therapy activities led by forest therapists, walking alone in the forest may also have restorative effects.

Keywords: Forest therapy program, Nature connectedness, State anxiety, Restorativeness, Mediation analysis

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

Active resource use is the basis for restoring and sustaining Broad-leaved woodlands across Africa'

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Regeneration and growth to maturity are key elements of sustainable resource use in natural forest systems, as in plantation forestry. However, perceived needs for their protection constrain such active use from natural forest systems. Zambezian and Sudanian broad-leaved seasonal woodlands represent the most extensive natural forest systems in Africa. They are dominated by strongly light-demanding canopy tree species with vegetative regrowth from rootstocks and cut stumps as main regeneration strategy (many canopy tree species show good regeneration from seed). Sustainable use of their products, values, and services is critical to sustain the livelihood needs of millions of people across Africa.

We present information from various comparative observations and time series studies (Zambezian Region) and experimental studies (both regions). The latter assessed thinning intensity (0 to 100% stem cutting) within stand development stages (early Stage 1 to advanced Stage 3). Mature stands (Stage 4) were excluded because of limited presence. Experimental thinning showed the woodlands suffer from protection. The time-series study in Zambian Copperbelt Miombo assessed recovery of biodiversity, productivity, and diverse resource use value over 15+ years in land uses of protection, single-tree timber harvesting, slash-and-burn traditional agriculture, and charcoal production. Contrary to general perception, the best to worse land use systems were charcoal production, slash-and-burn traditional agriculture, single-tree timber harvesting, and protection! Stem diameter growth (based on growth rings) was 0.5 to 2.0 cm/year in young regrowth stands up to stage 3 of up to 15,000 stems/ha, with no silvicultural treatment. In Sudaniand woodland, 60% thinning produced highest biomass production (0.88 t/ha/year) and tree height growth (in Stage 3).

Based on the results, we advocate selective stem thinning in Stages 1 to 3 (cutting suppressed and deformed stems, with branch-pruning remaining stems), and group-felling in mature Stage 4 (generally without active regeneration of canopy tree species). The proposed gap size in group-felling is 3-5 times the height of mature woodland - to provide ample light for diverse and productive shoot growth from cut stumps. Forest landscape restoration is synonymous with active resource use. It is like managing eucalypt plantations but in much more diverse natural broad-leaved woodlands.

Adoption and the Role of Fertilizer Trees and Shrubs as a Climate Smart Agriculture Practice: The Case of Salima District in Malawi

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Fertilizer trees and shrubs can improve degraded soil and avert the impacts of climate change on smallholder farmers in Malawi. This paper analyses the roles of fertilizer trees and shrubs and factors that determine adoption, as well as the intensity of use of fertilizer on trees and shrubs in maize-based farming systems using the Tobit model. A household survey involving 250 smallholder farmers was conducted in Salima district, Malawi. The analysis shows that adopters of fertilizer trees and shrubs considered fertility improvement, shade, source of food and erosion control as main roles of fertilizer trees and shrubs. The Tobit model shows that households with relatively more land are more likely to adopt fertilizer trees and shrubs than those with small land sizes. Adoption is higher among farmers who had been exposed to fertilizer trees and shrubs for longer periods than others had. Land tenure, education and availability of labor also influence the adoption of fertilizer trees and shrubs. Results further show that household and farm characteristics and availability of extension services explain the current adoption rates of tree-fertilizer technologies. Our findings can guide effective targeting of farmers to ensure higher adoption and sustainability of fertilizer-tree and shrub technology for climate-smart agriculture among the smallholder farmers.

Between the red lines: The effect of historical agricultural zoning policies on dry forests and rural welfare in Namibia

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Rural livelihood strategies are highly context dependent. This makes cause-effect relationships between poverty and natural resources, such as forests, chronically hard to establish empirically. Key contextual determinants of the relationship between poverty and the environment are known to include bio-geophysical and socio-economic factors, but crucially also cultural and historical trajectories. One way to infer on the role of these factors in shaping interactions between rural poverty and forests is to study the dynamics of these outcomes under different policy regimes, while holding other factors constant. Here we exploit a unique historical policy experiment that is likely to have had a lasting effect on land cover and rural poverty in Namibia. Long before Namibian independence, ruling authorities had divided the Namibian territory into two zones that allowed for different types and modes of agricultural activity. The location of the line that separated the two zones was changed several times due to political and veterinary reasons. We use the historical spatiotemporal variation in this agricultural zoning policy in a spatial regression-discontinuity design to explore heterogeneous impacts on rural welfare and vegetation dynamics. Preliminary results suggest that changes in the red line policy are likely to have partially contributed to substantial differences in todays rural wealth distributions with implications for the integrity of dry forests in the region. We discuss research needs and policy implications with a particular emphasis on the role of agency and power as determinants of rural poverty via land as well as market access and distribution mechanisms.

Forest incomes in Tanzania, Kenya and Namibia: a pathway 'out of poverty', towards aspirations?

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: The tropical dry forests (TDFs) of southern and eastern Africa are critical to the livelihoods of the world's poorest households. Their timber and non-timber products provide 15-44% of household income in the region and their ecosystem services irreplaceably support the agricultural systems on which smallholder farmers depend. However, TDFs are under threat: tree cover declined 11% in Tanzania, 32% in Namibia and 14% in Kenya between 2000 and 2021.

Poverty traps, alongside population growth, are major drivers. Poor access to credit and savings prevents the accumulation of capital, preventing future access. Raising the 'effort' needed to succeed, poverty also reduces individuals' aspirations, investments and chances of success. In this context, the literature suggests poor households turn to fuelwood to consume or sell so to i) meet daily consumption needs, ii) provide a safety net in times of shocks and potentially iii) provide a 'pathway out of poverty'. The latter refers to the accumulation of capital to specialise or diversify livelihoods but empirical evidence appears inconclusive.

This paper implements a novel approach to determine whether informal forest incomes provide a 'pathway out of poverty' for 2,228 households in Tanzania (Morogoro, Iringa regions), Namibia (Zambezi region) and Kenya (Baringo County). Linear and censored regression models are applied to survey data to analyse whether asset and social status aspirations lead households to raise their share of forest income in total income as a means to increase farm investment when credit or savings may be unavailable.

Results suggest that aspirations make households more likely to invest on-farm, with farming households in Namibia increasing expenditure and their Tanzanian and Kenyan counterparts diversifying. While poor households depend more on forest incomes, higher shares of forest income only increase spending a very small amount in each country. Accordingly, aspirational households do not substantially raise their shares. The case for a substantial 'pathway out of poverty' is therefore weak. Policy implications emphasise 1) informal forest incomes are no substitute for formal investment support and 2) addressing poverty's constraints on aspirations could contribute to sustainable livelihoods with at least no direct detrimental (albeit limited positive) impact on TDFs.

Incorporating Regeneration dynamics in developing Sustainable Silvicultural systems: A pathway to towards improved livelihood in the Zambezian region

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Many rural economies in Southern Africa are premised on subsistence exploitation aspects such as charcoal production and shifting cultivation. These aspects of woodland exploitation have been perceived as the major contributors of forest degradation, deforestation and biodiversity loss. Currently, many governments are putting a lot of efforts on ensuring that these aspects rather done away with. This is because specific studies on regeneration mechanisms of the Zambezian vegetation have been limited yet integrating the knowledge of these is a pre-requisite for developing appropriate silvicultural management regimes of this Southern African vegetation formation. Our study examined the different regeneration mechanisms tree species in the two vegetation formations (Biakiaea and Miombo) of the Zambezian region by excavating the around plants and assessing the aerial and basal sprouts within a number of plots along transects in different age classes of different disturbance categories: for example, among 63 species studied in the Miombo woodlands, 41 were observed to to regenerate through coppicing while others regenerated from both seed and root suckering. Significant difference in terms of the influence of regneration mechanisms on shoot collar diameter and height development were observed with coppicing ($p < 0.001$) and true seedling ($p < 0.001$). The variation in regenration mechanisms and associated influence on shoot development has a direct implication on developin sustainable silvicultural systems for the Zambezian region. The presentation disccuses how management of the Zambezian region for rural livelihood would require a strategy that incorporates regeneration mechanisms in planning such systems

Introduction to the session poverty alleviation and forest integrity in tropical dry forests

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Tropical dry forests are heavily threatened by deforestation, degradation and climate change. They are particularly affected by fuel wood extraction, exploitation of high value timber species, grazing and browsing, and conversion into agricultural land. Additionally, they are increasingly exposed to fires, as consequence of climate change and land use pressure with severe consequences for water availability, food security and livelihoods. Especially in poor countries and rural areas TDF are an essential basis for livelihoods. More than 2 billion people depend on wood fuel for their daily cooking and heating. While TDF are frequently considered as safety net for the poorest, others see TDF as a poverty trap. There is an urgent need to fill ecological and management research gaps and develop strategies towards a paradigm shifts for sustainable management. In this presentation we give an introduction to the session, highlighting the most important research question which shall be addressed: Is there evidence for management practices in TDF which foster livelihoods, maintain forest integrity and enable long term sustainable development pathways?

New knowledge for the restoration of endangered tree species in the Tropical Dry Forest in Colombia.

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: The conservation and protection of native endangered tree species is fundamental to guarantee, not only the existence of all the components that interact in an ecosystem, but also the ecosystem services provided by the tropical dry forest (TDF). For 8 years we have evaluated the behavior of four tree species of high use value by farming communities in the Colombian Caribbean region: *Aspidosperma polyneuron* Müll.Arg (Carreto), *Caesalpinia ebano* H.Karst. (Ebano), *Peltogyne purpurea* Pittier (Tananeo) and *Bulnesia arborea* Jacq. (Guayacan). Seed germination rate (GR), survival (S) and growth in height (HT) and Normal Diameter (ND) were determined. In 2007 these species were registered in the Red Book of threatened plants in Colombia with a high degree of vulnerability, mainly based on the reduction of native populations, high demand for their wood and lack of knowledge about their behavior. In this study, the GR, S, HT and ND parameters have been quantified; In addition, a height growth curve by species was made for the observation period. When evaluating different pre-germination treatments, no statistically significant differences were found between the treatments, in any case exceeding 50% seed germination rate. On the other hand, at the age of 8 years, survival ranged between 86% and 95%. Regarding the development in height and diameter, *C Ebano* was the species with the best behavior, with a record of 11.3 meters and 13.1 cm respectively. The other species reached height records ranging between 5.2 and 7.6 meters, with diameters between 6.7 and 10.9 cm.

Based on the results obtained, we can conclude that the restoration of the species is possible, based on the knowledge of its performance, its high use value and motivated by its degree of threat. However, it is necessary to deepen in terms of knowledge about the management of species, increase the support of local institutions for reforestation programs, conservation strategies and protection of native populations located on farms dedicated to livestock and agricultura.

Policy, legal and financial environment for promoting Non-Timber Forest Products in Africa

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Non-timber forest products (NTFPs) from forests or tree-based systems have been found to be crucial to enhancing livelihoods for millions of households in rural Africa. They help meet subsistence household needs for food, nutrition, income, and health and provide important alternative employment and sustenance opportunities during crises. NTFPs are also developed into commercial products and have contributed to development of pharmaceutical, biotechnology, cosmetics, therapeutic, and foods and beverages industries. Thus, the potential contribution of NTFPs as a basis for economic development including poverty reduction in African countries cannot be overemphasised, especially in the context of growing focus on green and inclusive growth. However, despite their potential NTFPs have both been overlooked and poorly regulated by governments. The policy and legislative frameworks and institutional arrangements in most African countries have been inadequate at facilitating optimal harnessing of the value of NTFPs. These weak links require strengthening. African Forest Forum studies and a review of literature on initiatives in some African countries on development of NTFPs reveal that many countries' accounting practices do not reflect their full economic values because they are almost exclusively in the amorphous informal sector. As a result, the economic system offers no incentive to preserve NTFPs that are not reflected in national accounts. The NTFPs are almost seen as common property, hence regulations governing access to NTFPs and intellectual property rights have not adequately addressed the needs and rights of custodians of these biodiversity resources. Further, in most cases, discussions on commercial exploitation are focused on theoretical treatment of the likely profitability of bioprospecting as an economic activity. The full potential for NTFPs is also not being realized because of factors related to insufficient research funding from governments and the private sector, and limited access to capital, technology and markets by local actors. This paper posits that functional policy, legislative and institutional frameworks are key to the sustainable development of the NTFP sub-sector of the forest economy in Africa for improved incomes to local communities and countries, thus, incentives for their conservation and management.

Public policies and social actions to prevent the loss of the Chiquitano Dry Forest

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: The Chiquitano Dry Forest (CDF), with an area of around 23 Mha distributed between Brazil and Bolivia, is located in a transition zone between the Amazon rainforest and the dry forests of the Chaco and Cerrado. Biodiversity in this forest is very high and at least 70 species are of global conservation concern. The CDF is catalogued as one of the largest and best conserved Tropical Dry Forests in the Americas. Currently, this unique forest is highly vulnerable and under considerable pressure, which should generate global attention, considering its importance in terms of biodiversity, climate change and social impacts. Despite efforts made for more than two decades to prevent the loss of the CDF on the Bolivian side, the processes of deforestation and forest fragmentation caused by agricultural expansion and forest fires have continued to put its ecological integrity at high risk. Our study highlights deforestation in the CDF, outlines its socio-economic and environmental importance and provides recommendations from the local experience. We identified that until 2020, accumulated deforestation in the CDF reached a total area of 2.7 Mha. Moreover, in the last years wildfires have affected an area of around 2.4 Mha. We propose critical courses of action from the local experience with a strong integrated approach, including: (i) adjustments to public policies that encourage deforestation and strength environmental governance (ii) adequate land planning and management with focus on reaching economic targets while minimizing environmental effects, (iii) creation of protected areas and strengthening and better management of existing ones (iv) raising public awareness through environmental education and effective communication highlighting the real value of forests and the importance of intact ecosystems. The CDF faces a critical moment and requires urgent global and national coordinated actions and commitments at all levels to combat deforestation and forest degradation.

Reviewing the evidence on the roles of forests and tree-based systems in poverty dynamics

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Many rural people experiencing poverty often rely on forests and tree-based systems, such as agroforestry, suggesting the existence of links between such systems and poverty outcomes. This paper reviews the evidence of such links across multiple dimensions of poverty and well-being, based on an expert panel convened by the International Union of Forest Research Organizations (IUFRO) and an extensive literature search. We consider whether, how, where, when, and for whom forests and trees in the wider landscape influence poverty dynamics. We organize the evidence according to four pathways through which forests and trees influence household poverty dynamics: 1) helping households move out of poverty; 2) maintaining well-being levels through subsistence, food security, health, and cultural and spiritual values; 3) preventing declines by mitigating risks and stabilizing consumption; 4) decreasing well-being by generating negative externalities that could trap or move households into poverty. We found that local context matters considerably, with the roles of forests and trees strongly varying across geographical, social, economic, and political settings. Another key finding is that evidence of forests and trees providing livelihood diversification and benefits that help households move out of poverty remains limited, based primarily on a small number of case studies. Evidence on the impact of gender gaps in relation to forest landscapes and poverty pathways is also lacking. However, our findings do suggest that ecosystem services provided by forests and trees play critical roles in maintaining well-being and food security and have the potential to contribute more to helping households move out of poverty and mitigating risks amplified by climate change. This review also highlights cautionary findings related to negative forest externalities that can maintain or move households into poverty. Together, these findings call for policy efforts to support the conservation and sustainable management of forest landscapes and agroforestry systems that are more targeted towards meeting the diverse needs of the rural poor. Our results also point to a need for greater effort to address gender disparities, which have been largely overlooked yet provide a critical opportunity to not only enhance gender equality but also advance sustainable poverty reduction goals.

Strategies towards multifunctional, biodiverse and sustainable productive dry forests in Uruguay

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Shifting the scientific gaze from merely natural ecosystems to human-modified landscapes regarding biodiversity conservation is an important goal to meet global challenges. Within the South American dry forests, the so-called park forests are composed of native xerophilous trees growing in a dense herbaceous stratum in the transition between natural riverine forests and open grasslands in Uruguay. As in the majority of dry forests worldwide, park forests have been destroyed because of agricultural expansion, over- grazing and selective wood extraction for fuel. Quantitative biodiversity studies and the underlying mechanisms driving tree regeneration are scarce. Assessing these contributes to the development of strategies to design multifunctional landscapes in agri- and silvicultural landscapes and provide valuable information for the management of one of the most threatened and poorly studied dry forests of Uruguay. We studied patterns of tree regeneration and biodiversity across park forests. Scattered trees exert parental care in highly modified agricultural and silvicultural park forests and therefore they act as important refugia promoting tree recovery with paramount importance in these ecosystems. Scattered trees facilitate tree regeneration by three different mechanisms: (i) by providing shade for light sensitive species; (ii) by reducing grass competition within the dense grass matrix; and (iii) by promoting regeneration linked to the attraction of seed dispersers. The park forests analyzed are similar in species diversity and vary in species composition showing high affinity with the Chaco and Espinal forests. Our results have practical implications for the management of park forests: woody species such as *Prosopis affinis*, *Prosopis nigra* and *Vachellia caven* appeared as excellent candidates for use as nurses in the restoration and can be combined with temporal exclosures of grazing to foster regeneration and grow. This can be a strategy to maintain or restore natural park forests, especially using native species. We propose that biodiverse park forests have to be protected for conservation and restored whenever possible, without necessarily preventing them from being used for traditional silvopastoralism. An integrated view of the forest– grassland mosaic has to be included in management practices, e.g. by assisting tree establishment and survival in grasslands to create silvopastoral systems.

The fate of degraded tropical dry forests under continuous grazing and extractive utilization

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Tropical forests cover about 45% of the global forest area and are important in maintaining biodiversity and ecosystem services. However, more than 90% of the global forest loss occurs in the tropics through anthropogenic disturbances. Kenya lost about 6% of its forest cover in the past three decades due to unsustainable management particularly illegal logging, uncontrolled grazing and excisions. In this study, forest dependence, status of woody vegetation and soils, and livestock stocking rates were assessed in Chepalungu Forest, a tropical dry forest in Kenya characterised by about 87% forest cover loss. Comparative data on vegetation and soil were collected through stratified systematic sampling in 53 plots of 0.13 ha in the degraded and adjacent intact forest. Stocking rate expressed in Tropical Livestock Units (TLU) per unit area was estimated using plant oriented approach, while forest use was determined by interviewing 450 households adjoining the forest. Currently, the community obtains 19 different goods and services from the ecosystem; firewood (57%) being the most common (4.79 m^3 per household annually). The degradation created open swards which encouraged intensive grazing at a stocking rate of 4.1 TLU ha^{-1} against a sustainable stocking of 1.1 TLU ha^{-1}. This led to soil compaction as demonstrated by a soil bulk density of 1.38 g cm^{-3}. Only 29% of the sampled woody species were mature trees, a majority were regenerates of gap opportunistic species. The stem density and basal area were significantly low at 7 stems ha^{-1} and 0.24 $m^2 ha^{-1}$ respectively against expected values of 581 stems ha^{-1} and 14.2 $m^2 ha^{-1}$. Although the forest exhibited a reverse exponential curve with high density of seedlings and saplings and few mature trees, only 13% and 0.3 % of the seedlings and saplings respectively recruited to the next age class. The findings suggest that recurrent extensive grazing, uncontrolled extractive use and lack of restoration interventions disrupt and slow down succession dynamics and recovery processes of degraded native forests and may ultimately cause irreversible forest condition. Forest managers should ensure optimal resource offtake to promote the successful recovery of degraded forests, biodiversity and enhanced carbon sequestration at landscape level.

Towards integrated fire management in miombo woodlands: reflections from a community-based experience in northern Mozambique

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Miombo woodlands constitute the most important forest type in the sub-Saharan Africa with a high socio-economic and ecological value, but under increasing human pressure. Fire is one of the main ecosystem drivers. Any progress toward long-term solutions to improve the miombo resilience requires community involvement, commitment, and adaptation in fire management. Initiative to catalyze changes in the behavior of local communities to safely and effectively capitalize opportunities for sustainable use of fire were implemented in the Niassa province, northern Mozambique. The initiative entitled "The early controlled burning and community awareness of forest fire management", was conducted in 2022 and evaluated the forest fire management by early controlled burning and community awareness, involving three phases: i) Meeting with local communities to reach an agreement and discuss a training strategy; ii) Identification of the demonstration location and experimental design, followed by setting fire breaks, forest inventory, fuel load assessment, controlled burning; iii) Demonstration and assessment of late-season fire occurrence and impact on vegetation and, eventually, fauna; and monitoring. Field surveys were conducted in 20 ha, involving observations, measurements of forest and atmospheric parameters. Finally, a seminar was held, involving all districts economic activities staff, community leaders, and protect areas representative, for discussion and evaluation the effective of management tool for forest sustainability. Preliminary results revealed shift in the awareness of communities about the danger of wildfires, which is currently translating into the application of prevention techniques and opening firebreaks to lower the fuel load around their houses and agriculture fields. From the seminar, it was consensual that the initiative must be disseminated and shared with other communities. Proving to be encouraging, the results are being replicated to other parts of the province through the creation of fire management committees, with the support of district governments. Controlled burning significantly reduced fuel load in areas with a high load of combustible material. In our opinion, engaging communities for the success and consolidation of fire management programs requires the establishment of income alternative activities to ensure the projects' long-term sustainability.

ZAMBEZIAN ECOLOGY, WILDLIFE AND LAND USE/LAND COVER (LULC) IMPACT ON CARBON BIOMASS: A CASE STUDY OF THE BAIKIAEA FOREST OF WESTERN ZAMBIA.

T4.16 How to reconcile poverty alleviation with forest integrity in tropical dry forests: ecological research gaps and paradigm shifts for sustainable management.

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Abstract: Tropical dry forests account for between 8% and 13% of all tropical forests globally (Hansen et al. 2013). They are important for provisioning of ecosystem services like climate stabilization by acting as carbon repositories, inaddition to, providing timber and non-timber forest products (Shackleton et al. 2007; Blackie et al. 2014). Forests are also a source of resilience for rural people (Gumbo et al., 2018) and also provide the rural poor with natural insurance or fulfilling a "safety net" function for mitigating risks in times of emergency such as times of crop failure due to droughts and other natural calamities.
Deforestation and degradation endanger virtually all remaining tropical dry forests, which should be given top conservation priority (Miles et al. 2006; Hansen et al. 2013). They are, nevertheless, among the under studied forest ecosystems, posing a challenge to sustainable forest management and formulation of appropriate forest policies and management strategies (Blackie et al. 2014). Human population and wildlife growth is the primary threat to Africa's tropical dry forests as it is associated with land use, land cover, and fire regimes (Miles et al. 2006; Leadley 2010; Sloan and Sayer 2015).

Carbon dynamics is an important aspect in the context of climate change mitigation. Forests store large quantities of C stocks in vegetation and soils and as such their management merits attention. Globally, C budgeting of forest ecosystem has seen an increase in scientific attention (Rotzer *et al.*, 2009) especially in the developed world. Grazing has been thoroughly researched (Steffens et al., 2008 & Lü FM, et al., 2011) and it's potential to directly affect plant output and, consequently, soil C inputs in other parts of the world. However, data on the implications of wildlife grazing on Zambezian ecosystems (Scurlock, 1998) such as the *Baikiaea* Forest is missing. Currently, the focus is on understanding the C reserves of rangeland ecosystems such as *Baikaiea* forest of Sioma Ngwezi National Park as data on these aspects is missing. As such, this study focusses on developing an understanding of how wildlife and human activities impacts on the carbon sequestration potential of *Baikiaea* forest under these disturbances.

T4.17 Human-Forest Relationship I - Ambiguity in “taking care of the forest”

Care as cultural practices and personal attachments towards forest among professional foresters in Finland

T4.17 Human-Forest Relationship I - Ambiguity in “taking care of the forest”

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Abstract: Human care towards forests is most visible in various management and conservation actions. The diversity of these caring attitudes and practices often cause conflicts in the society when stakeholders such as civil society or forest sector attach different cultural, ecological, economic and social meanings as well as sustainability aims to the forests. These meanings may relate very intimately to the key values and thus the identities of these stakeholders, producing intractable conflicts that are difficult to resolve.

One stakeholder group, professional foresters, are often involved in these conflicts. Within their professional cultures, foresters express the economic care of forest for future human generations. Care is also interlinked to e.g. aesthetic and technologal practices prevailing in their professionalism. Besides profession, care intertwines in diverse ways with their personal attachments with the forests, their freetime being and doing in the forest as well as memories and even family identities. Additionally, the caring human-forest relationships are considered reciprocal, and foresters themselves feel in many ways taken care by forest.

In my presentation, I describe the caring attitudes and practices of the forest professionals. My research is based on the interview data that I have conducted with 37 Finnish foresters working in forest management, conservation and administration. My qualitative phenomenological analysis about their forest-related experiences and meaning making contributes understanding about the multidimensionality of their care-related emotions, values, and practices. It shows that care is deeply rooted in their cultural epistemologies and ontologies affecting both their personal and professional embodiments and identities - and consequently their professional attitudes and behavior.

Caring for oaks trees in England when faced with Acute Oak Decline: land manager perspectives and values

T4.17 Human-Forest Relationship I - Ambiguity in "taking care of the forest"

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Abstract: There is an increasing number of pests and diseases that trees and woodlands are faced with in England. Oak (*Quercus robur and Quercus petrea)* is a valued species as it provides many ecosystem services, and it is culturally significant in Britain. Acute Oak Decline (AOD) is a complex disease involving a pathogenic bacteria causing damage and death to native English oaks. As part of a wider project interviews (n=21) and a survey (n= 297) were undertaken with land managers and owners in England to explore how oaks are valued, how they are perceived culturally and historically, and to what extent this might impact managers management and care for oaks and affect their decisions. We found that native oaks were highly valued particularly by land managers involved in managing oak in woodlands or in historic parklands. A distinction could be made between their professional values for oak such as biodiversity, timber, historical importance, and their personal values which highlighted more emotional connections, a love of oaks and a desire to care for them. Oak was viewed as culturally and historically very important and linked to English and British identity. Those with veteran and ancient oaks were more willing to spend resources (time and funding) conserving these specimens as symbols of strength, resilience and trees that illustrate the passage of time. Management responses to AOD need to be cognisant of different relational value systems held by a variety of stakeholders, and better understand how land managers care for their oaks. Therefore, understanding the values of a variety of land managers from private owners, non-governmental organisations and government bodies and their perspectives concerning different management options to deal with AOD is important. Difficult choices will need to be made concerning the deployment of resources and approaches to increasing the care for and the resilience of oaks.

Forest Stories: Knowledge, Affects and Care in Controversies around Forest Management in Germany

T4.17 Human-Forest Relationship I - Ambiguity in "taking care of the forest"

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Abstract: Since 2018, a wave of consecutive droughts has been hitting large parts of Germany, causing severe damages to large forested areas and triggering heated political and public debates. While traditionally, the German forestry sector held a strong position as central authority on all matters related to forests, a network of 'rogue' foresters, forest researchers and nature conservationists have openly challenged this privileged position in the wake of the crisis. Faced with the rapid transformation of the ecosystem, the opposing factions both highlight the urgency to act in order to 'save' the German forest and to make it climate resilient. Yet, there is a deeply rooted disagreement on how to reach those 'forests of the future', what they should actually look like in the first place and which 'facts' to rely on when making these decisions. Mutual accusations span from the profit orientation of the forestry sector to the romanticization of forests by those with a stronger ecological orientation.

We claim that beneath the surface of a seemingly rational and technocentric debate around the future management of German forests, a deep and complex web of competing, affectively charged narratives about the relationship between humans and forests can be uncovered. Those narratives carry with them a sense of care for the forests, unified by a fear of loss related to the massive changes in the forests of Germany which are becoming increasingly visible. Conflict thus does not arise around the question of whether or not to care about the forest, but rather around what 'caring' actually entails, and who should be or feel responsible for it. By drawing from different data sources, including newspaper articles, position papers and interviews with researchers and professional foresters, we attempt to reconstruct some of those "deep stories" (Hochschild 2016), revealing different forms of caring about the forests and ultimately opening up new avenues for better mutual understanding.

Taking care of forests in a changing climate – reactions to climate-damaged forests by the public and forestry actors

T4.17 Human-Forest Relationship I - Ambiguity in “taking care of the forest”

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Abstract: Among other things, forest is a place where human bodies are surrounded by non-human nature, a sought-after counter-world to mechanized, urbanized, or pandemic-limited daily life, a workplace and economic space, and a strongly identity-forming landscape element. Current climate-induced developments, such as drought, insect outbreaks, storm, or wild fires, are visibly altering forest landscapes. Between 2018 and 2022, large-scale forest dieback in Germany has altered entire landscapes at a rapid pace. Large areas of drought and bark-beetle damaged trees have been removed to prevent its further spreading, and in some places, forests have disappeared completely. These large-scale changes to our natural environment pose very hands-on practical challenges to natural resource professionals managing affected forest areas. Yet they also affect the intangible meanings people associate with forests and trigger sometimes fierce emotional reactions by both forestry professionals and local stakeholders.

Analyzing how people deal with and react to these developments offers insights into 1) the meanings and emotions associated with forests by forestry professionals and non-professional local stakeholders, as well as 2) the different social constructions of a caring relationship with the forest. We use qualitative data collected through go-along interviews and participatory observation with a particular focus on the metaphors used to express reactions to climate induced changes to the forest. What happens when the state of the forest becomes increasingly disconnected from established forestry concepts? What does “taking care of the forest” mean from different perspectives? And how to deal with conflicting interpretations of caring relationships?

We find that, in a forestry perspective, carrying the responsibility for a forest district represents an individualized, emotionally anchored care relationship that, traditionally, is timber and economy oriented. The climate-induced changes are, among other things, upsetting established silvicultural concepts, roles and notions of long-term intergenerational responsibility. The drastic climate-induced changes enable the analysis of particular societal relations with non-human nature, as well as problematic structures in forestry, such as the close coupling of territory and individuals, as well as the associated embodied professional practices and bodies of knowledge.

Taking care of the forest as a part of nature - conceptual thoughts and empirical insights

T4.17 Human-Forest Relationship I - Ambiguity in "taking care of the forest"
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Abstract: With our contribution we aim for an introduction and exploration of the concept 'care' in relation to forests and the study of forest utilization, protection and destruction. Our main questions are: What conceptual and critical potential lies in the application of the care concept for the study of human-forest relationships? And further, how can one study the societal, economic, and subjective relations with nature in the context of forest utilization through the lens of care?

'To take care of the forest' is a commonly used expression that does imply very different and sometimes conflictual meanings and practices. Care taking in the context of forest utilization is always connected with social and political power structures, different forest management traditions as well as economic rationales. On a subjective level, a caring relation with forests can also be linked to family traditions as well as mental and physical health. Currently, global warming and biodiversity loss as well as potential solutions for these socio-ecological crises, such as a bioeconomy or a circular economy, transform how forests need to be and are taken care of.

In our contribution, we will firstly provide an introduction to conceptual approaches of 'care' rooted in feminist theory (cf. Tronto 1993) and the study of reproductive relations (cf. Biesecker & Hofmeister 2006). In recent years, concepts of care have been increasingly applied and developed further for the scientific study of human-nature relations. We discuss in which ways care concepts are suitable for the study of human-forest-relationships. Secondly, we provide empirical insights based on our field research in Finland, Germany and Canada. These highlight the potential for critical analysis inherent in studying forest utilization through the lens of care. Based on the three case studies we will then, thirdly, elaborate on three dimensions of human-forest-relationships: forest utilization, forest protection and forest destruction. We synthesize how these dimensions are on different levels intertwined with care and care taking. We close by elaborating on 'care taking' as a vital part of human-forest relationships and show how this can transform forest utilization, destruction and protection.

Unraveling ecological care and violence in forest conservation and management: approaches from Feminist Political Ecology

T4.17 Human-Forest Relationship I - Ambiguity in “taking care of the forest”

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Abstract: Political ecologists are increasingly focusing on the fundamental role of care practices and affections in socio-natural relationships. As the green economy and market-based forest conservation solutions advance (e.g., carbon credit markets and bioeconomy), it becomes necessary to recognize two key factors. 1) The changes and interlinks between labor and notions of nature and sustainability involved in forest conservation and management approaches; and 2) the interweaving between care and violence that such changes may entail.

Drawing upon feminist political ecology approaches to the care of life, this manuscript explores how we understand ecological care and its framework while recognizing the power and violence exercised in current forest conservation and management systems. Based on qualitative research conducted in Mexico and Laos PDR, the manuscript explores how care practices, knowledge and affections situated with(in) the forests are linked to violent processes that intertwine the Global South and North.

Theoretically, the manuscript aims to extend the discussions on the production of the means of life and the production of life (care labor) at the intersection of ecological conservation and forest management. It thus addresses questions of ecological care labor. Ecological care is generally described as those attempts to reduce harm and violence on the earth, species, or other human beings. However, many of these attempts are often immersed in oppressive relations based on historically constructed social hierarchies based on gender, ethnicity, class, and racialization. Recognizing oppressive relations also reveals the diverse relations and the labor involved between humans and non-human species across different spaces at the local level (the household, the city/village, the cultivation land, the forest). While also exposing the coloniality of decision-making spaces at the national and global levels.

”I have a need to take care of my forests” - Finnish private forest owners' experiences and perceptions of care

T4.17 Human-Forest Relationship I - Ambiguity in “taking care of the forest”

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Abstract: Forest ownership is a complex institution. Besides relationship between the owner and the owned, it includes a complex set of both interpersonal relationships and other societal institutions but also human relationship with non-human nature.

In Finland, forests are largely privately owned. Thus private owners are an important group for citizens, national economy and forest. They own 60 % of forest land, 70 % of forest growth, the domestic forest industry buys 80 % of the wood it needs from them and everyman's rights give all access to private forests.

For individual owner, forest ownership is more than a societal institution. Forest ownership can be way of life and source of livelihood, part of the self, identity and leisure time, link to family and kin, relationship with a dear place and the people who have lived there.

Forest ownership is also about caring. Usually forest is taken care, managed, for the family, or humans more generally. Present forest owner takes care of the forest for the future generations, with respect for the past generations.

Experiences of responsibility and duty are common to owners. Forests cannot be left 'to their own devices', 'abandoned'. They must be looked after, cared for. Furthermore, experienced and lived forest ownership is also an interactive and embodied relationship with non-human nature. Physical forestry work and multi-sensory experiences in the forests are an important, nurturing part of lived and experienced forest ownership.

Global environmental issues have brought environmental ethics into the debate on forest owners’ rights and responsibilities. This paper explores, based on 50 interviews, forest owners' perceptions and experiences of taking care of their forests. What embodied and affective experiences do forest owners associate with caring for their forests? What cultural and societal meanings and practices arise from owners' perceptions and practices? What kinds of ecological, nature-sensitive meanings and practices emerge? What factors prevent or enable owners to take care of their forests more ecologically?

The concept of care in forest ownership is analysed within frameworks of environmental anthropology and critical heritology. Forest owners' experiences, practices and perceptions of care are scrutinized through the institution of forest ownership.

T4.18 Interactive forest management: Should silviculture and forest operations comply with governance or the opposite?

Analyzing Visitor Feedback to the Communication, Education, and Public Awareness Materials of Mount Makiling Forest Reserve ASEAN Heritage Park

T4.18 Interactive forest management: Should silviculture and forest operations comply with governance or the opposite?

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Abstract: In the Philippines, ecotourism offers both potential and hazards to the natural and social environment. Sustainable and responsible ecotourism is the key for mitigating threats. Mount Makiling Forest Reserve ASEAN Heritage Park (MMFR AHP) in the Philippines is the closest mountain to Metro Manila. It straddles portions of municipalities of Bay and Los Baños, and Calamba City in Laguna province, and Sto. Tomas City in Batangas province. The MMFR AHP continues to serve as a recreational and educational area for the public. Communication is essential to the effectiveness of visitor management strategies. The paper assessed the visitors' feedback on the communication, education, and public awareness (CEPA) materials in MMFR AHP. The Article 13 of the Convention on Biological Diversity (CDB) recognizes the role of CEPA in encouraging and engaging people to conserve biodiversity and use natural resources sustainably. Results revealed that the 242 respondents found maps (64%) to be the most helpful among the CEPA materials available followed by infoboards (60%), directional signs (58%), brochures (40%), videos (39%), and flyers (35%). These materials guide users, offer pertinent information, raise awareness, and give instructions on the proper use of the mountain. Respondents also suggested to include infographics about flora and fauna, exhibits, facts about the MMFR AHP and its resources, social media content, posters, and souvenirs. The history, biodiversity, natural resources, advantages, and role in shaping art, culture, and society are among the topics that respondents most want to learn more about. The respondents also revealed that their purpose of visit is for educational, leisure, hiking, biking, and photography. The paper provided proof of the materials' efficacy in raising visitor awareness and found that, depending on the respondent group, different methods of communication and resource promotion are required. Furthermore, it contributed to the development of the visitor management scheme for MMFR AHP as well as conveying conservation messages through an interpretation program. Thus, it will be easier for visitors to understand what MMFR AHP can offer and the significance of the natural resources if additional CEPA materials and programs are developed, highlighting the distinctiveness of various areas of interest.

Can social milieus help, to better target private forest owners and society, interested in forests, at large?

T4.18 Interactive forest management: Should silviculture and forest operations comply with governance or the opposite?

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Abstract: The paper/contribution introduces to social milieus (e.g. Sinus-milieus) and their application in sectors other than forestry. It further shows, how recent forest related research has taken into account social milieus or has otherwise, at least partly, considered actor or owner beliefs and preferences (e.g. in social networks). It provides insights, to what extent private forest owners or society at large, differ in their forest related preferences or activities, comparing 10 social milieus (Sinus-milieus). The exemplary results discussed are based on a new analysis of existing secondary data, from a representative survey on German society and forest owners. We will conclude on factors, with strong differences between milieus and provide an outlook how such results can facilitate the targeting of e.g. private forest owners, by the example of a selected social milieu.

Elaborations on the explanatory power of social milieus versus classical socio-demographic variables, for German society and forest owner 'profiles'.

T4.18 Interactive forest management: Should silviculture and forest operations comply with governance or the opposite?

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Abstract: The paper/contribution will contribute to a better understanding of the explanatory value of social milieus (i.e. 10 different Sinus-milieus) as compared to socio-demographic and forest structure variables, for the explanation of forest related belief and interest 'profiles' (i.e. a set of variables) of private forest owners as well as other society, in Germany. Results are based on a new analysis of existing secondary data, from a representative survey on German society and forest owners (about 2,400 respondents). We will conclude on the explanatory value of the compared factors (milieus, socio-demographic or forest structure) individually, looking at how frequently they reach comparatively strong relationships with dependent 'profile' variables. Finally, we will discuss implications for the use of social milieus in the practice of identifying or addressing e.g. private forest owner groups.

Interactive forest management, the case of FSC: Silviculture specialists and forest managers hand in hand with forest stewardship governance!

T4.18 Interactive forest management: Should silviculture and forest operations comply with governance or the opposite?

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Abstract: Governance is the way rules, norms and actions are structured, sustained, regulated and held accountable. The Forest Stewardship Council (FSC) is regarded as the pioneer of a multi-stakeholder governance system in the forest sector. FSC strives to give equal weight to economic, environmental, and social interest groups, to ensure SFM through the active participation of all stakeholders in the forest services supply chain. At the forest level, these stakeholders include for example forest workers, managers of small and large forest operations, environmental NGOs, Indigenous Peoples. In combination with an independent accreditation programme that verifies the certification bodies, FSC is also widely regarded as a credible and effective forest management certification system, which communicates through the label, the 'social license', to the public that certified products are coming from well-managed forests. This 'social license' is used as a reputational risk management tool, and mentioned as the most important reason for getting certified, as shown by a number of independent research papers.

On the other hand, not all forest managers feel comfortable with external auditors assessing their management against FSC's long list of performance indicators. FSC's rules for documentation and for public reporting on change management are also mentioned as a burden. These rules include for example to report on Health and Safety trainings for forest workers, work related accidents, and on harvesting techniques and equipment, rationale for species selection.

Using concrete examples, we will show where, how and when silviculture scientists and practitioners can take an active role in shaping FSC's certification requirements and in contributing to meaningful, science-based indicators for 'interactive forest management'. We will also point out strengths and weaknesses and lessons learned in engaging and communicating with different groups of stakeholders in processes such as auditing, conflict management, trust building, and the wider governance of FSC.

Public-relation strategies for reaching out to forest-distant milieus and transdisciplinary case-study development.

T4.18 Interactive forest management: Should silviculture and forest operations comply with governance or the opposite?

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Abstract: Private forest owners, today, belong to a considerably large share to social milieus, whose lifestyles are far away from classical, traditional forest-thinking, so called forest-distant milieus. These forest owners are increasingly difficult to be reached, by associations, advisors and other actors. In order to enhance the building of climate resilient forests for the future in Germany, we develop an approach, addressing private forest owners as well as other society, interested in forests, tailored to their social milieus. In this contribution, we will outline the development of public-relation strategies and provide strategy examples for selected social milieus. We will further draw on our approach and the concept to develop, implement and evaluate milieu-tailored activities in trans-disciplinary learning-labs.

Stakeholder involvement influencing forest management through the Forest Stewardship Council certification scheme

T4.18 Interactive forest management: Should silviculture and forest operations comply with governance or the opposite?

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Abstract: The Forest Stewardship Council (FSC) is a forest certification scheme based on stakeholder involvement. FSC members and stakeholders are part of the standard development and sets the requirements. The members set up the strategic goals for FSC as an organisation, both internationally and nationally. FSC has mechanisms for stakeholder involvement as part of the implementation and annual audits: certificate holders need to engage with affected stakeholders in planning their forest management; auditors are required to reach out to relevant stakeholders for comments on the performance of a certificate holder before the audit; and FSC has a complaints system for any stakeholder to bring up their views or dissatisfaction with certified forest management.

In Sweden the complaints system has been heavily used by stakeholders, especially the Environmental Non-Governmental Organisations. With time this has led to more professional handling complaints by the certificate holders, and an acceptance that stakeholders have opinions on the forest management that certificate holders need to be open to listen to.

However, there are many challenges for FSC with the complaints system. One is that the handling of complaints requires lots of resources for certificate holders and accredited certification bodies, but also for the complainers. Another is that no party within the system has the overall view of all FSC complaints. The FSC system is complex there may be a gap between the understanding and expectations of the stakeholders on one hand, and the certificate holders and the accredited certification bodies on the other.

Some solutions have been tested in Sweden such as reaching out directly to the complainers with information about the system and for certificate holders to invite stakeholders to have dialogue in the field, as well as finding ways to engage with certificate holders and the accredited certification bodies to get a better overview the complaints and what they lead to.

FSC's complaints system is an important link between forestry and its various stakeholders. An effective and fair complaints procedure is important for the credibility of the entire certification system.

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

A new Forest Governance Approach for Germany to cope with Global Change

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: On the occasion of the current revision of the German Forestry Act, and against the background of an enormous drought-induced forest die-back in Germany, the German Scientific Advisory Board for Forest Policy at BMEL (Federal Ministry of Food and Agriculture) developed a new forest governance approach to cope with global change. Its guiding principle is adaptability through a proper mix of policy instruments. We recommend six minimum standards mandatory to all forest owners, securing (i) forest preservation, (ii) avoidance of clear-cuts, (iii) accessibility for the public, (iv) adequate game stocks as well as (v) soil protection and (vi) water protection. Beyond these minimum standards, all societal demand shall be flexibly addressed by any of the following policy instruments: information; structural support; payments and other financial support; and regulations. Moreover, we recommend to create legal frameworks that incentivize private cooperation. In consideration of the public being the main beneficiary of most of the forest ecosystem services, we advocate for highest priority to financial instruments. The approach is rounded out by a specific example for forest adaptation to climate change.

Amplifying Social Innovation Impacts in the Forest Sector: Insights from Central and Southern Europe

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: In Europe, where a range of social innovations in the forest-based sector exists, many initiatives have failed to grow their impacts. As society aims to advance sustainability transformations, it becomes imperative to understand the processes concerning the expansion, spreading, and other approaches to the amplification of social innovation impacts. Recognizing the increasing relevance of social innovations in propelling the forest sector's role in the envisioned bio-based future, we explored the impact amplification strategies of three forestry-related cases in Central and Southern Europe. Using our proposed framework called the "*Ecosystem of Amplifying Social Innovation Impacts*" *(EASII)*, we analyzed data collected from semi-structured interviews and document analysis. Rooted in the innovation ecosystem approach, the EASII framework integrates identified structure (i.e., actors and interrelations) and process factors (i.e., motivation, interactions, knowledge, and financing) that regulate and shape amplification processes. Results from the analysis suggest that effective impact amplification entails: (1) adopting a combination of strategies; (2) employing constant amplification processes; and (3) driving behavioral change among innovation actors. Additionally, two key leverage points to reinforce impact amplification were identified: cultivating a strong sense of agency, and fostering robust relationships among the network of innovation actors. With this in consideration, policy support should thus be focused towards creating enabling environments and granting access to more innovation platforms that allow organizations to collaborate and exchange resources. Accounting for these leverage points further implies that innovation actors should implement support measures that are holistic and locally adapted.

An approach for the monetary valuation and remuneration of the climate protection services of forest enterprises

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Forests and forest enterprises are facing the climate change and its consequences: droughts, heats, storms, heavy rain events and bark beetle outbreaks. At the same time, forests play an important role in the climate change mitigation as carbon sinks and as bio-resource for substituting fossil-based materials towards a new sustainable bio-economy.

The objective of the present study is to develop a payment scheme model to reward the climate protection contribution of forests and forest enterprises. The approach is based on empirical data and it should be kept as simple as possible to avoid high administrative transaction costs and to guarantee accessibility for all forest ownership types.

The payment scheme consists of three key indicators: (i) volume increment of compact wood (i.e. > 7 cm DBH), (ii) closeness to nature of forest stands and (iii) the substitution effects of timber. Based on the volume increment of compact wood, the equivalent amount of CO_2 bound by the growing tree is estimated. The mathematical concept is a rather simple linear model.

In a case study, the remuneration value for the private and municipal forests of four different German federal states was calculated for every type of ownership. The data basis was the latest national forest inventory data.

The results are plausible with regard to comparable studies. The key factors are based on widely accepted values and methods. The main points of discussion are the timber use for energy, the applied closeness to nature approach, and the contribution of forest management to the climate protection.

The model developed in the present study follows the idea of providing economic support for the maintenance and expansion of the climate protection contribution, which is otherwise not a marketable service. The model should not be static. Instead, it should allow adaptions in accordance with potential changes of model assumptions that relate with system changes. A practicable remuneration system for forest enterprises for the provision of goods that cannot be traded on markets does not yet exist, at least not in Germany.

Co-management organizations as an innovative institutional arrangement in developing nature-based tourism in and around the Sundarbans of Bangladesh

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: The Sundarbans mangrove forest in Bangladesh is the world's largest single tract of mangrove forest and provides direct and indirect support to more than 3.5 million people. The forest is experiencing various illegal activities and over-exploitation for many years. The majority of the population is fully or partially dependent on the natural resources of the Sundarbans due to the absence of alternative income opportunities at the area. The Sundarbans is one of the prime tourism destinations of Bangladesh. In order to manage the destination sustainably, this study focuses on the potential social, environmental, and economic benefits of nature-based tourism (NBT) as an alternative source of income in the region. It also examines how co-management organizations (CMOs) can contribute in developing NBT in and around the Sundarbans and facilitate the conservation of this unique mangrove forest. This study was used mixed-method following a semi-structured questionnaire survey by conducting face-to-face interviews to gather empirical data. A mixed result was found, and the data were validated through conducting Focus Group Discussions. The research evaluated that the co-management approach reduced people's reliance on the forest for their livelihood. The respondents expressed a positive attitude toward the conservation and development of NBT in and around the Sundarbans. If CMOs could contribute in developing NBT, the Sundarbans could be conserved more successfully. However, locals also mentioned several problems that hindered the development of NBT. This study showed that CMOs had greater implementation gaps to create NBT in the area and acknowledged CMOs' challenges and potential contributions to the development of NBT. A well-planned, proper training, education, and support from the national and local governments, as well as active assistance from the Bangladesh Forest Department were needed to develop NBT in and around the Sundarbans through the active support from CMOs. The findings will aid policymakers in recognizing the challenges associated with CMOs in developing, managing and marketing NBT in and around the key biodiversity area.

Collaborative governance, regional development and local politics: the outcomes of forest policy programmes across contested landscapes

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: In 2018 the Swedish government adopted the country's first National Forest Programme targeting four priority areas: sustainable forest management with greater climate benefits, multiple uses of forest resources for more jobs and sustainable growth throughout the country, world-class innovation and processed forest products, and sustainable use and conservation of forests as a profile issue in Sweden's international cooperation. To realize these objectives, a key goal of the programme was to gain acceptance and initiate action across Sweden's 21 counties. The key tool of doing so was to adopt regional forest strategies and action plans targeting multiple use of forests primarily by the work of cross-boundary collaborative platforms. Inspired by an increasing scholarly literature on collaborative governance, this paper analyses the emergence, process and outputs of these collaboration platforms in the four northern counties of Sweden. It builds on statements from semi-structured interviews with participating regional state and non-state actors (*n*=35), meeting records as well as written comments from a public consultation. The results reveal a strong discrepancy between the goals communicated by the government in 2018 and the actual capacity for action by regional public administration and participating actors, especially since the collaborative platforms were not fully funded for the task at hand. Moreover, in most cases, collaboration outputs and actions were repeatedly constrained by unclear directives and coordination, current policy conflicts in national forest policy and diverse perceptions of, and possibilities for, sustainable countryside's, social innovation and regional labor markets. The paper concludes with key insights for research at the interface of collaboration, sustainable livelihoods and rural development and suggests ways forward with participatory action in contentious policy areas.

Community Forest Management and Local Development: Novel Institutional Arrangements in Resex Verde Para Sempre, Porto de Moz-Pará State, Brazil

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: In the last decade, a significant increasing participation of Associations and Cooperatives of Family Producers from Traditional Communities, Settlements and Sustainable Development Projects (PDS) organized for Sustainable Forest Management happened in Brazil. This changes the involvement of various actors, including: governmental agencies responsible for licensing and control of productive activities; teaching, research, development and technological innovation institutions (CT&I); forest extension; associations of autonomous professionals and the third sector. Herein, in order to address all the challenges posed by this changing scenario, collective actions such as proposed by Community and Family Forest Management Observatory (www.observatoriomfcf.org), the Development Sustainable Committee of Porto de Moz Municipality and the Amazon Forestry Forum (www.dialogoflorestal.org.br/foruns-regionais/forum-florestal-da-amazonia/) have been crucial to support the Communities to implement and successfully carried out their Sustainable Forest Management Plans, in the Resex Verde para Sempre - Porto de Moz-PA. Collective arrangements of institutions were also very important to overcome and adapt, field activities during the long period of Covid-19 pandemic. The Bom Manejo II Project started in 2017 with a main focus on the dissemination of Software and the Training of professionals from Government Institutions, Universities, Institutes (Federal and State levels), Professional Associations, Producer Cooperatives and private companies. Specifically to the Bom Manejo 2 Project´s activities field work were interrupted, with a gradual and virtual resumption in the home office format, our strategy was to intensify Communication and Outreach work, keeping the Sustainable Forest Management issue in discussion to assure the importance of the forest sustainable production, income generation and forest conservation. A trans-disciplinarity and institutional arrangements enabling long-term collective work, in pursuit of local development and common well living, together with approach of One Health perspective, i.e. that recognizes the interconnectivity between people, animals, plants and the environment, is an important strategy to overcoming of climatic emergencies and recurrent events of possible zoonotic outbreaks (Covid-19, Influenza, etc.) in the Amazon. The integration of Sustainable Management of Natural Resources, encompassing forests, water and food security through the participation of ethnic groups and a collective political will, is essential for providing sustainable solution for current and future generations.

Exploring social learning in multi-use forestry and family forest owners as grassroots agents for alternative forest management

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Alternative forest stewardship methods have the potential to diversify primary production and provide a wider variety of income opportunities in rural regions while also improving environmental services. In this study, we focus on Swedish family forest owners and their social learning networks as representing a potential fulcrum on which the adoption of multi-use and alternative forest management practices may hinge. Forest management practices in Sweden are embedded in an established industrial structure in which forests are managed for industrial timber supply, yet some have criticized this structure for hindering the adoption of a wider variety of management practices. The aim of the study is to investigate how networks and processes of small-scale change in forest practices already underway, can facilitate social learning for forest owners and thus a transformation of management practices. Social learning theory places emphasis on the role of organizations that act as bridges in the transfer of ecological knowledge in the forestry sector. By drawing on social learning theory and linking it with social innovation and transformation theory, the study addresses the possibilities and limitations of leveraging the existing social learning processes of family forest owners engaged in multi-use forestry and the organizations supporting such processes.

From data collected in three different contexts in Sweden, the study shows how social learning through networks can form social innovation in forestry. Especially by supporting the implementation of multi-use forestry methods. We argue that such insights have the potential to improve institutional interventions that enable the processes of learning and innovation between key actors to accelerate the implementation of more sustainable forest use and management.

Fostering Village Development and Empowerment through Social Innovation: A Case Study of the Rural HUB in Serbia

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Social innovations have emerged as a potential solution to address the current social-ecological and economic crises by fostering bottom-up initiatives for transformative social change. Particularly in rural areas, social innovations play a crucial role in promoting sustainable rural development and contribute to the overarching goal of building inclusive and sustainable economies. This study investigates the impact of social innovation on the development of rural communities through an in-depth empirical case study analysis of the Rural HUB, a co-working space located in the small village of Vrmdza in eastern Serbia, which operates on the concept of the entire village functioning as a hub. The research employs a triangulation approach, utilizing expert interviews, field observations, document reviews, and interviews with village residents to gather data. The development strategy of the Rural HUB is rooted in the sustainable eco-village model and is achieved through a collaborative effort between urban individuals and traditional farmers from the village, referred to as the rurban concept. The rurban concept serves as an open platform for the exchange of ideas, information, and experiences between diverse initiatives and individuals, aiming to integrate rural and urban knowledge to enhance personal and community life. The Rural HUB has had a wide-ranging impact on various aspects of the community, including economy, environment, culture, education, and personal development. Its comprehensive initiatives encompass educational programs, social business design training and application, the development of local products and services, sustainable farming practices, green job preparation, and service learning opportunities. This study demonstrates that the Rural HUB model can be successfully replicated in other rural areas within the country and the region, serving as a valuable best practice example that contributes to the design of more suitable and inclusive development policies and measures among relevant stakeholders.

Future of forest in the Ukrainian Carpathians in time of critical transition: why social innovation might be a trigger towards sustainability

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: The ongoing war in Ukraine has resulted in devastating consequences, including significant loss of life and the displacement of millions of people. Furthermore, the presence of mines and unexploded ordnance has made approximately 30% of Ukraine dangerous. This paper focuses on the Carpathian region in Ukraine (with 54% of forest cover), which has emerged as a refuge for war-displaced individuals and a vital center for providing humanitarian aid during this time of war in Ukraine. However, the Carpathian region now confronts increasing challenges, including the growing pressure on its natural resources, especially forest, and the lack of job opportunities. This study examines the critical transition occurring in the Carpathians and investigates the role of social innovations in forest-based sectors to facilitate this process. The analysis delves into the impact of the war on the Carpathian region, considering both the economic losses and the environmental damages to its forests. The findings emphasize the considerable potential of social innovations in addressing the challenges faced by the Carpathian region during this critical transition. By fostering collaboration among stakeholders, social innovations can play a vital role in promoting sustainable forest management practices, facilitating ecosystem restoration, and establishing initiatives such as green job opportunities and circular bioeconomy models. Additionally, the results suggest that social innovations offer valuable prospects for creating livelihood opportunities and implementing robust social support systems for the internally displaced populations in the region, with a particular focus on forest-related initiatives. Integrating social innovations into policies and strategies can alleviate the pressures on natural resources, mitigate conflicts arising from competing interests, and foster inclusive and sustainable development within the Carpathian region. Furthermore, by embracing sustainable practices and empowering local communities, social innovations provide a promising pathway toward building a resilient and prosperous future for the Carpathian region's forests.

Identifying and assessing conditions for successful joint innovation processes in wood and forest research

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Given that producing and using the same resource, the forest sector and the wood processing sector are linked closely. Although wood research and forest research are embedded in similar political, societal and economic contexts, both scientific disciplines are rarely integrated and cooperation between the disciplines is weak. This particularly applies to the level of individual research groups as well as to individual research projects.

In this context, research funders like the European Union or federal ministries initiate inter- and transdisciplinary research programs. Accompanying cross-sectional research offers networking opportunities, improvement of communication between researchers and projects, result synthesis, trainings and more. They often aim at facilitating social, procedural and technological innovations and creating additional scientific and social value.

On the basis of qualitative interviews and quantitative surveys with scholars of European research and innovation clusters with a specific focus on German case studies, this qualitative comparative analysis (QCA) sets out to identify conditions that lead to the successful integration and cooperation of wood research and forests research. By analysing potential best practices, possible constraints as well as promotive factors, this research is geared towards generating additional innovation processes in the field of inter- and transdisciplinary research.

Identifying conditions for an enabling institutional environment for social innovation: an analysis of Scottish policies in the forest context.

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: This paper proposes strengthening the institutional environment in the Scottish forest sector to enable the operationalising of approaches to more sustainable management and use of natural capital (NC) in Scottish forests and woodlands. These ecosystems form a significant part of Scotland's NC. Scotland's innovative National Performance Framework incorporates NC as a national indicator for economic success. However, Scottish forestry has not explicitly integrated NC considerations into policy design and a new impetus exists to engage local communities. Social innovation is a means through which communities could be mobilised for enabling impactful social and/or environmental change (e.g., the H2020 SIMRA project). However, whilst social innovation must be initiated from the bottom-up, the policy landscape must be supportive to ensure its development and sustainability. Through a thematic review of academic literature, Scottish policy instruments and grey literature, we identify an applicable set of conditions required to support the creation and maintenance of an enabling environment for social innovation in relation to forestry and woodlands in Scotland to allow it to emerge, be sustainable and spread. Key findings highlight necessary institutional changes, alongside access to financial support and capacity building. We observe that Scotland has already implemented policy instruments within the forest sector and beyond, which, subject to fostering institutional changes, provide unique opportunities to achieve the policy landscape necessary for social innovation to successfully spring up around the operationalisation of NC approaches. This necessitates innovative, transdisciplinary, and cross-sectoral networks to facilitate the emergence of converging, holistic narratives and solutions, reconfigured decision-making processes, strong social capital, and reciprocal knowledge sharing. The insights from this paper could be applied in future research to develop a framework built around the policy instruments already in place and those proposed, to enable social innovation and its contribution to the enhancement of sustainability in the forest context.

Acknowledgement

This project is supported by the Rural and Environment Science and Analytical Services Division of the Scottish Government through its Strategic Research Programme (2022-2027), project JHI-D5-1 in the Natural Resources Theme.

Identifying key stakeholders and driving factors in ecosystem services supply and demand matching

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Ecosystem services (ES) supply and demand has been research core of ES sustainable management. There are obvious differences between ES supply and demand in quantity, quality, spatial distribution and among stakeholders, which might lead to the heterogeneity of the match or mismatch between ES supply and demand. The mismatch between ES supply and demand is the potential cause of ecosystem degradation. Therefore, identifying the matching or mismatching relationship between ES supply and demand and their heterogeneity can effectively distinguish key regions, stakeholder groups and types of ES that need to be regulated to maximize the benefits of ES. Taking Wolong Natural Reserve as case study, the research evaluated ES supply and demand from perspective of local residents, and analyzed matching status of ES supply and demand and their difference among varied stakeholders. The results showed that significant differences existed in match/mismatch of ES supply and demand among different types of ES and stakeholders. Regard to ES types, local resident perceived four services including traditional crops, fresh water, soil conservation and maintain soil fertility were deficit, while perceived ES types including grazing, gathering, water source conservation were surplus. Three stakeholders were identified according to their perception to ecosystem service supply and demand. It was found that conservative stakeholders tended to demand ES related to agricultural production, while progressive stakeholders tended to demand ES related to alternative livelihood, such as fresh water, carbon sequestration, leisure tourism. Passive stakeholders had weak ability to change their livelihood style, and deemed most ES were low in both supply and demand. The study found that gender, age, education level, local knowledge, income level and its structure significantly affected local perceptions of ES supply and demand. This study identified differences existing in ES supply and demand matching from the perspective of local residents, and preliminarily revealed the underlying linkage and driving mechanism, which has certain significance for ecosystem management and biodiversity conservation. It also provides a new perspective to solve the conflict between nature reserve and local community in nature reserve management.

Moderation and mediation in collaborative governance platforms: the case of the Estonian national forest programme

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Managing contradictory expectations towards forest policy is a complicated governance task. By 2016, the tensions around Estonian forest policy had increased to such a level that the situation was dubbed "Forest War" in the media.

The process of preparing the Estonian Forestry Development Plan until 2030 was initiated in March 2018 and according to the timetable, the plan had to be submitted to the Estonian Parliament in spring 2020. The preparation of a central periodic policy document was planned as a collaborative governance platform, with a lead committee of 35 members (including 7 scientists) from 31 different organizations (ministries, universities, stakeholders' NGOs). As an innovative solution, professional moderators were hired to ensure constructive discussion. However, the policy discussion process failed badly after exceeding all deadlines. The new Minister of Environment dismissed the lead committee on December 07, 2020, and started to seek possibilities for relaunching the process. The new lead committee was formed at the end of March 2020. It consisted of 7 scientists, who were not members of the previous committee, and 2 officials. As of spring 2023, the national forestry program has not yet been approved, it now waits for discussions by politicians, the members of parliament.

We present an analysis of the design and process of this collaboration attempt that highlight the factors that helped and hindered the achievement of an agreement in the platform. Our analysis is based on collaborative governance theory (Ansell & Gash, 2008) and in-depth interviews (N=34) of the first lead committee members and analysis of documents. The results contribute to the theory of collaborative governance by differentiating between moderation and mediation and offer practical lessons for similar collaborations in the future.

Nature Based Solutions, Forest Landowners, and Professional Assistance: Practices, Opinions, Program Development, and Policy Implications

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Per the IUCN, nature based solutions (NBS) are "actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits." Rural lands offer diverse opportunities for innovation and application of NBS for a range of market and ecosystem values and benefits, such as timber production, carbon offsets, biodiversity, water quality and quantity, and amenities. We are conducting research to determine which NBS systems may be most useful for applications on forests and farms in North Carolina and the Southeastern United States and identify the factors that influence landowners participation in existing or proposed forestry and farm incentive programs. This research can help increase the application of NBS practices, including afforestation and forest stand improvement, agroforestry, stream restoration and buffers, and forest wetland banks, and common farm conservation practices.

We are conducting surveys of landowners of forests and farms, as well as technical assistance providers, to identify best practices for NBS, and desirable components and configurations of associated government interventions for achieving the diverse goals of NBS. The landowner survey focuses on existing forest incentives programs in North Carolina, and factors that affect landowners' willingness to participate in and invest in projects through to completion. A survey of technical assistance providers will collect information from forestry and natural resources professionals in the public and private sectors to assess their experiences and perspectives regarding the technical, administrative, and implementation needs for forest and farm NBS practices on rural private lands. Descriptive and statistical analyses of survey data will be conducted to explore answers to the research questions and to better understand the relationships among land ownership, NBS opportunities, technical and professional roles, and program and policy development implications.

On designing a regional innovation ecosystem to address transboundary forest and landscape challenges in Gippsland, Australia

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: This study analyzes the multi-level relationships between innovation actors in a regional innovation (eco)system to assess the potential for transitions towards sustainable landscape futures. The case study is the forest and natural resource landscape of Gippsland, Victoria, Australia, a region that is experiencing major environmental, social and economic disruption. The objective was to explore the design of the existing regional innovation system and assess the relationships between innovation actors to identify opportunities for enhancement. More specifically, we sought to understand the extent to which existing innovation communities (including government agencies, industry, communities, Indigenous and non-governmental agencies) are working together, sharing information, and fostering communicative relationships to support collective ideation and action towards desired futures. Based on key informant interviews and an anonymous survey of actors working towards sustainability transitions in the landscape, we identify a lack of collaborative architecture designed to help with managing commons – in this case the resilience and sustainability of the landscape. Importantly, there is no given common, and this needs to be collectively created through ideation, learning and exchange. The findings suggest the need for public policy to focus on rebalancing power relations among actors through a greater emphasis on niche design to overcome 'lock-in' effects; and supporting and stimulating the diversity of niches and their interactions to facilitate collaboration along complementary perimeters of action and experimentation. To this end, informal channels are identified as a potentially under-utilized opportunity to develop trust and reduce perceived risks of working together. Based on these results, we consider the extent to which innovation ecosystem thinking may help with designing novel multi-level architectures capable of supporting coherent transitions to more sustainable landscape futures in Gippsland. Future research and policy directions are then discussed. This study informs the ongoing efforts of regional and local governments and other stakeholders/ rightsholders to collectively innovate towards equitable, resilient, and efficient natural resource systems under increasing uncertainty through multi-level innovation processes.

Organizational models to associate forest sector's actors: experiences of integration of social and institutional innovation

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: The forest sector is hit by the global environmental and political crisis and its consequences on the market, characterised by unstable prices and an increase in energy costs, that force forest management organisations to seek new forms of competitive advantage and business opportunities, while challenging them to meet the societal demand for environmental services. From another (convergent) perspective, forest management can be vital for socioeconomic development, especially in regions where the use of forest resources represents a relevant opportunity for local communities. Land ownership fragmentation is an important issue that hinders forest management in many countries especially in Southern Europe, and land abandonment is a critical factor, exacerbating the magnitude of impacts and risks of climate change, e.g. forest fires. Management of small parcels is not profitable, many small-holders give it up, and the abandonment of forests accelerates the loss of land value and fosters a vicious cycle that definitively depletes forest-related communities. Various types of innovation have been supported through, e.g., the EU RDP and CAP funds, to aggregate forest properties or to support forest-related supply chains, in order to encourage forest management, including organisational, institutional and social innovations. We present the results of a developed in the context of the project LIFE ClimatePositive, based on semi-structured interviews to a sample of 25 Italian cases, plus 10 from other Mediterranean countries, of organisational models where forest owners/managers are associated among them and/or with other actors. The research is designed to assess whether associative organisational models are a viable solution to increase forest management in marginalized rural areas; how they were inspired and established; which challenges and threats they face and what the successful factors are; what they need to consolidate and scale up in different contexts. Results show that such models often derive from institutional or social innovation processes, eventually overlapping or converging after an initial phase more characterised by one type, they must be tailored according to actors, their objectives and the socioeconomic context. Moreover, in general terms, integration of different models and cooperation is needed to overcome challenges and limits.

Sharing Forests: Participatory Practices in Small-scale Private Forests

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Until now, due to the lack of sufficient financial support, small-scale non-industrialized private forests (NIPFs) in Taiwan generally have the dilemma of forest degradation, lack of management and low productivity. Moreover, because of the low average income of forestry, NIPFs cannot dedicate most of their effort to this industry. Taiwan's Private Forest policy tools are often used to enforce afforestation or economic incentives, but have not improved their performance. Therefore, this study uses the concept of “sharing economy” to separate forestland rights, such as land ownership, decision-making rights, management rights, and use rights. Forest owners can retain ownership, while other rights are shared to other partners who are interested in assisting the owners in managing forests.

In 2019, we searched for a private forest in southern Taiwan, then guided the establishment of the "Jiasian Sharing Forest Group", with 17 sharing partners, who agreed by the forest landowner for using his forest land freely, and helping him with removal of invasive alien species, afforestation, paving forest trails, etc. During the cooperation, the sharing partners can enjoy themselves by relaxing in the forest land, planting and harvesting short-term crops, and building the forest according to their own wishes. Under the sharing forest mode of social participation, everyone jointly decided that the forest would be used diversified when keeping productive functions, and agreed that this forest would not be changed in land use or resold, thus the threat of deforestation could be solved.

In addition, we also observed 3 sharing cases of other private forests in Taiwan. All of them only share use rights with others, but do not share decision-making and management rights yet.

To compare above four cases, we put the degree of their rights-sharing, social participation, and diversification of forest use in three axes, then got the spectral ranges from high to low. We found out that when the degree of participation and rights-sharing are higher, the changes of forest structure tend to be more abundant. So far, this study supports that sharing forest seems to be one of the solutions to the dilemma of private forest management.

Social innovation as a response of forest-dependent communities to contemporary societal, environmental, and economic challenges

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Keywords: stakeholder engagement, policy, forest, people, green recovery

In this paper, we advance conceptual and practical knowledge of social innovation and based on empirical examples from across Europe and beyond, suggest on using it to contribute to meeting the UN Sustainable Development Goals and those of the Green Recovery. Results of the application of qualitative social science techniques, including of participatory methods, combined with visualization tools, provided evidence that by adding to improving human wellbeing, social innovation can create new responses to pressing social demands that are not adequately addressed by markets or existing (e.g., public) institutions. Findings demonstrate that social innovation can assist in tackling societal challenges and utilising the opportunities available and newly emerging in marginalised wooded areas. We show how social innovation can enable forest-dependent communities to realise and develop further their capabilities, while reducing inequalities, and promoting social justice and inclusion. We believe that the conceptualization and operationalisation of social innovation in the context of forestry offered by the SIMRA and SHERPA projects of H2020, and our findings from case studies and living labs, including in Scotland (e.g., on attitudes of local people to sustainability challenges; their innovation actions; improved participation in decision-making and on impacts of social innovation on the ground) can help informing policy decisions and those on management of natural assets and the design of practice measures for a long-term sustainability of marginalised rural areas and their socio-ecological systems.**Acknowledgement**

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Social innovations in forestry: Lessons-learned from more-likely cases

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Social innovation is defined as a process of change in social practices that is driven by collective agency at local level, aimed at well-being of multiple stakeholders, and related to institutional change (Rogelja et al. 2023, Weiss et al. 2021). It is a comprehensive concept and differs from other types of innovation incl. product, service, and technological innovations. The forestry sector has been described as slow to innovate and traditional, with a narrow focus on new technologies and process development. Social innovation in forestry might drive transformative change towards greener and more sustainable business and society. This process, however, is demanding and comparative research limited. The present contribution to the T4.19 session seeks to address this issue and enlarge scholarly research on facilitators and barriers for social innovation in forestry by focusing on more-likely cases.

Attention goes to the GAP-funded Operational Groups (OGs) as likely sites for (social) innovation in the forest-based sector. OGs are based in agriculture and/or forestry, bring multiple actors from different sectors together to advance new ideas and implement them on the ground. They receive funding for 3-4 years. In total, more than 2.500 OGs have been initiated across Europe yet at a far larger scale in agriculture than in forestry and unevenly distributed across the EU Member States. To address the question whether social innovation in forestry and agroforestry has distinct facilitators and barriers and how it rolls out in practice, evidence from survey data and desk research in the Horizon Europe project "European innovation partnership network promoting operational groups dedicated to forestry and agroforestry" is analysed (Project number: 101086216). The influencing factors covered in the collaborative research are: values and attitudes, cooperation, resources, market, society, and government and policy. The focus on OGs allows to control for some of the framework conditions, which eases the comparative analysis.

Socially Innovative Forest and Landscape Restoration in Brazil: Empowering Local Communities for Sustainable Change

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Social innovations (SI) have emerged as transformative tools in the global effort to restore social-ecological landscapes through Forest and Landscape Restoration (FLR) initiatives. Traditional groups such as Indigenous, Kalunga, Geraizeiros, and rural and peri-urban communities actively implement Socially Innovative Forest and Landscape Restoration (SIFLR) in Brazil. This study employed mixed methods and social network analysis to examine Brazilian Networks of Native Seed Collectors (NNSCs) and their role in SIFLR. The findings highlight the significant investment of US$ 12 million received by these NNSCs from 2018 to 2021. This funding facilitated the production of 180 tons of native seeds, generating US$ 1.01 million in revenue for 997 seed collectors, with 55% of them being women. Notably, 46% of the collectors belong to traditional groups, and 23% rely solely on seed collection as their income source. The involvement of government, non-governmental, and university organizations is prominent in these NNSCs. Through partnerships, these networks enable knowledge exchange and cooperation in political action. The study further explores five cases within the SIFLR framework, revealing that local experimentation, familiarity with administrative procedures, and active participation in decision-making processes significantly influence the agency power of social-ecological innovators. These individuals play a vital role in driving change and empowering local communities. This research emphasizes the effectiveness of social innovations in promoting inclusive and sustainable FLR initiatives. It underscores the significance of scaling up and supporting SIFLR efforts, which have demonstrated their value in restoring social-ecological landscapes while empowering local communities. SIFLR provides a promising pathway towards achieving social and environmental goals in forest and landscape restoration by mobilizing capital, creating networks, and reconfiguring social structures. In conclusion, this study contributes to understanding the potential of social innovations in FLR initiatives, particularly in Brazil. The findings emphasize the need to prioritize and expand SIFLR

approaches to ensure the restoration of social-ecological landscapes while benefiting local communities.

Standards – consensus driven agreements to achieve and communicate several sustainability goals of forestry

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Standardization provides a well-established method for developing common solutions to recurrent problems in an industry or within a subject area. International standardization within ISO and CEN has been ongoing for almost 100 years. Standardization has four principles for the work: consensus, voluntariness, openness and is stakeholder driven. Through collaboration and together with the business community, standards are developed for many topics, including ones regarding forestry.

The substantial advantage of working within the framework of standardization is that standards have a high credibility and respect in the market and authorities often refer to standards as a possible way to meet laws and regulations.

Bio-based products are an important piece of the puzzle to achieve the UN's SDG:s and in the transition to a fossil-free society by creating a bioeconomy. There are several standards for bio-based products that are important for forestry. Within Europe, the standard EN 16751, *Bio-based products - Sustainability criteria*, was developed in 2016. In Sweden, we also wrote a handbook for the implementation within the Strategic Innovation Programme BioInnovation during 2017-2020.

In the same standard series, EN 16760, *Bio-based products - Life Cycle Assessment* is published, and in 2024 a new standard that builds on the existing LCA methodology and sets additional requirements and guidelines for comparing the life cycles of bio-based products with their fossil-based equivalents is to be published.

Globally, there is an ISO-committee on *Sustainable processes for wood and wood-based products*. There, a series of three standards are developed regarding the climate effect of wood and wood-based products, taking a more inclusive approach than traditional LCA methodology, looking at the carbon balance of the forest, the value chain emissions, temporary carbon storage in products, and the displacement that occurs when wood-based products replace e.g. fossil-based ones.

These standards (and many more) can be utilized by industry to respond to various requirements placed on forestry and to achieve several sustainability-related goals as well as to communicate on and promote their products. They can also facilitate research and public debate by setting a common framework for calculation and evaluations, leaving less room for ambiguity and misunderstandings.

The causal dynamics of emergent social innovation in Swedish forest landscapes and its potential contribution to sustainable rural development

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: As social-ecological systems, forest landscapes face a range of interconnected demographic, socio-economic, and environmental challenges, which have focused research and policy attention on the role of social capital and networks in the delivery of rural development. At local levels, these challenges have triggered the emergence of social innovation – e.g., new networks and reconfigured social practices – amongst non-industrial forest owners to develop more diversified income streams and reduce the vulnerability of rural communities.

With a broader aim to understand the causal mechanisms linking social innovation to rural development, we explore an innovative social network that has recently emerged in rural Sweden. *Skogens mångbruk* connects non-industrial forest owners who practice multiple use forestry to better support a diverse set of income streams, including tourism and recreation opportunities, high quality wood and food production, hunting, and handicrafts.

Based on 25 semi-structured interviews with network participants and key stakeholders representing public and private sectors, we apply a complex systems approach to analyse this network as an emergent phenomenon within the wider social-ecological context that influences rural development in Sweden. Using qualitive systems modelling and network analysis, we identify the core underlying causal dynamics (e.g., drivers, triggers, feedbacks, etc) by which this social innovation has emerged, and by which it contributes to rural development. We show how the network emerges in response to, and continues to be shaped by, a series of path-dependent constraints and opportunities relating to institutional, economic, technological and socio-cultural factors. We compare core causal dynamics with those of a recent social innovation in small-scale agriculture as well as with other recent studies concerning multifunctional forest landscape collaborations. Our findings make a key contribution towards the development of a robust causal model for the emergence of social innovation in rural development settings, and better enable identification of suitable strategies for scaling up social innovation initiatives in support of sustainable rural development policies in Sweden.

The Potential for New Collaboration in Trail Maintenance in National Parks: A Case Study of Chubu-Sangaku National Park, Japan

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Many national parks in Japan are maintained by the private sector because of lack of management by the government. In recent years, extraordinary weather conditions have caused the deterioration of mountain trails. One of the reasons for the lack of progress in administrative management is the lack of staff and budget for maintenance. Moreover, there have been reports of cases in which the spread of COVID-19 has made it difficult for the private sector, which is the main actor, maintain the mountains. The collapse of mountain trails leads to soil runoff and the decline of mountaineering culture. Therefore, a new approach to trail management in national parks in Japan needs to be considered.

This study examines collaboration and cooperation in trail management based on a case study of volunteer trail management in Chubu-Sangaku National Park in Japan. The research methods are based on observation and participation in trail maintenance by climbers, in order to analyze the techniques and methods required for them. In addition, questionnaires and interviews were conducted with climbers and volunteers in order to promote trail maintenance.

The results indicate that maintenance by climbers has the potential to become a new leader in trail maintenance. This study also revealed that although there are many climbers who desire to maintain the trails, they do not have many opportunities to do so, and the lack of information about maintenance activities does not promote their participation. Therefore, it is necessary to actively engage climbers as maintenance leaders and provide them with the appropriate information and support.

The social and institutional innovations in forest management and nature conservation in Nepal: Are they transformative?

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Transforming the way we manage forests and conserve nature is alarmingly essential to fulfill emerging societal objectives of sustaining forests and nature while improving human well-being. In doing so it is important to change our views, values, and practices that degrade forests and nature from both individual and societal levels. It also requires a close look at the processes followed and outcomes achieved in forest management and nature governance. However, there is a strong dependency of households or society on forests and nature for livelihoods, thus requiring social and institutional innovations that could halt degradation of forests or nature in one hand while fulfilling households or societal needs on the other. In this context, we examine community forestry approach to manage forests and park-people approach to manage protected areas in Nepal. We highlight the salient features of these approaches, progress made, challenges encountered and outline some possible ways forward for sustainability. In addition, emerging societal objectives on forest management and wildlife conservation are becoming more and more complex as they need to balance nature's capacity and human needs, requiring transformation in our current practices. In this later context, we further examine existing social and institutional innovations with reference to community forestry and buffer zone policy in Nepal from a transformative change perspective. We argue that social and institutional innovations were able to bend the curve from continuing degradation to towards more sustainable paths, but the transformative change required to address the challenges to fulfill forest, nature and human objectives are yet to be materialized.

Transformational Change in the Canadian Forest Sector: Shifting from Timber Production to Ecosystem Health

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: Canada's forest sector has been experiencing a transformational change in the past two decades. Changing societal demands, intensification of competition at the global forest products market, and increasing climate change impacts have altered the way in which timber is harvested and forests are managed. Unique to the Canadian context, calls for recognition of Indigenous peoples' rights with respect to the forests and creating the conditions for greater participation by forest-dependent communities in forest governance have become new driving forces in policy considerations.

This paper provides an overview of the major trends in Canada's forest sector, in terms of the significant contributions of forests to the Canadian economy, society and the environment. The main factors at play are examined, using examples and developments in the context of British Columbia's forest sector. The paper argues that Canada's forest sector has entered a new era where forest practices are expected to facilitate a shift from the traditional dominance of timber production towards the protection of ecosystem health and resilience. The transition from woodland management to forest stewardship calls for a broader spectrum of partnerships involving industry, non-government organizations, government agencies, as well as Indigenous peoples and forest-dependent communities. To succeed in realizing the new vision will require forest professionals to change their mindset from viewing forests as a source of wood fibre to embracing forests as the places where people live, work and play.

Unlocking the Transformative Potential of Forest-Based Social Innovation for Sustainable Rural Communities in Europe

T4.19 Institutional and Social Innovations in the Forest-based Sector as a Response to Contemporary Challenges

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Abstract: In the last ten years, social innovation (SI) received increased attention from policymakers and academia, due to its potential to revive marginalized rural areas, contribute to the sustainability of natural resources, and improve the well-being of local, forest-dependent communities. In general, European research on forest-based SI is based on case studies related to ecotourism, health/well-being, traditional forestry practices, participatory decision-making, gender initiatives, and others. Although those cases address various dimensions of SI processes (e.g., institutional frameworks, actors, trade-offs, benefit sharing, and impacts), to a lesser extent, they comprehensively deal with the mechanisms leading to the institutionalization of SI in the forest-based sector, as well as the long-term effects of such institutionalization on forest governance. Institutionalization is crucial for understanding the transformative capacity of SI, e.g., its' capacity to influence the system change, as formal institutionalization is the structuration process in which new formal rules are established or existing ones are reaffirmed. Our contribution aims to better understand the transformative capacity of forest-based SI by building on research on SI in rural areas and forestry (e.g., H2020 SIMRA project), and meta-analysis of several European case studies. Using constructivist institutionalism, we identified the moments of "institutional disequilibrium", as points of "contact" of informal and formal rules during the development of selected SI initiatives. Our results indicate that in the SI process informal, cross-level institutionalization precedes formal institutionalization. In the moments of formal institutionalization, local-level initiatives might get disempowered by top-down, command, and control regulation. Although a SI initiative might already achieve positive effects, the change in formal rules and thus forest governance might remain largely unlikely (at least within the policy-making arena). To scale and influence the modes of forest governance, forest-based SI needs to be coupled with institutional innovations (and changes) and supported by public actors on the national level. Forest-based SI initiatives need periods of "exceptional'' policy-making, which is deliberative, adaptive, and innovative, to fulfill the transformative potential and substantially affect forest governance. Our study offers insights into the institutional dynamics of SI pointing out that systemic changes are needed to transition to a more sustainable, green, and just society.

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

Adaptation of forest management system under the armed conflict in Ukraine

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Armed conflict as no predictable factor of the external environment, necessitated the adaptation of the management system and forestry practices in Ukraine. This adaptation required updating the tools for achieving the goals of responsible forest management. One of the measures for elimination of risk to the health and life of people is excision the areas contaminated by explosive objects (CEO) from the FSC certification scope. Certificate holders shall make relevant changes in forest management and practices in Ukraine if there are CEO areas (which should be reflected in the Annex of the FSC National Forest Stewardship Standard of Ukraine):

- take into account the applicable legislation of Ukraine in terms of hazards associated with explosive hazardous areas;

- outline approaches to the identification of CEO areas, their demarcation, mapping, take into account the best available information and be based on the application of the documented procedure;

- provide for appropriate adaptation of a management plan in terms of all its components (policies, objectives, targets etc.) and adaptation of monitoring system;

- assess, document and monitor impacts related to the CEO areas and ensure an appropriate response to such impacts through adaptive management;

- define the requirements for systematic protection of the CEO areas from unauthorized or illegal resource use and other illegal activities;

- support the legal rights of the affected stakeholders by the presence of CEO areas within a management unit;

- ensure strengthening of management strategies and actions to maintain and/or enhance of High Conservation Values on the territories that are not contaminated with explosive objects;

- prevent forest products from CEO areas from entering FSC supply chains, in particular by implementing appropriate procedures for tracking and tracing of all forest products, as well as procedures for use of FSC name and trademarks.

Incorporating these provisions in the national criteria, indicators and verifiers for excision of CEO areas from the scope of FSC certification will help to preserve the integrity of FSC certification and appropriate adaptation of forest management to the conditions of martial law and post-war situation.

Armed Conflicts, Climate Change, Wildfires and Human Security in the Cultural Landscapes of Temperate-Boreal Eurasia

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Cultural landscapes of temperate-boreal Eurasia, which were formed by traditional agrarian societies over centuries, are undergoing rapid changes. Rural exodus and the accelerating trend of urbanization in some regions are associated with abandonment of land cultivation and thus directly or indirectly affecting fire regimes in some regions. Climate change is contributing to aggravation of wildfire risk and wildfire severity. This contribution looks at the specific issues linked to the heritages of civilization including industrial and nuclear accidents and armed conflicts in temperate-boreal Eurasia.

In Europe, armed conflicts have resulted in collateral damages, including wildfires, and left behind significant areas contaminated by unexploded ordnance (UXO). In regions affected by military operations, UXO and land mines constitute a major problem for post-conflict forest management and fire management. Over more than a Century, large territories have been affected by collateral wildfire damages during wars. Wildfires occurring on lands contaminated by UXO and land mines as consequences of armed conflicts are posing high risk to human security. Examples are provided from the Western Balkans (World War I and military conflicts related to the dissolution of Yugoslavia 1991-2001), Central and Eastern Europe (World War II and military activities during the Cold War), South Caucasus (dissolution of the Soviet Union and recent armed conflicts) and Ukraine (since 2022).

In the early 2000s, the Global Fire Monitoring Center (GFMC), which was established in1998 to serve the science-policy interface towards developing informed fire management policies, governance and practices, started addressing fire management solutions in conflict and post-conflict areas. Besides developing technological and managerial solutions, the GFMC is facilitating cross-boundary cooperation in fire management for confidence-building and peacekeeping in regions of political and military tensions. In the light of socio-economic changes, land-use change and the climate crisis, the collateral damages and remnants of war constitute a major challenge for regional and international security. Joint bilateral, regional and international cooperative projects and programs in landscape fire science, integrated landscape fire management and policy development are exemplary for realizing joint interests in environmental protection, wildfire disaster risk reduction and sustainable integrated fire management capabilities.

Contribution of FirEUrisk project to risk assessment and prevention of forest fires in the Chornobyl Exclusion Zone

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: The Chornobyl Exclusion Zone (CEZ) were established after the disaster 26 of April 1986 that contaminated of environment by radionuclides (RN): Sr-90, Cs-137, Pu-238-240, Am-241. The CEZ territory was fenced with area 260 000 ha, including most contaminated 10-km core zone around ChNPP. Special State Forestry Enterprise “Chornobyl Forestry” were established to prevent radioactive forest fires. Due to climate change and lack of funding regular large fires have been occurred in CEZ: 1992 (17000 ha), 2003 (5000 ha), 2015 (15000 ha), 2016 (1200 ha), 2020 (80 000 ha). Russian military invasion 24.02.22 resulted in damage fire engines and contamination of CEZ with unexploded ordnance (UXO) and land mines. From 12 forest fire stations only 2 left undamaged with few fire engines.

While details maps of radioactive contamination exist and allow to predict doses for fire personal, unexploded ordnance (UXO) and land mines were not mapped and create huge uncertainties and high risks for life and health of firefighters and engines. Under these conditions scientific products (models, data sets, maps), special technologies of prescribe burning and armored vehicles to protect fire personal from UXO are only solution to manage risks and prevent fires.

EU Horizon FirEUrisk project (project number 101003890) will develop, evaluate and disseminate a science-based integrated strategy to: 1) expand current wildland fire risk assessment systems, including critical factors of risk previously not covered; 2) produce effective measures to reduce current fire risk conditions, and 3) adapt management strategies to expected future climate and socioeconomic changes.

Regional Eastern Europe Fire Monitoring Center (REEFMC) within the project developed two products and DSS to address risk for personal and forests from fires in CEZ: 1) Combining Landsat time series and GEDI data for improved characterization of fuel types and canopy metrics in wildfire simulation; 2) Modelling of the extinction moisture content for main fuel types of the CEZ; 3) DSS system for prevention and safe suppression of radioactive fires on terrains contaminated by UXO. All products will be demonstrated in CEZ and extended on larger area of Ukrainian Polissia based on Ukrainian Landscape fires portal (www.wildfires.org.ua).

Damage to Ukraine's forests due to Russian aggression: estimates for the year 2022 based on satellite data

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: The Russian-Ukrainian war (since 2022) has already entailed multiple negative consequences for Ukraine's natural environment. Shelling and accompanying fires have reportedly ravaged agricultural and grassland ecosystems in vicinity to active battles. Resulting fires, mechanical shelling damage, and tree harvest for fortification purposes severely fragmented Ukrainian forest landscapes that are already a complex mosaic. The greatest amount of damage was reported along the frontline in southern and eastern regions of Ukraine. However, also severe wildfires occurred in Chornobyl Exclusion Zone (CEZ, north of Ukraine) after Russian forces left it in April 2022.

We estimated damage to forests in three areas of interest (AOI): East (20 counties in Donetsk, Luhansk, and Kharkiv regions); Kherson (8 counties in Kherson and Mykolaiv regions); CEZ. We used Sentinel-1 and Sentinel-2 imagery to predict pre-war land cover and derive a forest mask, and high-resolution satellite imagery to digitize visually damaged forest cover. We calibrated a binary classification model using spectral Sentinel-2 to determine the difference between August-September medians for the years 2021 and 2022. Our model derived damage estimates with 88% overall accuracy.

24,180 ha were damaged in East AOI (9% of 2021 forest cover). Damage estimates for Kherson AOI (7,293 ha, or 16% of pre-war forests) and CEZ (7,116 ha, or 5% of 2021 forest cover) are similar. Additionally, we found that 89% of damaged forest patches in Kherson AOI are highly fragmented and share an edge with highly-flammable open landscapes. For East AOI and CEZ this estimate is lower, at 70%.

Forests in southern and eastern parts of Ukraine are extremely crucial for the ecological functioning of local landscapes. Precise estimation of war-related damage is important for designing post-conflict forest regeneration.

Demining of Ukrainian forests

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Humanitarian demining is high on the agenda of Ukraine and its allies, as it is the unsurmountable condition for fully reclaiming the territories that have been freed from occupation or simply used to be close to front lines for an extended period of time. Without demining roads, settlements and agricultural fields, neither normal everyday life nor economic activities can fully resume, as large areas will remain mortally dangerous or inaccessible. Yet a large part of country that has suffered from the war still lacks such attention: these are Ukraine's forests and other natural landscapes. Not the responsibility of the State Emergency Service, forest lands are left to the devices of forest management authorities, who are overstretched with their core tasks and do not possess the expertise, capacities and indeed the budget for carrying out demining operations at the required scale. The contamination of Ukraine's forests with landmines and unexploded ordnance already regularly puts at risk and kills forest guards and local inhabitants. And as long as forests will remain contaminated, neither regular maintenance nor emergency interventions, e.g., in case of fire, are going to be possible. While the former endangers forest conditions in the longer-term perspective, the latter bears the tangible risks of losing even more forest land than what has already been lost during the war. The contaminated forests will remained barred for the local population, depriving people of their essential livelihoods and recreational resources. Even more critically, the mined forests will continue to put at risk those who dare to venture into the dangerous terrain notwithstanding warning signs and roadblocks. Children are particularly prone to such behaviour. For an effective response to this large-scale challenge, a collective international effort is needed to specifically focus on surveying and demining Ukraine's forests. Along with that, urgent and systematic efforts are required to make people fully aware of the risks and to help them contribute to their mitigation.

Enhancing Close-to-Nature Silviculture in Ukraine: The Utility of martelage.sylvotheque.ch in Fostering Post-War Forest Recovery

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Close-to-nature silviculture (CTNS) covers a broad variety of techniques that rely on natural processes to influence forest development to provide essential forest ecosystem services. A profound understanding of forest ecosystems and their underlying processes is crucial, alongside the ability to adapt to local conditions and choose appropriate silvicultural methods that align with societal and forest owner expectations. Creativity plays a vital role in discovering innovative approaches to climate adaptation and enhancing resilience, particularly in Ukraine, where 690,000 ha of forest affected due to the war.

This paper presents the potential of combining the "marteloscope" concept with digitalization to train forest students and practitioners in Ukraine to address the challenges of post-war forest recovery.

The “marteloscope” concept has proven to be useful for teaching CTNS. It helps to enhance knowledge, but also to develop ones “own know-how”. A large network of marteloscopes is useful to cover the manifold aspects of CTNS. Digitalization has been instrumental in establishing and managing such network, enabling data analysis, comparisons of marteloscopes, and promoting experience sharing both in the forest and through virtual reality. The *martelage.sylvotheque.ch* (MSC) internet platform, along with the complementary *MSC Mobile smartphone app*, were developed for this purpose. Currently, there are over 200 marteloscopes in four countries.

With extensive experience in applying CTNS in Switzerland and leveraging digitalization, BFH-HAFL has developed a course of action in collaboration with NUBIP to support Ukrainian forest stakeholders in building capacity for post-war recovery. Through workshops and knowledge transfer events, we have shared Swiss expertise with Ukrainian researchers, students, and practitioners. *Martelage.sylvotheque.ch* has served as a catalyst for promoting CTNS among Ukrainian stakeholders. We have successfully established a dedicated network of researchers and practitioners committed to implement CTNS in Ukraine. The potential and limitations of Marteloscope and MSC have been assessed, and efforts to establish MSC plot networks are underway. Our next objective is to develop guidelines on different CTNS approaches and elaborate training concepts for students and practitioners. By facilitating knowledge sharing with policy makers, we will promote CTNS principles into forest management practices in Ukraine, fostering sustainability and resilience in post-war forest recovery endeavors.

Impact of armed conflict on Tigray's arid-land ecosystem restoration efforts: a remote sensing approach

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Over the past century, there have been numerous civil wars and interstate wars in Africa, some of which are still raging today. Many of them have resulted in dramatic environmental consequences, including biodiversity loss. One among the many, Ethiopia's Tigray region sustained immense environmental damage. However, this has not received due attention, ostensibly due to people's sensitization to the overwhelming devastation to lives and livelihoods. Here we aim to investigate changes in forest cover during the war period (2020 to 2022) using the advances in earth observation techniques, supplemented by field testimonies and secondary data. Vegetation indices such as the Normalized Deviation Vegetation Index (NDVI) and Gross Primary Productivity (GPP) are considered to indicate the extent of change. The magnitude, direction as well as the drivers of change in vegetation cover varied throughout the study period. Preliminary results suggest that woody vegetation cover (NDVI >0.3) over Tigray's dry Afromontane forest declined from about 16% in 2020 to 11.43% in 2021 and 9.8% in 2022. This indicated that 39.4% of the forest cover in the region has been lost in two years period. Land restoration practices meant to avert desertification were interrupted; warfare accompanied by shelling ravaged dry Afromontane forest landscapes, further modifying weather and climate; and the denial of essential services such as electricity for household or industrial use created a heavy reliance on natural resources such as firewood and charcoal. Tigray being at a very high risk of desertification and sandwiched between desert areas, the magnitude of damage, which went unattended, over the last two years leaves a top alarm. Continued ecosystem damage could eventually make the domain part of a wider desert connecting the Sahel to the Afar Triangle, a scenario which may render the area uninhabitable.

Impact of war in Ukraine on wildfire regimes, fire management and carbon emissions

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Military aggression of Russian Federation against Ukraine heavily impacted forests and fire regimes of landscapes. Direct impacts included shelling, mechanical damage of trees and soils, trenches, increasing ignition sources as collateral damages during combat. Indirect impact resulted in unaddressed fires on occupied territories during weeks, loss and limitation of fire management capacities, lack of personal and equipment, contamination of large areas of forests with unexploded ordnance and land mines that pose high risk for personnel. For assessment of impact of war, all fires in Ukraine in 2022 were manually delineated and classified using Sentinel 2 imagery. We defined three discrete burn severity classes using the following delta NBR (Normalized Burn Ratio) thresholds: low (0.090-0.179), medium (0.180-0.549), and high (0.550 and higher). The Copernicus Dynamic Land Cover map was used to attribute the burned area to a specific land cover (coniferous forests, deciduous forests, croplands, other natural vegetation, and urban territories). Average values of burn severity obtained for each land cover type were used in carbon loss calculations over Ukraine. Carbon emissions were estimated using averaged data on the structure of forest biomass (Shvidenko et al., 2014) and yields of agricultural lands. The total area of landscape fires in Ukraine during 2022 reached 755 638 ha, including croplands (419 313 ha), forests (56 719 ha), and abandoned lands (273 987 ha). In total 19 948 fires were occurred. They were mostly (50.3%) burned within 60-km buffer zone along a daily front line, while 42.3% of all fires occurred in occupied territories. The war directly affected about 25% of the protected areas of Ukraine. The area of fires burned on the Emerald Network reached 88 427 ha. Over entire Ukraine, landscape fires in 2022 resulted in more than 1.3 million tons of carbon emissions. Almost 48% of carbon emissions were caused by fires within occupied territories of Ukraine. We expect that fuel loads in landscapes due to the impacts of war will create high risks of wildfires at level of emergency situations, similar to 2020. In future, the development of a national interagency system of landscape fire monitoring and management is required.

Mapping forest conflicts – what did we learn?

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Abstract: The efforts to combat the negative effects of climate change are large. Forests as one of the most promising allies in this battle are therefore under enormous pressure. Increasing demand for forest products and services for commercial and non-commercial use positions forests at the centre of various conflicts around the globe. This study focuses on the forest conflicts in 28 member states of the European Union (27 + UK) to map different conflict cases, describe their main characteristics and observe potential emerging patterns among them. Content analysis of academic literature from the period 1999-2020 resulted in 84 conflict cases, where each case was assigned a location, type of conflict, intensity and main stakeholders. Based on these characteristics, we can discuss that the most common forest conflicts occurred in and around urban areas, followed by conflicts over forest conservation. The majority of the mapped conflicts were characterized by low intensity, i.e. restrained conflicts, followed by open conflicts. Open conflicts are those often involving protests, petitions or lawsuits. Six conflicts involved violent actions like attacks and were under the category of violent conflicts. The analysis of the observed forest conflict features resulted in the development of three emerging patterns: conflicts over forest protection, conflicts over the development of forests and conflicts over the recreation in forests. Based on the information obtained during the analysis it can be discussed that effective communication, transparent planning process and proper involvement of all stakeholders are the key approaches to prevent harmful high-intensity forest conflicts.

Pest management and forest health monitoring of forests contaminated by UXO

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: The stands with a predominance of host trees, with low density, adjacent to clear-cuts, burnt areas are most favorable for forest pest mass propagation. During hostilities, the forest structure over a large area is disturbed due to the construction of fortifications, fires, and damage to trees by shells. Forest defragmentation brings to a weakening of trees, an increase in their vulnerability to phytophagous insects and pathogens, and the formation of permanent outbreaks of these pests. With the intensive movement of people, troops, and equipment, the risk of the establishment of alien pest species increases.

Traditional methods of early detection of pests and diseases, prevention, localization, and elimination are impossible in a significant part of the territory of Ukraine, which is mined or contaminated with explosive objects during battles or shelling. The detonation of unexploded ordnance and mines can cause the death of personnel during forest protection measures, as well as cause a fire, and the death of trees and forest animals. At the same time, the detection of pests and pathogens in the forests contaminated with explosive objects is necessary to prevent the spread of forest decline and obtain wood in the event of an irreversible weakening of the stands.

In forest enterprises, first of all, it is necessary to demine the seed stands, seed orchards, the territory of greenhouses, nurseries, and unclosed plantations, and, first of all, protect these objects from pests.

Pest outbreaks in massive forests should be detected by remote sensing. At the macro level, Landsat or Sentinel images with a spatial resolution of 10–30 m should be obtained at different periods of the year. At the micro level, the plots of forest deterioration must be identified using fire surveillance cameras. Such images must be taken once every two weeks from mid-April to the end of August in coniferous forests, and once a month in May, June, and August in deciduous forests. If a change in crown color, or density is detected, images obtained on adjacent dates are compared to assess the rate of forest health deterioration, and damaged area, and to plan forest protection measures.

Postfire forest management: science-based assessment, monitoring and restoration

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Due to the climate change, the risk of forest fires in Ukraine remains high while the massive military Russian invasion multiplied those risks. Therefore it`s relevant to develop science-based silviculture approach to mitigate loses caused by wildfires. This creates additional risks for human safety and health. Forest health deterioration of the damaged stands leads to significant economic (losses of timber that can be obtain after salvage logging) and ecological losses (forests after severe wildfires are not able to fully provide most of ecosystem services).

As a result of forest fires, areas with completely or partially dead stands are formed. If, in the first case, forestry treatments are focused of salvage logging of stands and reforestation of these areas, then in the second case, decision-making process is more complicated. To evaluate the post-fire development of burnt areas and the possibilities of their restoration, researchers from URIFFM have developed a set of recommendations and guidelines to support postfire assessment and forest restoration for different climatic conditions (including restoration in severe condition of South Steppe) and specific natural features of each area. Multiple regression analysis as well as logistic regression analysis were used to develop tree mortality models. Postfire monitoring (forest health monitoring) of damaged stands are performed using remote sensing methods. Similar approach with the active use of LIDAR and optical sensors now also under development (Myroniuk, Zibtsev, 2023).

To predict tree mortality and the possibility of damaged forest to restoration, an experimental three level framework was proposed: I) stand level – prediction of the share of trees that will die, depending on the type and intensity of fire damage as well as forestry characteristics of tree stand (age, DBH etc.); II) individual level – estimating the mortality probability of each tree in the same stand; III) remote level – monitoring of forest health changes of each damaged stand for several years (up to six years) after the fire (vegetation indices for the control period and after fire damage were used).

These approaches combined with adequate forestry treatment can be used to significantly mitigate both ecological and economical losses caused by forest fires.

Preliminary assessment of environmental damage during the war in Ukraine in 2022

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Russia's war against Ukraine has had devastating humanitarian, social, economic and environmental consequences. The OSCE preliminary assessment of the environmental damage and risks caused throughout the first year of the war between February 2022 and February 2023 has contributed to shaping response and recovery planning in Ukraine. The report has covered the environmental context before February 2022; military conduct; the impacts of the war on industrial and energy infrastructure, nuclear facilities and other radioactive sources, the built environment, the rural environment, freshwater resources and infrastructure, the coastal and marine environment and the climate and climate policies; as well as the evolving legal and regulatory environments.

Although the dynamics of the war varied throughout the year, it remained a high intensity armed conflict characterized by severe damage to settlements, environmentally hazardous infrastructure and landscapes. Long-range weapons affected sites nationwide, while the indiscriminate use of explosive force devastated areas along mobile and static front lines.

The war has seen the unprecedented occupation of current and former nuclear energy-generating sites, and underscored the range of direct and indirect threats to nuclear and radiation safety, and nuclear security, which can be triggered by armed conflicts.

Alongside the environmental damage linked to the fighting itself, natural resources and geographical features proved strategically important for the conflict parties. This included woodlands and forestry, rivers, canals, reservoirs and coasts, offshore islands and infrastructure, agricultural shelter belts and industrial spoil heaps. The use, targeting and militarization of these features contributed to environmental harm. Fighting also affected nationally and regionally important habitats and protected areas, with a wide range of direct and indirect impacts.

Based on the findings and an assessment of Ukraine's needs, the report suggested a set of specific recommendations for improving the information and knowledge base, building Ukraine's capacity for assessing and addressing the environmental impacts of the warm, and mainstreaming the environment in recovery policies and planning altogether.

Seeing the Forest for the Trees: A Multi-Actor Approach to Trigger Sustainable Forest Governance in Post-War Ukraine

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: This paper aims to contribute to the conceptual and practical understanding of sustainable transformations in forest landscape governance within a post-war environment, using Ukraine as a case study. By employing a multi-actor approach that integrates the participation of local communities, policymakers, and experts from forestry and agriculture, we propose an innovative tool for fostering discussions and devising strategies to promote sustainable and resilient landscapes. Recognizing the dialogue process as a valuable instrument for disaster risk reduction and conflict resolution, we emphasize the importance of ensuring the inclusion of all relevant stakeholders, particularly local communities, who play a crucial role in shaping the future of their landscapes. Our research findings demonstrate that a sustainable and inclusive landscape governance dialogue, which adopts a holistic perspective by considering the intricate interconnections between the environment, economy, and society, should be firmly rooted in principles of inclusiveness, transparency, and collaboration. By facilitating evidence-based decision-making through comprehensive data gathering and analysis, forest landscape management effectively supports informed discussions among all stakeholders. We believe that modeling human-environmental interaction using a multi-actor approach that integrates people, landscapes, and policy represents an effective means of fostering sustainability in post-war Ukraine. Through the implementation of this comprehensive framework, we can effectively address the complex challenges faced by post-war forest landscapes and promote long-term resilience.

The Restoration of Ukrainian Damaged Forests by War: a Way to Providing Improved Planting Material

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Europe's forests, particularly in Ukraine, are highly vulnerable to climate change. In connection with the frequency, intensity and timing of fire events, hurricanes, droughts, ice storms and insect outbreaks resulting from human activities and global climate change, forest ecosystems are even more prone to damage.

Since 2022 due to Russian aggression, Ukrainian forests have experienced a new negative impact. As per preliminary data from Ukrainian experts, over 2.5 million hectares of forests were lost due to military operations. High-quality plant material will soon be needed to restore the Ukrainian forest.

The maintenance and improvement of forest health are high-priority issues, and various stakeholders have shown an interest in understanding and utilizing ecological interactions between trees and their associated microorganisms. Endophyte microbes can influence the health of trees either by directly interacting with the damaging agents or modulating host responses to infection. In the framework of this work, ten morphotypes of endophytic bacteria from the tissues of unripe acorns of *Quercus robur* L. were isolated. Based on the results of the sequenced 16S rRNA gene, four species of endophytic bacteria were identified: *Bacillus amyloliquefaciens, Bacillus subtilis, Delftia acidovorans*, and *Lelliottia amnigena*. Determining the activity of pectolytic enzymes showed that the isolates *B. subtilis* and *B. amyloliquefaciens* could not cause maceration of plant tissues. Screening for these isolates revealed their fungistatic effect against phytopathogenic micromycetes, namely *Fusarium tricinctum, Botrytis cinerea*, and *Sclerotinia sclerotiorum*. Inoculation of *B.*

subtilis, *B. amyloliquefaciens*, and their complex in oak leaves, in contrast to phytopathogenic bacteria, contributed to the complete restoration of the epidermis at the damage sites. Inoculation of *B. amyloliquefaciens* and *B. subtilis* isolates into oak leaf tissue were accompanied by a decrease in the total pool of phenolic compounds. The ratio of antioxidant activity to total phenolic content increased. This indicates a qualitative improvement in the overall balance of the oak leaf antioxidant system induced by potential PGPB. Thus, endophytic bacteria of the genus *Bacillus* isolated from the internal tissues of unripe oak acorns have the ability of growth biocontrol and spread of phytopathogens, indicating their promise for use as biopesticides.

Towards developing forest monitoring capacity in Ukraine in the post-war reality

T4.20 Managing Safety and Resilience of Forests and Forestry affected by Armed Conflicts and the Climate Crisis: Past and Future Contribution of Forest Science

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Abstract: Effective post-war forest management in Ukraine requires accurate and timely information on forests in a spatially explicit form. Since 2022, large forests in Ukraine have been affected by the russian invasion, leading to increased vulnerability of forest stands under climate change or total forest loss in the war zone. Assessment of the impact of the war on the environment and decision-making can be supported by the use of innovative solutions. Forest monitoring capacity in Ukraine can be strengthened through close scientific cooperation with the international community, technology exchanges, and training.

Large areas in Ukraine will remain restricted by landmines and unexploded ordnance, so forest monitoring requires more advanced use of remote-sensing data. Since forest inventory information cannot be collected in such areas, research into advanced technologies to propagate spatially explicit estimates becomes crucial. Thus far, efforts in Ukraine have been fragmented and therefore ineffective for long-term management. The forest information in Ukraine in the post-war period is expected to be little updated. To improve the situation in the future it is important to update data collection with innovative solutions. Satellite time series and airborne scanning technologies (i.e., LiDAR) can provide strong support for strategic forest inventories to inform forest management. Thus, there should be a systematic basis for regularly updating forest information in accordance with new disturbances, as well as forest growth forecasts.

Forest monitoring technologies based on the combined use of forest inventory data, satellite time series and LiDAR scanning data have been used in many developed countries, so their experience can reinforce the potential of forest monitoring in Ukraine. We also note professional expertise as an important component of strengthening forest monitoring capacity in Ukraine. This can be improved by developing the essential skills through trainings involving leading international experts.

T4.21 National perspective of Forest resources policy and governance in countries of Latin America under a sustainable perspective

Building policies for a just transition: Challenges and opportunities in national incentive programs for land restoration in Latin America

T4.21 National perspective of Forest resources policy and governance in countries of Latin America under a sustainable perspective

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Abstract: Through the Bonn Challenge and Initiative 20x20, countries in Latin America and the Caribbean have pledged to begin restoring over 50 million hectares of land by 2030. As countries move from pledge to plan to on-the-ground implementation, it is increasingly clear that incentive policies are necessary to meet these ambitious targets. However, governments face difficult decisions when building these programs to meet a wide range of complementary and competing goals. For example, should government programs target smallholders to increase community benefits or private landowners to increase scale? How can programs include women and traditionally marginalized communities where land tenure may be a challenge? And how should governments weigh social, economic, climate, and biodiversity benefits?

This talk will share honest perspectives on the challenges and opportunities for governments in building effective and equitable incentive policies through experiences in the Landscape Policy Accelerator and Landscape Monitoring Accelerator. These two innovative peer-to-peer capacity development programs for policymakers and government officials support the improvement or design of incentive programs for restoration as well as policy monitoring to track performance and impacts. The discussion will highlight work from Chile, El Salvador, Guatemala, and Costa Rica and consider pathways forward for countries aiming to develop restoration incentive programs.

Challenges and opportunities in the implementation of policies of Payment for Environmental Services for forest conservation in the Brazilian Amazon

T4.21 National perspective of Forest resources policy and governance in countries of Latin America under a sustainable perspective

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Abstract: The study aimed to evaluate the scenario of federal public policy instruments aimed at Payment for Environmental Services (PES), as an alternative for forest conservation in the Brazilian Amazon, highlighting its advances, challenges and opportunities. The research method adopted was exploratory, based on bibliographic research, which consisted of identifying, locating, compiling and summarizing information and ideas on the subject. The main source of research for the elaboration of the study was carried out through consultations related to the theme, in the current legislation, projects and programs, official websites, scientific journals, reports, guides and manuals. The results showed 13 instruments of PES policies at the federal level, in almost two decades. Although they are not directly PES policies, the National Fund on Climate Change and the National Policy on Climate Change - mention the modality. In the Forest Code economic instruments were established as an alternative to reconcile the economic activity in rural properties with nature conservation through PES, being an old demand from the productive sector. After the Forest Code, PES gains more strength in the years 2020 and 2021 with the creation of the Green Rural Product Bill and the Floresta+ Program and its axes: Bioeconomy, Carbon, Entrepreneur and Agro, all with goals and guidelines to promote the valorization of activities developed in the Amazon, such as sustainable forest management and integrated production systems. In the same period the National Policy for Payment for Environmental Services is enacted, a fundamental law to guide state and municipal PES actions. After the launching of the policies and programs, PES actions started as pilot projects in the states of the Legal Amazon, helping in the environmental regularization and transfer of resources. We can conclude that despite the important advances observed in the last two years, the regulation of PNPSA is urgent in order to provide legal security to PES actions. It is recommended to create clear rules about the forms of valuation and definition of environmental services provided, as well as to encourage the participation of the private sector, so that PES does not remain a policy of income transfer.

Forest policy and governance in Uruguay: evolution and projections of a strategic sector

T4.21 National perspective of Forest resources policy and governance in countries of Latin America under a sustainable perspective

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Abstract: Uruguay developed its forest sector within the framework of a specific regulation that strategically positioned it in terms of the country's economy and development. Forestry Law 15.939 of 1988 was approved by all the members of Parliament. Despite the alternation of the majority parties in the government, the Law was not changed. However, after thirty-five years, Uruguay is still facing the challenge of diversifying the sector. On the other hand, critical voices have emerged regarding the evolution of the sector, both from the political spectrum as well as from non-governmental organizations and environmental movements. This paper aims to analyze the current situation of governance in the Uruguayan forest sector and its implications in terms of its development. The concept of governance has evolved from origins anchored in institutional economics (early 20th century), as well as with the school of regulation (1970s). It has subsequently expanded its application in the field of social sciences, where it is now used to address different processes from a multilevel perspective, encompassing the global, regional, national, subnational, and local levels, analyzing development processes in their multidimensionality. On the other hand, the conceptualization focuses on participation and relationships that go beyond the traditional political format of government hierarchies, encompassing links with civil society actors and the private sector. Considering the Uruguayan case, this framework is particularly interesting to analyze the initiatives that have been promoted during the last decade by the government to promote the forest sector. In this regard, the results have been uneven depending on the emerging coalitions: while in some isolated cases governance has been strengthened, in others there is a lack of coordination to generate cumulative processes in a strategic sector of the country. A substantive aspect in the projections is the role to be assumed by STI (Science, Technology, and Innovation) policies as well as the possibilities of the so-called 'green finance'.

Forest Policy Reform and Implementation in Peru

T4.21 National perspective of Forest resources policy and governance in countries of Latin America under a sustainable perspective

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Abstract: Peru is among the top ten countries in the world in terms of forest extent (ranked ninth in 2020 according to FAO) and has undertaken significant forest policy reforms aimed at reducing deforestation and enhancing forest sustainability in the past two decades, including the 2011 Forestry and Wildlife Law (No. 29763), the 2014 National Pact on Legal Timber, and the National Multisectoral Strategy to Combat Illegal Logging 2021-2025. Despite increases in participation and transparency in forest policymaking, devolution of forest authority to regional governments, incorporation of community based and economic instruments, and forest policy integration across sectors, forest loss and degradation persist across much of the country. As reported by FAO, forest loss in 2020 was the highest in Peru's recorded history. We examine forest policy reforms and their implementation in Peru through an historical institutionalist lens taking into consideration internal and external factors as well as the critical junctures, feedbacks and recursive dynamics that influence policy formulation and implementation. We explore the institutional factors that have shaped new forest policy approaches and instrument mixes, including the role of state and non-state actors, the influence of international agreements and initiatives, the effects of historical paths and legacies on policy reform and broader sociopolitical and environmental factors. We also incorporate top-down and bottom-up perspectives on policy implementation to shed light on policy effects and effectiveness. We aim to identify strategies for enhancing the effectiveness of policy design, reform, and implementation and to contribute to broader discussions on the state of and advances, challenges, opportunities and perspectives of forest policy and governance in the tropics.

PROSPECTS OF PINUS AND EUCALYPTUS PRODUCING COMPANIES IN THE STATE OF PARANÁ

T4.21 National perspective of Forest resources policy and governance in countries of Latin America under a sustainable perspective

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Abstract: The forestry industry supplies raw materials for fuel, cellulose, mechanical pulp, paper, reconstituted panels and solid wood products that supply other industrial segments and/or the end consumer. More than 10% of Brazil's wood product companies and one of the most diverse industrial parks in the Brazil's entire forestry setorare located in the state of Paraná. The objective of this study was to analize the forest production phase in the supply chain – pine and eucalyptus in particular – through the lens of policy drafting principles. To this end, perspectives for the next 5 years with respect to planted forest area, forest productivity, investment intent and staffing prospects were identified. Critical factors in the forestry supply chain were identified and prioritized using factor analysis (to determine critical factors) and the Friedman Test (to verify differences between factors and rank them). A Wilcoxon test was used to verify differences in perception between integrated and non-integrated companies with respect to the critical factors. A content analysis technique, grounded in a PESTEL structure for theoretical foundation, allowed us to examine the external environment, and identify challenges and opportunities and their respective macro environmental causes. Results suggest a perspective where planted area grows by 10% and productivity grows by 18% between 2017-2021 and where non-integrated industries form a group that proportionally grow more than the integrated companies, especially the TIMOs. Integrated companies in the solid wood and reconstituted panel were the most affected by the domestic and international economic conditions, negatively in fact. Given the peculiarities of pine and eucalyptus companies of Paraná, two additional conditions were identified beyond the six dimensions proposed by the Pestel structure: Infrastructure and Market. The economic dimension includes most of the threats and opportunities to which companies are sensitive, wherein the current economic recession is seen as the greatest threat. The chief opportunities are perceived to hinge upon the recovery of the domestic economy. Legal and regulatory instruments, and especially labor and environmental laws, are seen as the greatest threats to the industry. The most important critical factors were: demand, technology, macroeconomy, and logistical, social, and legal costs.

Regulating deforestation through the Brazilian Amazon Soy Moratorium: a hybrid environmental governance mechanism

T4.21 National perspective of Forest resources policy and governance in countries of Latin America under a sustainable perspective

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Abstract: This paper analyses the Soy Moratorium agreement for the Brazilian Amazon signed in 2006 between non-governmental organizations (NGOs) and transnational soybean commodity traders. The current literature describes the Moratorium as an effective solution for halting deforestation, as well as a replicative model for other regions or commodities. Yet, to date there is no explanation of its emergence and maintenance as a hybrid governance mechanism. To narrow this knowledge gap, we applied the Baptist and Bootlegger political economy theory of regulation and analyzed data through content analysis of qualitative interviews and documents, to describe and explain the adoption and governance mechanisms of the Moratorium over a 15-year timeframe. Our results show that the agreement implements a hybrid governance mechanism, firstly developed as a non-state market driven governance, but integrating state-like regulation ("bans"), enforced through a longstanding strategic alliance between NGOs, industries, and later in collaboration with state institutions. Our analysis provides a clearer distinction of each actor's role in the agreement, and how this influences who 'gains' or 'loses' from its regulatory design, contributing to overall lessons of its replicability for environmental governance of forest-risk agricultural commodities.

Systems analysis as a tool in land use planning with special reference to Northwest of the Colombian Amazon.

T4.21 National perspective of Forest resources policy and governance in countries of Latin America under a sustainable perspective

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Abstract: Deforestation caused by cattle ranching in the Colombian Amazon has been a persistent issue that poses a threat to both food security and biodiversity. Our aim is to provide a system analysis of deforestation in the Colombian Amazon region through Causal Loop Diagrams (CLDs) showing the causal relationships between cattle ranching, deforestation, biodiversity loss, and food security. Causal loop diagrams were developed based on the knowledge obtained from literature, semi structured interviews, and stakeholder participatory workshops. The complex feedback mechanisms behind cattle ranching-driven land use change and its consequences in the Colombian Amazon were captured by the CLDs. The system analysis reveals that deforestation poses a significant threat to food security and biodiversity, with land use change causing the loss of tree cover, soil degradation, decreased agricultural productivity, and reduced access to nutritious food. The study also explores potential policy interventions that could break the negative feedback loops and promote sustainable land use practices in the region. The findings of the study can help policymakers and stakeholders to understand the underlying causes of deforestation and degradation, and to target and develop strategies to mitigate its negative impacts on food security, biodiversity, and other ecosystem services.

T4.22 Nature-climate Solutions: Lessons to move from buzzword to transformative practice in tropical forest landscapes

Can REDD+ safeguards 'do better' for Indigenous Peoples and local communities? Perspectives from comparative research in the DRC, Indonesia and Peru

T4.22 Nature-climate Solutions: Lessons to move from buzzword to transformative practice in tropical forest landscapes

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Abstract: Safeguards for the UNFCCC's REDD+ mechanism arose in response to concerns voiced by forest-dependent communities over its potential to infringe upon their rights and territories. Since then, several institutions have also developed voluntary standards for carbon markets, in addition to safeguards guidelines adopted by multilateral funding institutions. Across these standards and guidelines, safeguards are conceptualized and articulated in different ways: as bulwarks against the impacts of interventions ("do no harm"); as means to achieve sustainable development outcomes ("do good"); or as mechanisms to catalyse the transformation of forest-dependent communities ("do better").

It is urgent to clarify and understand the role of safeguards as the climate crises prompts interest on the part of countries and corporations in 'nature-based solutions' to meet their emissions reduction targets and commitments to biodiversity. This influx of investments in tropical forests can bolster sustainable development objectives, but also poses risks to communities, including the creation of perverse incentives and the deepening of existing social and economic inequities.

This paper will present the results of comparative fieldwork on the design and implementation of REDD+ safeguards in the DRC, Indonesia and Peru to understand when safeguards work, for whom, and why. We found that while safeguards have become a mainstay of REDD+ discourse and practice, there is considerable variation in their underlying objectives, the ways in which they are formulated, and the extent and effectiveness of their implementation. Thinking through safeguards, we will present a typology to understand their potential for change, how nature-based solutions may re-engage with the men and women of IPs and LCs and their rights and justice concerns, and synthesised factors to enable initiative to support and protect those rights.

Does it pay off to try harder? The role of REDD+ treatment intensity for forest and livelihood impacts

T4.22 Nature-climate Solutions: Lessons to move from buzzword to transformative practice in tropical forest landscapes

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Abstract: Impact evaluations have shown that REDD+ has significant, but disappointingly modest, impacts on both tropical forest conservation and livelihoods. However, these impact evaluations typically abstract from the heterogeneous and often small-scale and short-term interventions applied in the numerous but small-scale pilots of REDD+. We move beyond a traditional 'treated' vs. 'non-treated' binary analytical framework, to investigate whether and how treatment intensity – i.e., how many people were reached, with how much of resources, and for how long time – matters for the size and significance of the intended forest conservation and livelihood-improving impacts. We draw on quasi-experimental data from 16 REDD+ sites in Brazil, Peru, Cameroon, Tanzania, Indonesia, and Vietnam, as part of CIFOR's Global Comparative Study on REDD+, combining remote-sensing data with surveys applied in nearly 130 villages to 4,000+ households in 2010-2011 (pre-intervention), 2013-2014 (post-intervention I), and 2018 (post-intervention II). We characterize the highly variated treatments applied in these sites as incentives, disincentives, or enabling factors, as well as more graduated measures of the intensity of treatment. Our analysis suggests that it matters not only just whether or not 'something' has been done in targeted sites, but also 'how hard' these interventions have tried. Methodologically we thus contribute to a previously called-for extension of the literature on heterogeneous conservation impacts. Our results may also have important policy implications: the ongoing shift from REDD+ projects towards jurisdictional approaches may be associated with higher treatment intensities, which have implications for both costs and effectiveness. Future research should look closer at the implications for the comparative cost effectiveness of different forest interventions.

Impacts of Transnational Aids for Climate Change Mitigation: Evidence from Ghana

T4.22 Nature-climate Solutions: Lessons to move from buzzword to transformative practice in tropical forest landscapes

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Abstract: Much like development aids, a multilateral environmental financing mechanism provides developing countries with climate change mitigation and adaptation funding. For example, the EU and other developed countries pledged to provide 100 billion USD annually until 2025. This fund is used toward financing projects or investments that help mitigate climate change and increase the adaptative capacity of the vulnerable population. A major focus of these projects at national and sub-national levels has been to sustainably manage forests by curbing deforestation and promoting conservation by providing training and resources for tree management and improving livelihoods.

In this paper, we estimate the impacts of the Forest Investment Program (FIP) on households' tree-planting activities and livelihood outcomes using a household panel survey in Ghana. Our investigation involves whether and how those programs that aim to conserve/restore forests and improve livelihoods have effectively promoted forest conservation/reforestation and livelihoods. Ghana was selected as a pilot country for the FIP under the Climate Investment Fund (CIF) in 2010. It aims to reduce greenhouse gas emissions by reducing deforestation and forest degradation while improving people's livelihoods and generating income sources. It reduces pressure on existing forests by restoring forest cover in off-reserve areas by planting trees and increasing monitoring of illegal activities, and enforcing laws.

We find significant and positive impacts of FIP activities on households' participation in tree planting. People who have participated in FIP activities are 4-10 times more likely to have been involved in tree planting than those who have not participated in those activities. However, the FIP has not significantly impacted total income or expenditure. This might indicate that the benefits from participation in FIP could have offset the potential loss resulting from reduced access to forests due to increased monitoring and enforcement. This reduces concerns for negative livelihood impacts of increased enforcement and monitoring when coupled with livelihood-promoting activities. Intergovernmental and government agencies, non-governmental organizations, donors, and other stakeholders, including the science community interested in environmental conservation and economic development interventions, will find the results of substantial interest.

Promoting Nature Based Technologies for Enhanced Resilience to Climate Change in Horn of Africa

T4.22 Nature-climate Solutions: Lessons to move from buzzword to transformative practice in tropical forest landscapes

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Abstract: Much of the Horn of Africa is dry and highly degraded and suffers from frequent and severe droughts. Therefore, accelerating technology transfer through knowledge sharing and promoting adoption of existing good practices was identified as a strategy to collectively address natural resource management (NRM) challenges in Horn of Africa (HoA). A regional Initiative known as Africa Initiative for Combating Desertification (AI-CD) was developed in 2016 for implementation in seven HoA countries namely; Djibouti, Eritrea, Ethiopia, Kenya, Somalia, South Sudan and Sudan. The Initiative aimed to address NRM challenges and contribute to making nations and communities resilient to climate change. The partnership was formalized through Terms of Reference (TORs) developed and adopted to guide participating HoA countries to work harmoniously. Tools for identifying, collecting, and documenting good practices in NRM from farmers within the region were developed. A series of workshops and meetings for Horn of Africa AI-CD participating countries were held for policy and technical level officers. The objectives of policy level forums were for participants to familiarize with the Initiative activities, and facilitate dialogues among member countries. The aim of technical level workshops was to build capacity of technical officers on field data collection and repackaging of information for farmers and other community based end users. Participating countries identified and documented good practice information from the field in home countries. Information collected was used to develop good practice knowledge materials which included; books, manuals, guidelines and brochures, which were shared through internet and non-internet based platforms. A major lesson from farmers was that they preferred integrated farming approach as it guaranteed food security, ensured income generation and provided ecological benefits such as soil and water conservation, biodiversity conservation and promoted adaptation to climate change. The farming approach encompassed various time-bound farm enterprises namely: Short-term enterprises which involve food crop growing; medium term enterprises mainly fruits trees farming and livestock keeping; and long-term enterprises which involve tree growing. Good practices that have shown high adoptability by farmers in one area, should be promoted widely to enable HoA to collectively combat land degradation, desertification, and enhanced resilience to climate change.

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

(How) does tree diversity influence insect herbivory in urban trees?

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Cities exacerbate the impact of global change on trees. Higher temperature and impervious surfaces make urban trees strive closer to their physiological limits, in addition to increasing their vulnerability to insect herbivores. Because of the essential role trees plays in the functioning of urban socio-ecosystems, it is crucial to understand which ecological factors could buffer the impact of urbanization on insect herbivores and their impact on trees. Theory predicts that tree species diversity promotes the abundance, diversity and activity of herbivores' enemies, therefore resulting in a stronger top-down control of herbivory in tree species rich stands. We tested this hypothesis in the city of Montreal (Canada), using 24 urban forest plots defined as 200 m radius circular buffers in which we exhaustively identified every single tree, being in the public or private domain. Plots were uniformly distributed along gradients of canopy cover, population density, and deprivation index. We selected four trees per plot, belonging to the most frequent species (13 species in total). We excluded birds from one branch per tree with a mesh, and identified a second branch as a control, and attached 20 dummy caterpillars to each. We estimated bird predation attempts as the proportion of dummy caterpillars with beak marks and assessed the top-down control of insect herbivores through the comparison of insect herbivory measured on leaves from the control and bird-exclusion branches. In parallel, we characterized bird communities using passive acoustic monitoring. The direct effect of tree diversity on insect herbivory and its indirect effect mediated by changes bird diversity and predation attempts will be analyzed using structural equation models .

Analyzing multiple values of a complex peri-urban forest system under climate change

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: In our study, we analyze the peri-urban forest system of the city Freiburg in southern Germany. The forest system holds multiple values with the most important being recreation and eco-tourism, timber production, carbon sequestration, biodiversity protection and water services. With an area of over 5000 hectares, it is a complex and highly divers forest that ranges from lowland deciduous dominated to mountainous conifer forests. The combination of multiple functions and the forest's complexity possess high challenges to the local forest management, especially for adaptation strategies to climate change.

We simulate the forest system with the process-based forest growth model LandClim on the landscape-scale under climate change until 2100. Hereby, we integrate the local forest service's management plan for the next decade and repeat it until 2100. We evaluate the management strategy on achieving resilience to climate change and sustaining the multiple values.

For the simulation, we apply a state-of-the-art initialization process that makes use of a detailed inventory network (+2000 inventory points in the area) and integrates GIS data to depict the forest's initial conditions (e.g., species distribution, stem number, ages, DBH) in high resolution. We apply climate change data of different RCP scenarios and different underlying climate models to address uncertainties.

Our analysis focuses on changes in productivity and mortality, caused by stress factors (e.g., droughts) and disturbances (e.g., storms, beetles). Hereby, we evaluate feedbacks to the multiple values and identify areas where values are threatened, e.g., loss of forest cover in water protection area for drinking water recharge. In addition, we link the results to socio-economic data of the corresponding applied climate change scenarios to evaluate changes in economic conditions for selected values.

Summarizing, our study contributes to understanding future ecological and economic challenges under different climate change scenarios for a complex peri-urban forest system with multiple values. Furthermore, we assess the local forest management strategy's adaptation potential and help to identify trade-offs but also synergies between the multiple values.

Biodiversity conservation in the Leipzig Floodplain Forest – Using a demographic forest model to support conservation planning

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: The Leipzig Floodplain Forest is a biodiversity hotspot of national significance. Much of this biodiversity is associated with characteristic hardwood floodplain forest tree species, especially pedunculate oak (*Quercus robur*) and European ash (*Fraxinus excelsior*). However, the share of oak and ash has been declining over the last decades due to regulation of the hydrological regime, recurrent droughts, and invasive pests and pathogens. A revitalization of the hydrological regime (higher groundwater table, more floods) has started, but it is unclear whether this will be sufficient in ensuring the conservation of oak, or whether active oak planting is required.

To answer this question, we apply the Perfect Plasticity Approximation (PPA) forest model. The PPA model is a demographic forest model which simulates changes in forest dynamics according to growth and mortality rates in dynamic discrete canopy layers, as well as recruitment rates. We use forest inventory data from the 'Lebendige Luppe' project, including approximately 8000 trees growing in either ambient conditions or artificially flooded plots, to quantify these demographic rates for eight focal tree species and to characterize their dependence on the hydrological conditions. In addition, we use data from small-scale oak plantations with differing sizes (0.1-0.5 ha) to inform potential management scenarios.

In the baseline scenario (no revitalization of the hydrological regime, no oak planting), the basal area of oak trees is projected to decline by half in the next 50 years, indicating that natural regeneration alone is insufficient to conserve oak and its associated biodiversity. Likewise, a scenario where the hydrological regime is revitalized does not ensure sufficient oak recruitment. However, oak planting on <0.2% of the area per year ensures the long-term conservation of oak. Our results can support the design of an optimal biodiversity conservation strategy for the Leipzig Floodplain Forest.

Emerging fungal pathogens of Aesculus hippocastanum across Europe and the worsening condition due to the correlation with Cameraria ohridella

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: The Horse Chestnut tree (*Aesculus hippocastanum*) is a widely distributed urban area and forest species across Europe. However, in the last two decades, it has encountered significant challenges due to a climate change promoted emergence of various fungal pathogens, and infestations of the destructive leaf miner (*Cameraria ohridella*).

To monitor the tree health along a climate gradient, a comprehensive study was conducted along a Southwest to North Europe transect across six countries and ten urban forest areas. Approximately 700 trees were investigated, and 750 symptomatic leaves were sampled to isolate fungal pathogens. Molecular markers were used for species determination of the pathogens. Additionally, the study aimed to examine the composition and distribution of fungal communities along the transect, accounting for local variations.

During the monitoring phase, notable observations suggested a potential correlation between the presence of specific pathogens and the activity of the leaf miner, *C. ohridella*. Therefore, a field experimental study was undertaken using insect nets to enclose 40 individual trees to explore this association further. Four different treatments were implemented, with ten trees assigned to each group: 1) moths transporting fungal spores by exposing five litres of fungal-infected and moth-infested leaves from the previous year; 2) enclosing five litres of fungal-infected and moth-infested leaves in insect nets, allowing spores to infect the enclosed leaves while retaining the moths; 3) moths only; and 4) control group (untreated trees). Additionally, two methods were employed to differentiate between airborne and moth-transmitted fungal spores. Illumina MiSeq sequencing analysed fungal spore traps to assess the entire fungal community composition, while media Petri-dishes captured cultivable spores using an air particle sampling device.

The study results underscore the presence of specific fungal communities exhibiting distinct patterns along the Southwest to North Europe transect. In addition, these findings highlight the influence of climate and geographic regions on the distribution of fungal populations. Moreover, the study supports the correlation between specific fungal communities and the presence of the Horse Chestnut leaf miner, *C. ohridella*. The elevated temperatures and growing correlation significantly threaten urban environments and heighten the mortality risk of Horse Chestnut trees.

Enhancing ecosystem services of urban trees under a changing climate

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Urban trees and shrubs will be critical to maintain and improve the human well-being of our cities as climate change continues. They are very effective in modifying the climate of a site, a neighborhood or even of an entire city by providing a range of ecosystem services such as cooling by transpiration or shading, mitigation of the urban heat island effect, carbon sequestration or storm water runoff. The extent of these modifications, what they depend on, how they vary with climate change and what can be done to mitigate negative effects of global change are largely unclear. By using the process-oriented climate-sensitive urban tree growth model CityTree, simulations can be done that give answers to these questions. We will present a simulation study for different cities along a climate gradient through Europe that quantifies growth and ecosystem services of common urban tree species under current conditions as well as under changed anthropogenic conditions. Hereby, possible site conditions and their changes include variations of soil sealing percentage, soil water storage capacity or the radiation reduction (sky view factor). Information and quantification to maximise or at least maintain ecosystem services in the face of climate change, drought stress and other anthropogenic stressors will be provided. Preliminary results indicate that ecosystem services for temperate cities will decline significantly under future climate conditions. The level, however, strongly depends on the small-scale local conditions. For example, reducing soil sealing under trees, increases carbon sequestration and cooling, and reduces storm water runoff. For healthy and efficient urban tree populations, it is essential to improve growing conditions, including soil water storage, nutrients and radiation. At the same time, tree species should be chosen to enhance ecosystem services, particularly with regard to climate change. In our presentation, we will quantify and discuss growth and ecosystem services of common urban tree species for cities along a climate gradient, and identify mitigation measures for the negative impacts of climate change.

Exploring Urban Forests in Europe: Access, Usage Patterns and Insights from 33 Countries

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Urban forests in Europe cover around 10-15% of city areas, varying in extent and quality across regions and countries. They offer numerous ecological, social, and economic benefits. Accessibility to these forests is important and can be influenced by factors like distance, transportation options, motivation for visiting, and citizen preferences. However, not all residents have equal access to or spend the same amount of time in forests, emphasizing the need to enhance accessibility, quality, and management for inclusive community benefits.

To investigate these issues, an exploratory research was conducted in 33 European countries to investigate the patterns of use and access to urban forests. The study utilized a standardized online survey, resulting in a sample size of 10,462 participants.

The initial results reveal that a majority of respondents visit urban forests regularly, with 58.8% visiting 2-3 times a month or more frequently. The preference for accessing forests or parks by foot was indicated by 53.0% of the participants. Interestingly, variations exist among countries regarding the types of forests visited. Almost half of the countries predominantly favor 'Parks in cities or towns', while other countries show a relatively even distribution between 'Forests in the countryside' and 'Forests in or nearby cities or towns' (10-50%). The study further highlights that the intrinsic

motivations for visiting urban forests in Europe, including the enjoyment of climate and beauty, seeking respite from daily routines, and the desire to learn about nature, are predominant. Extrinsic motivations, on the other hand, revolve around spending quality time with children and engaging in physical exercise. Notably, South-West and South-East European countries place higher importance on accessibility facilities in urban forests, including parking spaces, public transport, and secure bike stalls. In terms of intrinsic reasons for green space visits, such as physical exercise, escape from everyday life, climate enjoyment, and appreciation of nature, these regions also demonstrate stronger inclinations.

This research illuminates the diverse patterns of urban forest use across Europe. The findings underline the importance of considering socio-demographic factors and regional differences when planning and managing urban forests to cater to the needs and expectations of diverse populations.

Green balconies: enhancing urban spaces through environmental contribution

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Urban greening is the planning and management of all urban vegetation to create or add value to the local community in an urban area. Hence, urban greening is increasingly being considered as a possible sustainable urban design and development alternative. In urban greening studies, the contribution of vegetation to urban spaces is only studied at the level of streets, green roofs and green walls. There is no consideration for urban residential transitional spaces such as balconies and terraces, which represent the third dimension of space greening. With an increasing urbanization rate, residents of countries with mild climates have planted their balconies. In this context, our investigation aims to examine the impact of balcony plants by quantifying their small tree canopy equivalent. In order to achieve this objective, structure from motion was applied to ornamental plants. Multiple images will be collected around the plant (360°). Commercial photogrammetry software such as Agisoft Metashape is used to obtain the 3D shape from the images. This shape will be divided into a voxel grid. From the resulting grid, and after applying semantic segmentation, the volume of the canopy can be approximated by calculating the fraction of voxels that contain leaves. The resulting canopy volume will be used to calculate the small tree canopy equivalent of each recorded species. Results of this study provide quantitative estimates that shed light on the potential role that residents of urban dense neighborhoods can play in contributing to urban greening. However, due to the ongoing progress in this field of study, the results of this research will not be immediately accessible. Therefore, a presentation regarding the validation methodology will be provided.

Impact of neighborhood-scale urban site factors and soil conditions on street tree health

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Street trees are a critical part of the green infrastructure that provides valuable ecological and economical benefits to cities. Urban conditions pose several challenges for healthy tree growth, and climate change along with urban heat island effects will further amplify urban tree stress. However, the impact of micro-scale site conditions on street tree condition has not been sufficiently explored. Quantifying how site conditions impact urban tree health and growth could support developing more targeted management plans to improve street tree health. We present findings from a neighborhood-scale tree survey where we rated tree condition for 118 Norway, red and sugar maples (diameter 36-67 cm) growing as street trees or in park-like settings. The tree survey was adapted based on the International Society of Arborists (ISA) Tree Risk Assessment Manual and the ISA Basic Tree Assessment Form. Diameter, tree height, living crown height, canopy size, branch mortality, root damages, branch dieback, and signs of leaf senescence were recorded. Soil metrics including soil temperature, pH, conductivity, and compaction were measured. Mineral profiles were analyzed with inductively coupled plasma optical emission spectroscopy. Wood samples were collected from a subset of dormant trees for nonstructural carbohydrate analyses with enzymatic digestion and spectroscopy. We will discuss the impact of impermeable surface, soil conditions, soil mineral profiles, and urban heat island effects on street tree health. We will also discuss the potential of using non-structural carbohydrate levels as a proxy for street tree health. The results of this project may have applications for early detection of stressed street trees, targeted management, and in predicting the impacts of urban heat island effects on tree growth and the carbon budget of urban trees.

Increasing social-ecological resilience of urban and peri-urban forests through inter and transdisciplinary research

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: The concurrent increase in the supply of ecosystem services and resilience in urban and peri-urban forests (UPF) warrants involving multiple stakeholders and disciplines. Therefore, we applied holistic inter-and transdisciplinary research approaches in the "GreenLung" ("GrüneLunge") project (2018-2023, https://www.projekt-gruenelunge.de/) in Karlsruhe region, southwest Germany. We executed an inventory and health survey by installing 201 random circular plots (404 m² each) in the study area. Further, we sampled City Tree Register's (CTR) trees for dendroecological, tree-ring stable-isotopes (C, O, and N stable isotopes), biodiversity, and meteorological analyses. During heatwave conditions, mobile measurements allowed us to study the thermal influence of land use, urban morphology, tree species density, and diversity to atmospheric conditions. A participatory map-based questionnaire survey with the respondents from the two cities was carried out to identify the perceptions of cultural ecosystem services, especially during the COVID-19 pandemic. During a series of excursions, training, expert meetings, and workshops in real-world labs with citizens and stakeholders, we identified possible solutions for improving the current management of UPF. Our study revealed a significant trade-off between supporting and regulating ecosystem services. For example, exotic oak species (*Quercus rubra*), for example, had less microhabitat diversity, abundance, and bat activities than native oaks (*Quercus robur*) but had a higher supply of regulating ecosystem services than native oaks. An increase in drought tolerance at the species level reduced the magnitude of dieback in our study area. Dendroecological and stable isotope analyses revealed high plasticity in climate-growth relationships between species. *Quercus robur* and *Platanus* hybrids had the highest tolerance to periodic droughts. The relative air temperature (2m from the surface) cooled with increasing vegetation cover during night and morning during heatwaves. The participatory map-based questionnaire survey revealed a high public appreciation of cultural ecosystem services. During the pandemic, citizens without access to private gardens and balconies visited public green spaces more often to reduce psychological stress. Our project was a unique attempt to combine inter- and transdisciplinary research to develop solutions for climate change adaptation and mitigation in urban forests.

Plant diversity mitigates the effects of urbanization on soil organic carbon stocks

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Urbanization is increasing worldwide, which can have a major impact on ecosystem functions such as soil carbon (C) sequestration. Although the effects of urbanization on forest ecosystems have been addressed, little is available to quantify the effects of urbanization on soil C sequestration, C stocks, and the underlying microbial mechanisms. To investigate the relationship between urbanization and soil organic carbon (SOC) sequestration-related properties, we quantified the spatial patterns of plant diversity along the urban-suburban-rural gradient and measured the relationship between plant diversity and the effect of urbanization on SOC stocks (SOCs). Plant diversity was significantly and positively correlated with nutrient concentrations and SOCs, while it was weakly correlated with the degree of urbanization, and the correlation between plant diversity and urbanization varied between forest types. Urbanization regulates forest SOCs by affecting temperature, soil C: P ratios, and the relative abundance of key enzymes for C sequestration and degradation, while plant diversity mitigates the negative effects of urbanization on SOCs by affecting soil C: P ratios and microorganisms. Urbanization significantly reduced surface SOCs but had no significant effect on substratum SOCs. Effects of plant diversity were greater than those of urbanization on SOCs. Results imply that plant diversity is influenced by urbanization but can mitigate the negative effects on soil C sequestration in the context of global warming, which provides a sound theoretical basis for effectively improving forest quality and ecological functions.

Preserving and improving the integrity of urban forests: Insights from Shai-Hills Forest Reserve

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Forests in urban areas are threatened as a result of increased population growth and the pressure on forest resources. Shai-Hills is one of the three forest reserves in the Greater Accra region of Ghana and faces a series of threats from surrounding communities. Preserving and improving the quality of urban forests is critical for reducing climate change, enhancing urban quality, and progressing the sustainable development agenda. However, knowledge of urban forest health and changes within land classes urban is inadequate. This study investigates land use and land cover (LULC) changes within the Shai-Hills Forest Reserve using images from 2002, 2012, and 2022. The Normalized Difference Vegetation Index (NDVI) of these images was analyzed to provide information for policymakers to devise strategies for improving the integrity of urban forests. The results indicate the presence of a primary forest in the 2002 image which was not present in the 2012 and 2022 images. From 2002 to 2012, the land cover change showed that 67% of the secondary forest changed to grassland. 2012 to 2022 LULC showed that 19% of secondary forests remained as secondary forests and 0.007% changed to grassland. The Kappa coefficient for 2002, 2012 and 2022 classified images are 0.81, 0.81, and 0.85 respectively. The NDVI of the 2022 image ranges between 0.05 to 0.4. This suggests the need to intensify forest restoration measures to improve the quality of the forest.

Re-visiting the concept of urban forests' ecosystem services in the cultural context of West African cities: A participatory study from Kumasi, Ghana

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Numerous studies on ecosystem services of the urban forest in Europe and the US found that cultural ecosystem services are perceived as more important than provisioning services. The local population in Europe generally rates ecosystem disservices as less important. However, we hypothesize that in the context of West African tropical and sub-tropical forests, patterns may be found that contradict the Western understanding of ecosystem services fundamentally. Therefore, it is crucial to understand and adapt the concept of ecosystem services to the local context. Doing so may serve as an efficient framework to support the sustainable management of the urban forest in West African cities in the future.

With more than 3 million inhabitants in the Kumasi metropolitan region, it is one of the largest cities in the country and, like many cities in sub-Saharan Africa, is characterized by rapid growth and high population density. As late as the 1960s, the city was considered the "Garden-city of West Africa". However, especially since 2009, much of the green space in the city has been lost, and remaining fragments of urban forests are under pressure from increasing urbanization and extreme weather events.

To increase the knowledge base on urban forests' ecosystem services in West African cities and to understand the population's use, access, and perception of the urban forest, we conducted in-depth group discussions and participatory mapping exercises. The study included each three groups - male, female, and youth - in three different communities in Kumasi, including the gradients from diverse socio-economic backgrounds and from highly urbanized to peri-urban areas. This approach creates an in-depth understanding of the historically grown human-nature relationship in tropical urban areas and how global and environmental changes influence it. It allows an analysis on the place attachment, cultural identity and negative implications of urban trees and the local population's expectations regarding urban forests. This will have significant implications for managing future urban forests to increase social-ecological resilience.

Smart Canopies: Optimizing Tree Layouts for Enhanced Thermal Comfort -- An Edinburgh Case Study

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Urban forestry plays an important role in improving thermal comfort, mainly due to their layout to mitigate temperature and improve the microclimate. Current urban forestry articles focus on simulation of microclimate or land practices. However, there are few researches mention about upgrading the existing landscape especially canopy structure to realize a better outdoor thermal comfort (OTC). Therefore, how to enhance the design and layout after simulation, particularly improving urban forestry layout will be a bright spot in the future.

In this study, an open green space was selected to test the mean radiation temperature (MRT). Some of common tree species in UK cities were selected to propose in the site for landscape improvement. The prediction used 3D-LiDAR and point clouds to construct urban model, applying a deep-learning algorithm to improve the accuracy of existing tree location in the site. After that, the discrete anisotropic radiative transfer (DART) was used to calculate MRT of above-mentioned model. On the other hand, in order to realize the tree layout diversity, genetic algorithm (GA) was utilized to simulate different kinds of tree planting. 10 typical layouts were selected into MRT calculation. Then through comparison of the fore-and-aft temperature changes, a better tree layout was chosen.

The results confirm the potential of urban tree to reduce the open space temperature. Moreover, the abundant canopy structure and the more numbers of tree can significantly enhance outdoor thermal comfort in the city open green space.

The method shows a high accuracy of site modeling, especially the simulation of urban forestry. Because manually producing dense annotations of LiDAR 3D point clouds of vegetation is a laborious task, thus using deep-learning method (weakly supervised learning) for realistic outputs. While, the simultaneously providing visual and interpretable predictions of urban tree layout. The using of GA provides sufficient layout outcomes, which reduces the risk of falling into locally optimal solutions.

The Urban Tree Observatory: monitoring stress and resilience of urban trees

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Urban trees provide a range of important ecosystem services, including carbon sequestration, evaporative cooling and flood mitigation. As urban populations increase, growing and maintaining urban forest is crucial to create sustainable places to live. However, less is known about how urban environments impact the health and function of trees themselves, with urban settings presenting several challenges to tree health and function, as well as some potential benefits. As climate change threatens to exacerbate already stressful urban conditions, for people and trees, a greater understanding of how urban trees respond to urban conditions is needed.

This study utilises a network of over 60 Internet-of-Things tree sensors installed on four common UK tree species *(Tilia x europaea, Betula pendula, Acer pseudoplatanus, Quercus robur)* along an urban intensity gradient in Sheffield, UK. The tree sensors allowed near real-time, temporally-continuous measurements of sap flow, growth rate and canopy structure, every 60 minutes over a 3-year time period; capturing diurnal, weekly and seasonal and inter-annual variations in tree health and function. Additional manually-collected data included leaf chlorophyll content, leaf area index and leaf C:N, approximately every 10 days.

Preliminary findings show that trees in more urbanised areas were generally not water limited, but were less resilient in the face of extreme heat and drought events, taking longer to recover afterwards. However, the extent to which trees were impacted was species dependent, with *Acer pseudoplatanus* affected more than *Tilia x europaea*. Different species also exhibited different levels of ecosystem service provision, with, for example, slower growth rates in *Betula pendula*. Our findings also highlight the particular need to consider ecosystem service trade-offs in tree disease management, with *Tilia x europaea* trees at early stages of *Phytophthora spp* infection maintaining similar levels of ecosystem function as healthy trees of the same species. Improving our understanding of how different tree species respond to changing urban conditions is critical to guide planting and management strategies for healthier urban forests and more sustainable cities.

Translating forest ecophysiology to urban trees; introducing the Urban Trees Ecophysiology Network (UTEN)

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: As urbanization continues to increase, the majority of the world's population resides in urban areas that are exposed to a range of environmental stressors. As cities experience temperatures up to 10°C higher than nearby rural areas due to energy consumption and urban infrastructure, urgent measures are required to mitigate and adapt to these stressful conditions, particularly in the face of climate change and projected urban population growth.
Increasing tree canopy cover has emerged as a powerful tool to enhance the quality of urban life. Trees offer numerous benefits such as reducing energy consumption, mitigating air pollution, and improving overall well-being. Through shading and transpiration, trees can effectively lower local temperatures and the heat index, and increase human thermal comfort. However, urban trees face multiple abiotic and biotic stressors, further intensified by climate change, risking their functionality, productivity, and survival and reducing their cooling potential.
Understanding the complex relationship between urban environments and the ecophysiology of trees is crucial for addressing climate change, promoting urban forest health, and making informed decisions.
In response to all that, we have established the Urban Tree Ecophysiology Network (UTEN), a global collaboration platform involving multiple researchers around the world, stakeholders, and municipal governments.
UTEN aims to investigate two fundamental questions: how the urban environment affects tree functioning and health, and how trees modify the microclimate of cities.
Through a comprehensive campaign-based approach, we continuously measure trees' transpiration, growth, and diameter changes, as well as the surrounding temperature and relative humidity using IoT technology. Additionally, we employ seasonal physiological measurements to assess tree health

and functionality.
These shared and aggregated data, enable researchers to address common questions related to tree health and stress in the face of a changing climate. Additionally, network nodes can utilize the accumulated knowledge to explore site-specific inquiries tailored to their own urban realities.
By fostering international collaboration and data sharing, UTEN aims to maximize the ecosystem services provided by urban trees. This global network, currently comprising 10 cities, endeavors to enhance our understanding of the intricate interplay between trees and the urban environment.

Understanding the cooling mechanisms of trees in contrasting climatic and growth conditions

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Urban forests have emerged as one of the most feasible strategies for promoting adaptive capacities of cities to climate change by alleviating urban heat island and thus heat stress for humans. However, a detailed understanding of the two cooling mechanisms, namely shading and transpiration from different tree species under different climatic conditions is still lacking. A study in Munich, Germany where we compared two ecologically contrasting tree species: *Tilia cordata* and *Robinia pseudoacacia* under contrasting meteorological and edaphic conditions showed that shading is the prominent mechanism of cooling, in particular, when the atmospheric aridity is high. In temperate or oceanic climate with soil moisture availability, comparatively light shaded tree canopies might induce higher grass evapotranspiration. Therefore, we propose dense tree canopies over built environment but over grass surfaces, light shaded tree canopies could be preferred. To further investigate the cooling mechanism over contrasting climatic conditions, we studied local tree species at ‘tree lab’ sites in Munich, Germany (temperate climate) and in Beer Sheva, Israel (hot arid climate), within various settings (park, street, square) with natural and sealed surface conditions. The comparison of transpiration cooling was based on linear relationship of midday canopy resistance to atmospheric vapor pressure deficit (VPD), where the slope is proportional to tree hydraulic conductance and midday stem water potential. Even though irrigated, trees in Beer Sheva showed higher hydraulic resistance that limits transpirational cooling (regression slopes of 0.25–0.44 in Beer Sheva vs. 0.10–0.18 in Munich). Analysing the proportion of latent heat to total available energy, we found transpiration cooling was about 40% less significant at noon hours in summer in Beer Sheva than in Munich. In addition, the linear relationship of midday canopy resistance to VPD showed promise to be used as an operative tool for comparing transpiration cooling between local trees in different climatic regions. These results suggest that with anticipated higher atmospheric aridity, shading will become even more important, thereby, denser tree canopies would be of higher importance. Whereas, irrigation maybe in combination with the grey water recycling would ensure optimization of shade and transpiration cooling benefit in temperate and oceanic climate in future.

Urban Tree Guard- Safeguarding European urban trees and forests through improved biosecurity

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Green infrastructure, including urban forests, has been proposed by European Commission as a strategy to support climate adaptation capacity and sustainable development in the urban areas where over 70% of the EU's population live. Alarmingly, the green infrastructure and especially its characteristic elements, trees, are increasingly threatened by alien pests (insects and pathogens) that are introduced via trade and transport. In a new environment, these pests may become invasive, causing devastating environmental and economic losses, and threatening also unique cultural values such as those linked to veteran trees. The current biosecurity system fails to capture alien pests that often also benefit from the altered climate. New tools and better integration of different knowledge pools are urgently needed to support better biosecurity in urban settings. COST action (an interdisciplinary research network that brings researchers and innovators together to investigate a specific topic (funded by the EU) brings together a pan-European and international network of scientists and stakeholders to meet this challenge. The network 1) Collects, shares and harmonizes scientific and stakeholder knowledge, 2) Accelerates the development of innovative technological tools and solutions for biosecurity purposes, 3) Informs policy and supports the implementation of the EU plant health regime while providing science-based recommendations for decision-makers, especially at operational levels, 4) Fosters an inclusive and open research environment, with explicit support to young professionals, and 5) Increases European competitiveness in the field of biosecurity, improving also the quality of everyday life for people, especially urban dwellers, in Europe and beyond. A co-created Wiki database, teaching tools for education in urban forest health, and a decision support tool will ensure the long-term impacts of the Action.

Urban tree insect pests and pathogens: awareness, risk perceptions and responses

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Tree insect pests and pathogens are a growing threat to the urban environment and human wellbeing. There is, however, little data on the knowledge and risk perceptions of different stakeholders and on how these might respond to this growing threat. We undertook a survey of a wide range of stakeholder groups associated with urban trees in Germany and assessed their level of awareness and the tree health measures they are taking. We present the results of this survey and what implications they have for policy and practice. The findings will help increase urban tree health in an increasingly challenging environment.

Urban trees for a cooler future - Growth patterns of urban trees in a changing climate

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Urban trees provide essential environmental services and are indispensable for regulating a city's climate, whilst growing in stressful conditions with low water and space availability. However, little is known about urban trees' capability to cope with climate change compared to their forest counterparts. Due to the heat island effect, Montreal has already experienced 1.4°C higher temperatures, creating increasingly challenging conditions for urban trees. To minimize the efforts needed to ensure their health and performance and the provisioning of environmental services it will be of utmost importance to plant trees resilient to new climatic conditions. Through dendrochronological analyses, we have compared the growth rates of four common urban tree species Norway maple (*Acer platanoides*), silver maple (*Acer saccharinum*), lime (*Tilia cordata*), common hackberry (*Celtis occidentalis*). Trees were sampled in the metropolitan area of Montreal across an urban gradient, from trees growing in pavement pits to lawns in residential areas, and in parks. Contrary to expectations, in the last decades, the least accommodating conditions of the urban centre have been showing an increase in growth rates. Both *Acer* species growing in pavement pits have shown a significant increase in growth rates, reaching the ones achieved by park trees. Climate correlations indicate a strong positive effect of autumn temperature, indicating an increase in the vegetative period in this area and therefore an increase in growth. Eastern Canada has recorded an increase in temperature as well as precipitation, explaining the consistent increase in growth in the last decades. Dendrochronological results proved to be a necessary assessment to understand the complex system of urban forestry.

Which trees are suitable in urban environments at risk of flooding in northern Europe?

T4.23 Preserving and improving the integrity and functioning of urban forests in the context of global change

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Abstract: Urban trees provide numerous ecosystem services of which many are dependent on large and old trees. It is therefore important that we plant trees that can tolerate the harsh urban environments as well as the changing climate of the future. In Northern Europe, the frequency and intensity of heavy precipitation events are expected to increase in the future, increasing the risk of flooding. Urban settings, such as dense built-up areas, compacted soils, and non-permeable surfaces, enhance the risk of flooding, making urban trees especially vulnerable to heavy precipitation. Hence, the demand for water management solutions, such as rain gardens with trees tolerant to flooding, will increase. Currently, the species diversity of urban trees in northern European cities is low, further increasing the vulnerability of urban forests to both biotic and abiotic stressors. This study investigates the flooding tolerance in a large number of trees with varying physiological and morphological traits to assess their suitability for planting in northern European cities. Previous studies have been focused on one or two species, by increasing the number of species we can explore more tree traits and connect those traits to stress tolerance, further expanding the number of tree species for city planners to choose from. This study includes species that are both common as well as rare in northern European cities today. 16 species will be exposed to three treatments: control, short flooding (3 days of flooding), and long flooding (8 days of flooding) in August 2023. After the flooding period, the trees will have a recovery period of two weeks. The tree responses to flooding and their among-species variation will be investigated by ecophysiological measurements including gas exchange, morphological measurements including the formation of adventitious roots and leaf loss, and measurements of the meteorological factors and soil conditions. The results from this study can be used as a guide for stakeholders when planting new trees in areas that are at risk for flooding, thereby increasing the chances for urban trees to grow large and old.

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

Application of the typical enterprise approach in forestry: a pilot study to collect economic key figures in small-scale private forest enterprises

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: In the EU, forestry as a supplier of wood and other ecosystem services, is an important source of employment and income and has a high ecological, social and cultural significance. About 50% of the European forest area is managed by private forest owners. In this context, small-scale private forest owners with less than 20 ha of forest account for about 33% of the total privately owned forest area (Hirsch et al. 2010). As a result of the need to adapt forest management to climate change as well as increasing societal demands, European (small-scale) private forests are facing major challenges.

For evidence-based policy decisions, knowledge about the economic situation of small-scale private forest enterprises (SSPFE) is of high importance. So far, however, there are no or only few operational key figures on forest management in SSPFE in many EU Member States. Furthermore, the few existing key figures are hardly internationally comparable. Against this background, the collection and comparative analysis of economic indicators of forestry production in SSPFE is of great importance. For this purpose, an EU-wide harmonized approach for data collection in SSPFE is necessary, but does not exist yet.

Therefore, in a pilot-study within the joint research project "Valorising small scale forestry for a bio-based economy (ValoFor)" comparable key figures on forest management in SSPFE in Germany, Finland, Austria, Sweden and Slovenia were collected, using a modified "typical enterprise approach". For each country, a typical SSPFE with typical management measures and economic indicators was created through in-depth literature analysis and expert interviews. On this basis, comparable key figures for forest management in the five partner countries were derived for the first time. Exemplary, it was found that in the reference year 2021, the highest timber revenues in typical SSPFE were achieved in Austria (66 €/m³). This was followed by Germany with 57 €/m³. For the typical enterprises in Finland, Sweden and Slovenia, timber revenues of 41 - 42 €/m³ were calculated.

The "typical forest enterprise" approach, which can be realized with comparatively little effort, can serve as a valuable basis for further forest economic impact assessments for EU policy processes.

Climate Credits: a new tool to incentivize the provision of forest ecosystem services in small private forests.

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: Climate change and biodiversity loss are two of the planet biggest challenges to which forest-based solutions can make a significant contribution. However, the lack of context-specific integrative solutions along with the lack of incentives and governance problems are hindering their adoption in regions with a high share of small private forest owners. Based on this, the LIFE CLIMARK project consortium (2017-2022), proposed an innovative approach to incentivize the provision of ecosystem services (ES) from forest management in Catalonia (NE Spain): the creation of a local voluntary market of "climate credits". The aim was to design a tool capable of matching the willingness of companies to invest in nature-based solutions (NbS) in Europe, with the need to find new ways to finance improved forest management (IFM) in privately owned forests. Inspired by current carbon markets, the Climate Credit market aims to overcome their limitations by addressing the joint provision of different ecosystem services in an integrated manner and through high integrity and quality projects. Three characteristics make the market of climate credits unique: i) the concept "*Climate* Credit" itself, which integrates into a single unit the benefits of IFM on 3 ES: carbon balance (including fire prevention), blue water availability and biodiversity conservation; ii) the inclusion of a broad set of IFM practices, beyond tree planting, which are context-adapted; and iii) a bottom-up participatory landscape approach to overcome fragmentation, tackle trade-offs between different ES, make a bigger impact and strengthen social resilience. Since 2022, the market is being tested in eight pilot sites and it is expected to be formally created in Catalonia during 2023. The results of these tests show the high existing demand by both parties, sellers (forest owners) and buyers (companies and local institutions) and highlight the role that these PES-type schemes can play in the policy mix, beyond the economic return, by granting the forest owner a new role as provider of ecosystem services demanded by society. The pilot tests have also allowed the identification of levers and bottlenecks for the broad replication of the market, as well as future lines of improvement.

Coordinating landowners for wildfire prevention: socio-economic lessons learned from incentive schemes

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: Wildfires do not understand from property boundaries; thus, their effective risk reduction (a regulating ecosystem service) needs to take into account spatial scales beyond the individual landowner. Yet, incentive mechanisms to reduce fuel load are typically designed without zoning nor with minimum intervention areas.

Our study aims at drawing lessons from the few economic incentive mechanisms in Catalonia (Spain) that foster collaboration among adjacent landowners to reach intervention areas critical for effective wildfire risk reduction effects. The analysis grounds on document review, complemented with in-depth interviews during 2023 with incentive managers and participating landowners. We followed a deductive-inductive approach, employing pre-identified variables as initial content analysis codes, complemented with emerging variables. Studied factors span from (i) social capital characteristics (ex-ante and post) considering interpersonal trust and, local networks of information or collaboration, (ii) payment magnitude, (iii) transaction costs, (iv) perceived direct and indirect benefits, (v) degree of innovativeness, (vi) wildfire risk perception, and (vii) duration of the commitment.

Preliminary results indicate that the pre-existence of social capital (previous networks) facilitate the decision to participate in collaborative commitments towards fuel load reduction. The risk aversion (fear to fire-related losses) prevails over other potential profit-oriented variables yet modulated by fire probability perception. The presence of a facilitating agent emerges as key factor to catalyse different interests and profiles, to bridge the administration-technical-practitioner divide, while it implies transaction costs. These factors seem to allow the necessary agreements among participating forest owners. Being the initiatives rather young, further implementation is needed to ascertain the potential consolidation of these social innovations backing coordinated wildfire risk management. These findings help designing future incentive mechanisms aiming at landscape-scale coordination.

Forest Certification as a Tool to Support Forest Ecosystem Services

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: Sustainable Forest Management (SFM) certification provides a way to demonstrate the positive impacts of SFM on ecosystem services. Ecosystem services provide society with a wide range of benefits, from carbon sequestration to soil erosion control, from clean water and biodiversity protection to the production of wood and non-wood products. We evaluate forest owners' and managers' perceptions of forest certification as a tool to support SFM and forest ecosystem services in several Countries among PEFC endorsed systems. Among the important factors influencing the level of understanding of forest certification and its role in ensuring forest ecosystem services is the size of the managed forest area and the implemented certification scheme. The results of this study indicate that forest certification is positively perceived as a supporting tool for ecosystem services, and certified forest owners are sufficiently aware of the objectives of SFM. In general, forest certification is mainly perceived as a supporting tool for the ecosystem services related to the control of erosion, soil formation, and natural composition, as well as the function of species and ecosystem diversity, followed by the provision of aesthetic, scientific, and educational values.

From Profit to Added Value: A Portfolio Selection Model for Optimizing Ecosystem Services of Private Forests

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: Originating in financial economics, the portfolio approach has been widely applied in environmental decision-making in various fields of study, including forestry. Most of the studies pursued ecosystem service (ES) profit optimization, where return and risk are often measured via financial return and price, respectively. Simultaneously, there is evidence that private forest owners, who own approximately 60% of European forests, do not orient their management choices primarily based on the rationale of profit, with some of them lacking entrepreneurial thinking.

Following the objective to develop a portfolio selection model that supports private forest owners in optimizing the forest ecosystem services (FES), this study accounts for the potential nonprofit orientation of the landowners and includes both market and non-market values of FES. Returns from FES are measured as the added value for the forest owner, whereas risks are interpreted as the effort required to change management practices.

The scope of the study is limited to the Alpine forests due to their biophysical similarity. In addition to collecting data on biophysical indicators of the study area and retrieving real market values of FES (e.g., timber, recreation), private forest owners are surveyed to normatively assess the added values of FES and changes in management practices. The survey is framed according to the analytic hierarchy process methodology. Collected data are aggregated into a portfolio selection model to estimate the most optimal FES portfolios.

Measuring returns from FES through a combination of market prices and non-market values will demonstrate how much change is acceptable for a forest owner to maximize the added value of the forest. We expect that forest owners could be further categorized as innovative (i.e., ready for a high-effort change despite a low added value) and conservative (i.e., prefer a high added value for a low effort). The final results will be presented at the conference.

A normative perspective on the portfolio selection model will allow for developing a tool that communicates potential solutions for the FES provision and required management changes, while simultaneously aligning to the nonprofit orientation of private forest owners.

FSC's Ecosystem Services as a solution for small forest owners; challenges and perspectives from Portugal and Sweden

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: In FSC certified forests, valuable ecosystem services are protected. FSC's National Forest Stewardship standards require forest owners to preserve or restore ecosystem services and to preserve forests with high conservation values. In 2018, FSC introduced a procedure to verify the effects and measure results in FSC certified forests. In this way, forest owners can demonstrate and communicate about the positive impact of their responsible forest management on ecosystem services. Impacts can be verified for biodiversity, carbon, watershed services, soil conservation and recreation services. Verified positive impacts can be used to access payments for ecosystem services by businesses that want to communicate their dedication and contribution to sustainability.

For smallholders, that often has a more diversified aim with their ownership than companies. FSC Ecosystem Services can incentivize smallholders to get certified and verified positive impacts can be used to access payments for ecosystem services that are not recognized by traditional markets. For areas that are focused on conservation purposes this can make a huge difference, and act as a way to promote responsible forest management in such areas.

Portugal and Sweden are two countries from different parts of Europe where FSC ecosystem services has been introduced for smallholders. One of challenges in introducing the Ecosystem Services procedure in these countries are in providing simple and clear methodologies for measuring some of the ecosystem services. Another challenge has been to find the right match between smallholders and businesses willing to finance or sponsor the Ecosystem Services claims. Also the principle of additionality in the Swedish context, where the landscape is already very forested, is a challenge that requires careful communication and good methodologies.

In Portugal it has been challenging to demonstrate the value of all the ecosystem services that are possible to verify according to FSC's Ecosystem Services Procedure, in a market that is very "carbon oriented". It is crucial for smallholders to have access to methodologies that demonstrate the complete value of the forest they manage and to be able to communicate it.

Future development of ecosystem services in European forests, the role of small-scale forest owners and how to engage them

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: Forests are one of the most important ecosystems to counteract today's challenges such as accelerated climate change or the biodiversity crisis. They provide a broad range of ecosystem services (e.g. carbon stock, wood and non-wood products, biomass for energy production, biodiversity), yet it is often unclear to which extent these ecosystem services might encounter trade-offs in multifunctional forest management. As around 60% of Europe's private forests are managed by small-scale forest owners, the impact of their decisions on future provision of ecosystem services should not be underestimated.

We used national forest inventory data from five European countries (Finland, Sweden, Germany, Austria, Slovenia) to simulate the future development of forests until 2100 under different climate change (no climate change, RCP4.5, RCP8.5) and management scenarios (no management, business as usual, low intensity, high intensity). The simulations allowed us to calculate future ecosystem services, to analyze potential synergies and trade-offs among them and to better understand the role of small-scale forest owners.

Overall, the simulated change (e.g. in growing stock or timber harvest) was driven more by the forest management scenarios than by the climate change scenarios. Further, we generally found limited synergies and trade-offs among different ecosystem services, e.g. carbon stocks did not correlate with forests' biodiversity indices. The great potential for/of small-scale forest owners was highlighted e.g. by the finding that their modeled timber harvest was above the overall average.

Our study shows the importance of engaging small-scale forest owners and the ability of adapted forest management to mitigate climate change-induced risks, without inevitably leading to conflicts of interest. To make our scientific results easily accessible to forest owners and to show them the significance of the choices they make today, we develop an online tool with 3D-visalisations of the different possible future forest developments in an ongoing project. By additionally providing information on different ecosystem services, potential risks as well as economic factors, our tool aims at supporting (small-scale) forest owners in their decisions, as their active participation in climate smart forestry is essential for securing the future of resilient and multifunctional forests.

Neutral taxation of the income from different forest ecosystem services and types of agreements in Finland

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: In Finland, after the end of areal site-productivity taxation, the allocation problem related to progressive taxation caused by annual variations in timber sales income have been resolved by defining timber sales income as capital income taxed at a fixed tax rate and using the forest deduction procedure. The definition of income from timber sales as capital income has led to a situation where forest income is taxed in two separate sources of income, according to the Income Tax Act and the Agricultural Income Tax Act. The Income Tax Act has an exhaustive list of gross capital income from forests, which includes especially income from the sale of wood, but also public support for forestry, including environmental support that preserve the natural values of forests. Forestry incomes other than those listed in the Income Tax Act are taxed as agricultural income. The forest income received from the rental of the forest area is agricultural income, regardless of the content of the rental income. In agricultural income taxation, net income is divided into earnings and capital income based on the net assets of agriculture. The forest is excluded from agricultural capital, which leads to taxation of forest income as earned income. In addition, the forest deduction, based on the cost of acquisition of the forest and reducing the final tax rate, is set to be deducted only from the capital income of forestry. When the earned income of the forest owner is taxed at a progressive tax rate that increases in relation to income, and capital income is taxed at a fixed tax rate, the taxation of forest income that is taxed as agricultural income can become much greater compared to the final tax rate of forestry capital income. This leads to unneutral forest taxation and places forest owners' income from the sale of wood as trade agreements and compensation received as public support in a more favourable position from a tax point of view than the income and compensation received from private operators from other ecosystem services of forests and all income from rental agreements.

Non-timber forest products in French metropolitan forests: Assessment of an ecosystem service

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: Forest recreation allows a connection between forest owners and society and supplies goods and services that are responsible for human welfare. Several non-timber forest products (NTFPs) such as mushrooms, berries and chestnuts are collected during recreational activities in France. These NTFP also have cultural values associated with forests, called value for forest goods and services. A survey conducted by EFESE (2020) was used as the basis for statistical analysis. In addition, geographic information layers were used to identify the type of forest ownership around the respondents residence, and how these information are directly related to the collection of NTFPs. The results provided some indication in terms of forest visits that are positive and significantly correlated with French NTFPs collectors. From the econometric models, it was possible to analyze that pickers have a tendency to frequent private forests with the presence of deadwood more often. In addition, the travel cost method demonstrated that the willingness to pay is higher when visitors go to collect NTFPs in the forests. This information can help the forest owner to generate income from the recreational activities that occur on his property.

Payment for Environmental Services as an income alternative for small rural producers in Central Amazonia

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: Payment for Environmental Services (PES) has been considered an alternative tool for the maintenance of forests in the Amazon and their ecosystem services and for the remuneration of the providers. This work aimed to evaluate the potential for applying PES schemes in small rural properties with implemented forest management projects. The method consisted of a case study in the central Amazon, municipality of Rurópolis/PA. Secondary data were evaluated, available in the online platforms of the managing agency, corresponding to the period from 2007 to 2022. The eligibility criteria were: having the Rural Environmental Registry (CAR) and having the environmental license for the forest management activity. Included in the study were properties of 1ha to 300ha (up to 4 Fiscal Modules-MF). The remuneration value was US$ 81.22/ha/year, using the Floresta+ Conservation Project as reference. The results show that the municipality has 3,473 properties registered in the CAR, of which 96.7% are in areas up to 4 MF (up to 1 MF = 29%; >1 to 2 MF = 60.0%; >2 to 3 MF = 5.3%; >3 to 4MF = 2.4% and >4 MF = 3.4%). A total of 123 properties (3.5%) with environmental licenses for forest management activities for timber production were identified during the period evaluated. The average area per property with forest management in the municipality is 91.6ha (min. 42.08ha; max.168.76ha), which can remunerate the small producer on average US$ 7,439.49 per year (min. US$ 1,510.53; max. US$ 13,706.12). After executing the forest management, the small producer has this area immobilized for a period of 25 to 35 years, which corresponds to the cutting cycle established in the legislation, having during this time the cost of maintaining the area. The financial incentive in the form of PES would be a way to encourage the practice of forest management, which contributes to forest conservation and the legal production of wood. PES on small properties, adopting forest management as an eligibility criterion, has the potential to become an income alternative for small producers. The information can help the government, in partnership with farmers and the private sector, to develop PES schemes in the municipality.

Private forest owner's priorities and motives of the voluntary protection of biodiversity and forest ecosystems

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: New green transition policy in a context of climate change empowered the process of protected areas increase in Lithuania. Main goals of the forests protection issue are expanding and optimal shaping a network of Natura 2000 territories, and increasing the total protected areas in Lithuania. Private forests play the significant role on these goals achievement. There is a lack of knowledge about voluntary forest protection initiatives in private forests and nature conservation management practices in voluntary set-aside forests in Lithuania. The objective of this study is to analyse biodiversity and ecosystems voluntary protection priorities and motives of private forest owners in Lithuanian and to foresee possible financial promotion mechanisms for the transition from mandatory to voluntary protection. The Delphi method was used for gathering the views of experts. More than 25 experts from various target groups (foresters, forest management advisors, ecologists, representatives of governing institutions, private forest owners etc.) have been invited to participated in the survey. The survey results showed that private forest owners would disagree or partially disagree with the state regulatory or voluntary protection of biodiversity and ecosystem models without compensations. Two types of Protection Agreements would be most suitable in Lithuania: 1) Long-term (permanent) protection with retention of forest ownership and compensation of incurred economic losses and 2) Sale of forest land to the state. External motives (compensations), when the compensation amounts to 100-125 per cent from losses, are the most important for private forests owners in Lithuania. Experts also rated as the most important internal motives, which are related to a person's intention to realize his biodiversity and ecosystems conservation idea. High attention should be paid to the intensity of compensation rate when drawing up loss compensation schemes. Low-intensity loss compensation schemes should not be applied in Lithuania. The results of the expert's survey provided a scientifically proved basis for further voluntary protection of biodiversity and ecosystems model and compensation schemes development in Lithuania.

Provision of ecosystem services from private forest owners in southern Sweden

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: In southern Sweden, private forest owners own about 80% of the productive forest land. Consequently, in this region, these owners significantly impact the provision of forest ecosystem services. We collected data through in-depth interviews with 23 private forest owners aiming to, from their perspectives, examine the potential to develop environmental and other values on private land and to examine existing barriers. The owners were 36-84 years old and owned 10-825 ha of productive forest. 26% of the owners were female. Collected data were analyzed with semantic content analysis resulting in themes. The study showed that there is a potential to provide ecosystem services on private land since 1) What matters most to forest owners in forest management and ownership was demonstrated in a diversity of factors, above all that relate to social and emotional dimensions, 2) Forest owners desired management included a range of management ideas that could bring a diversity of benefits and 3) Forest owners already carry out a variety of forestry measures that intentionally or unintentionally benefit environmental and other values. The forest owners also perceived that there are barriers in forestry primarily related to financial aspects, rules, lack of time and forest estate site conditions. Some barriers could be reduced by financial incentives and by designing policy instruments that encourage forest owners' initiatives.

Survey of Forest Owners: Attitudes towards Climate Change Mitigation and Adaptation

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: Carbon sequestration is one of the most crucial ecosystem services provided by forests. Forests play a vital role in mitigating climate change by absorbing and storing carbon dioxide from the atmosphere through photosynthesis and the growth of trees. Forest owners, therefore, have a significant opportunity to contribute to climate change mitigation through their management practices.

This study presents the results of a survey conducted among non-industrial private forest owners during early summer 2022. The survey aimed to assess forest owners' attitudes towards climate change, its mitigation, and adaptation measures. The data included 1,224 usable responses, yielding a response rate of 20.4%.

The results reveal forest owners' perspectives on climate change and their willingness to implement mitigation and adaptation measures. It was found that various climate change mitigation actions are not yet widely adopted among private forest owners, with less than 10% of respondents reporting engagement in most of the assessed measures. However, more commonly practiced actions include following current forest management recommendations. Adaptation measures were more widely used with more than 25% engagement rate.

Utilizing a multinomial regression model, we analyze the factors influencing forest owners' intentions to implement selected measures, their uncertainty about implementation, or their lack of intention to implement. The preliminary results indicate that, in addition to demographic variables, attitudes towards climate change and its impacts and forest ownership goals influence the implementation of climate change mitigation and adaptation measures.

Additionally, forest owners have diverse motivations for engaging in climate change mitigation actions, such as protecting biodiversity, a sense of responsible forest management, and economic benefits. These varied motivations should be considered when designing policy instruments to encourage the implementation of different measures. Recognizing and incorporating these underlying reasons can enhance the effectiveness and acceptance of climate change mitigation strategies among forest owners. These insights can inform policymakers and stakeholders involved in sustainable forest management practices, aiding in the development of targeted strategies to promote climate change awareness and encourage forest owners' active involvement in mitigation and adaptation efforts.

The Need to Establish a Social and Economic Database of Private Forest Owners: the Case of Lithuania

T4.24 Provision of Ecosystem Services from Small-scale Private Forests - Is it viable?

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Abstract: In Lithuania, as in other analyzed countries, greatest attention is concentrated on the protection and monitoring of state forests, while the situation in the private forest sector is quite unclear and uncertain. In most European countries, as well as in Lithuania, there are a lack of socio-economic data, and there are no planned forest monitoring methods and permanent programs. We claim that the problem of achieving sustainability in the forest sector, in the case of the estates of the private forest owners, could be partially solved by implementing the monitoring of social and economic indicators. This study proposes the need for the establishment of a social and economic database of private forest owners in Lithuania. In this article, we have carried out a detailed analysis of scientific sources and selected socio-economic indicators to help the adoption of optimal management solutions for sustainability in the private forest sector. To explore the need to establish a social and economic database of private forest owners in Lithuania, we conducted an empirical study by applying the method of semi-structured interview to a group of experts/specialists in the forestry field. Summarizing the results of the research, it can be concluded that the need for socio-economic information about the owners of private forests in Lithuania is obvious, as it would clarify the most pressing problems that forest owners face when farming in their forest estates. This information would also allow the improvement of policy formulation and implementation, the adoption of legal regulations, and the organization of the necessary changes in private forestry. Therefore, it is necessary to establish criteria and indicators that could ensure more sustainable forest management.

T4.25 Public engagement to keep urban trees and communities healthy

A tale of two cities: Assessing changes in street tree health in NYC and Philadelphia

T4.25 Public engagement to keep urban trees and communities healthy

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Abstract: Every tree in an urban forest is expected to provide a multitude of benefits to the city. Because of this, municipalities invest tremendous resources in their urban trees, making their growth and success even more important. The ability to quantify how healthy a tree is provides added value to urban forest managers allowing them to be proactive in their management decisions and able to plan for stress mitigation instead of tree replacement. In addition, fine scale health metrics that can be deployed across large areas of a city may also help with early detection of new invasives such as Asian long-horned beetle and emerald ash borer.

We have created a tree health assessment protocol for urban trees by adapting and refining methodology used in rural forest health protection and monitoring. This protocol and accompanying statistical techniques are at the core of the “Health Check” module in the Healthy Trees Healthy Cities mobile app. This app is freely available.

This protocol has been used in eighteen cities in the United States by scientists, community groups, and in job training programs. Here we present the results of a study designed to rigorously assess street tree health changes over time. In Philadelphia, PA 2,690 street trees were assessed in 2015 and these same trees were visited again in 2021. In New York City 3,646 trees were assessed in Bronx and Manhattan in 2015 and again in 2022/2023.

This study and the associated methodology is one example of how both scientists and civic ecologists can use the same methodology to get more eyes on trees in cities. This in turn can provide managers with valuable information about the health of the street trees they are responsible for managing.

Community engagement can enhance biosecurity

T4.25 Public engagement to keep urban trees and communities healthy

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Abstract: People are part of ecosystems and biosecurity is a shared responsibility. Protecting our forests from invasive pests requires constant and broad monitoring, beyond the capacity of any individual agency or sector. Programs designed to empower more people as guardians can increase capacity for biosurveillance and strengthen the resilience of our communities to respond to forest threats. Many programs exist to empower participants as first detectors and respond to the impacts of invasive species. This presentation will review approaches for engaging the public across the stages of biological invasions and summarize the merit of public engagement within the Forest Health Watch program (https://foresthealth.org/).

Correlating characteristics of urban trees with human wellbeing in Singapore and Wellington, New Zealand

T4.25 Public engagement to keep urban trees and communities healthy

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Abstract: There has been a significant amount of research on the effects of urban greenspaces, and by association, urban trees on human health and wellbeing. The majority of these studies have examined the relationship between greenspace and/or trees and specific medical conditions, or more generally mental health. In this study, we examine the relationship between the urban forest, encompassing both individual street trees *and* trees in greenspaces, and overall human wellbeing. Using the OECD wellbeing framework, we developed a weighted index of human wellbeing, comprising the following domains where data was available: income and wealth, work and job quality, housing, health, knowledge and skills, environmental quality, subjective wellbeing, safety, work-life balance, and civil engagement. The examined urban tree measures and characteristics included those which have rarely been considered in this context before, such as tree age, size, and species (native and exotic), as well as tree density and remote-sensing derived proxies of canopy cover.

Disease risk mapping has rarely been used outside of its specified purpose. Since our research questions/hypotheses are concerned with how the various measures and characteristics of urban trees affect human wellbeing and several other indicators, we have adopted several modelling approaches for disease mapping – logit models, Bayesian hierarchical modelling, and Lasso models. All of these models appear to be appropriate in this instance as they are often used to measure spatial variation in disease. While we are not measuring disease per se, we will be measuring the “condition” of wellbeing on the population of Singapore and Wellington.

Early logit results have shown weak correlations between the different urban forest characteristics and individual data components that make up the weighted index of wellbeing for Singapore. Results of the modelling of for Wellington will be complete by the end of the year. Our preliminary study in Singapore examined the relationship between income and greenery using correlations and map visualization. The study revealed relatively high correlations for greenery per capita and income per capita in a planning area. Further investigation to verify the study's results and sampling of other indices are ongoing.

INQUIRES ABOUT GOVERNANCE MODELS TO APPLY IN URBAN FOREST AT THE CITY OF LUJAN, IN ARGENTINA

T4.25 Public engagement to keep urban trees and communities healthy

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Abstract: The concept of 'good governance' requires transparency, accountability, and social participation and it is related to good citizenship. Sustainable governance then is the set of written and unwritten rules that link ecological citizenship with institutions and norms of governance. Good governance is reflective of community empowerment and ecological wisdom, the absence of good governance is characterized by the lack of either or both. In this context, this proposal will identify various levels and types of good governance and describe the decision-making system related with the urban forest of the city of Luján, province of Buenos Aires, in Argentina, to recognize strengths, weaknesses and gaps - of a legal, administrative, technical or other nature - that need to be addressed to consolidate a governance model. It is a bibliographic-documentary, descriptive and qualitative type of research and a bibliographic survey has been carried out. Scientific papers, regulations and public documents have been taken as sources of information. Also, interviews have been carried out with key informants as a mechanism for corroborating the information and a survey of the perception of the population of Luján regarding the city's urban forests has been carried out through surveys of the population. As an analysis technique we apply legal hermeneutics and we implement an adaptation of the conceptual framework proposed by the study The Economics of Ecosystems and Biodiversity. We can conclude that to implement a governance model with an ecosystem approach, in any environment, it is necessary to work with various sectors and disciplines. A favorable political context is one of the most important conditions when applying this approach, since it can enable all the others (mainly human, financial and institutional resources). However, it is essential that there is a society that recognizes the value of urban forests and participates in the application of the approach. Not only from the demand and claim, but also from the commitment and participation. In turn, the university occupies a key role for the articulation between parties and for the development of research-action projects.

Nutritional Composition and Phytochemical Content of Ceiba pentandra and Vitex doniana leaves in Maklurdi, Benue State, Nigeria

T4.25 Public engagement to keep urban trees and communities healthy

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Abstract: *This study investigated the nutritional composition and phytochemical content of the leaves of Ceiba pentandra and Vitex doniana. The leaves were collected from Makurdi, Nigeria. The leaves were ground into powder with a mortar and pestle and put into a clean, dry container. The dried powdered leaves were then taken to the Chemistry Laboratory of Federal University of Agriculture, Makurdi for proximate and phytochemical analyses. The proximate and phytochemical compositions of these tree species were determined according to standard method. The results showed that the Ceiba pentandra* ***s****ample has an appreciable amount of fiber (27.861.1%), followed by carbohydrate (27.492.4%), while the least was moisture (8.77±0.3%). The Vitex doniana* ***s****ample has an appreciable amount of carbohydrate (25.62±0.5%) followed by fiber (22.03±0.3%) while the least proximate content was moisture (9.94±0.03%).The phytochemical screening revealed that flavonoids and tannins (+++) were very strong in Ceiba pentandra. Terpenoids and phenols (++) were present in strong quantity. Saponins (+) were present in weak proportion while alkaloids, glycosides, steroids, anthraquinone, resins, and balsam were absent. The results also revealed that saponins and tannins (++) were strong in Vitex doniana. Alkaloids, flavonoids, anthraquinone, and terpenoids (+) were weak in Vitex doniana, while glycosides, steroids, phenols, resins, and balsam were absent. These results imply that these species are good sources of nutrients and could have ethno-medicinal potential for drug formulations. Thus, the consumption of these species (Ceiba pentandra and Vitex doniana) should be encouraged as they could help lower cholesterol and regulate body sugar.*

Keywords: Phytochemicals, Ceiba pentandra, Vitex doniana, etho-medicinal, Proximate analysis

Pubic engagement to integrate urban city forests and university forests through service learning

T4.25 Public engagement to keep urban trees and communities healthy

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Abstract: Building public engagement between cities and universities can be enabled through community action that incorporates aspects of service learning in both the establishment and connection of the urban forest to each organization. The tenets of service learning call for frank and earnest engagement in the long term success or each partner. The first is to recognize the resources of each partner and to compare and contrast these current resources and resources for the future. Examples are group plantings and GIS data base management. Next is to assess long - term partnerships for the future. Examples include Tree Capital of Texas; Tree City USA; Ladybird Johnson Wildflower Center affiliate garden; and Tree Campus USA and to assess how each benefits the partners. Third, to be attentive to the goals and visions of each partner. Examples include connecting the urban landscapes through trails and web-based story boards in ArcGIS Online that tell public stories and interactions. Fourth is to share the legacy of the program. Examples include assessing the monarch butterfly and the American bumble bee as integral parts of the urban forest as both are being considered for endangered species status. Additionally, hazard rating of the urban forest to evaluate change over time can be completed either using standard on the ground methods or by the use of drones with comparable results. Fifth is shared responsibilities for completion and evaluation of the change in the urban forest. Examples include a renewed planting campaign using sustainability dollars at the university and to establish a tree nursery in both the community and the university. Lastly is to to evaluate the human dimension of the partnerships and to match individuals in each organization on tree boards and urban forest activities. As public engagement increases, the quality of the urban forest will increase through renewed commitment to the beautification of the community and the planting of the future urban forest.

Reaching out to the public – Feelings of human wellbeing and the wellbeing of urban trees in Wellington, New Zealand

T4.25 Public engagement to keep urban trees and communities healthy

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Abstract: Urban trees provoke many different feelings in people: joy, wonder, peacefulness, relief, sadness, anger. Wellington City Council in New Zealand receives more complaints about urban trees than accolades. To understand what is behind these feelings towards urban trees, we have designed "tree walks" through Wellington City. These are designed to elicit peoples feelings and the reasons behind them as they interact with trees along streets, pocket-parks, and in the Wellington Botanical Gardens. Initially, seventeen trees in the Botanic Gardens along pedestrian commuter paths have a QR code attached to them, inviting people to scan it. Twenty street trees will follow.

The QR code directs to a website that provides brief narrative information about the particular tree and species. This includes information about the tree's health, history and information about the species – its native range, and how it came to be in New Zealand (if exotic). Readers are invited to answer three short questions about how their interaction with the tree made them feel, why, and what they would like to see done about trees in Wellington. The collection of this data is ongoing, and will be completed early next Antipodean autumn.

We have also assessed the wellbeing of the urban trees themselves, observing how the trees have been placed, planted, their management, and using the 3-30-300 "rule", their ability to "see" other trees, are part of 30% local canopy cover, and less than 300m from a greenspace. These observational findings show that many of Wellington's street trees suffer compared with those in the Botanic gardens. While all street trees had close neighbours and were within 300 m of a park, they form just 6.4% of cover, and are smaller, younger and with less diverse neighbours than trees in the Botanic Gardens. Street trees also have high proportion of injury and adverse impacts from poorly planned lighting, signs and linear urban infrastructure; canopies deformed and restricted by buildings and highly managed 'clear zones' and paving often extends up to and around the trunk. However, this diminished tree wellbeing does not appear to impact the feelings of wellbeing people receive from trees.

Ten years of Observatree: The evolution of a tree health citizen science project and the challenges that lie ahead

T4.25 Public engagement to keep urban trees and communities healthy

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Abstract: Ten years ago, Observatree, a UK-based partnership project was initiated to investigate whether a network of volunteers could be trained to identify and report on a number of priority tree pests and pathogens. Could citizen scientists support official tree health surveillance activities and help to form part of a tree health early warning system? Many professional tree health surveys focus on the large public forests managed by government bodies, the tree nursery sector, or at dockyards, where imports of trees and wood products are inspected. But professional inspectors have a finite capacity, and may be less active in many urban and semi-urban environments. Raising awareness of tree health concerns within the wider community increases our surveillance network, helping to protect the trees in urban green spaces and the wider environment.

Ten years later, Observatree continues to train members of the public to identify tree pests and pathogens and to date, over 20,000 reports have been submitted. Some of our volunteers have been with the project since its launch and now help to guide and support new people who join the network. During these ten years, the project has evolved, responding to feedback from the citizen scientists engaged with the project, from tree health inspectors, researchers and policy makers. The project now forms an important part of the GB national plant biosecurity strategy and whilst the volunteers continue their routine monitoring and surveillance, the network can also be called upon to provide additional support to respond to incursions when necessary.

This presentation will focus on some of the lessons learned during the last ten years and how the project has adapted in response to stakeholder requirements. We have invested in new methods of data capture and engagement, but there are further challenges ahead in reaching a wider range of community groups and continuing to broaden our network of people who regularly monitor the health of their local trees.

The economics of engaging the community in forest health surveillance programmes

T4.25 Public engagement to keep urban trees and communities healthy

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Abstract: It is widely acknowledged that the community can play a key role in preventing and responding to exotic, new and emerging pests and diseases, including those that affect urban trees. Community members might provide the first reports on the location of new and pests and diseases, or form networks that are useful in invasive species management responses. However, the economics of involving the community in urban forest health campaigns is unclear because programmes and activities are seldom subject to economic analysis. Without this information we do not have any insights into the appropriate level of funding to enable community engagement in forest health surveillance, or how best to use the community to complement government surveillance and monitoring efforts. This presentation discusses how we might undertake useful economic analysis of community engagement programmes that aim to improve urban tree health. It considers data collection and the planning that is required to ensure appropriate evaluation can take place.

Tree health and urban heat: engaging communities to study urban forest disparities

T4.25 Public engagement to keep urban trees and communities healthy

Joseph Hulbert[1]
Marianne Elliott[1], Gary Chastagner[1]
[1] Washington State University

Abstract: More than 80% of people live in cities and rely on healthy, functioning urban forests. Urban trees provide critical services for keeping communities healthy, such as mitigating the impacts of heat waves, but these benefits are not equally distributed, and more research is needed to improve the services or urban forests equitably. In the northwestern United States, there is enormous need—and opportunity—to equitably increase the resilience of communities by advancing knowledge and stewardship for growing healthy and vibrant urban forests. In this presentation we summarize how community scientists have assessed tree health across urban heat islands as part of the Forest Health Watch program.

Who are urban tree bodyguards? Birds, schoolchildren, or both

T4.25 Public engagement to keep urban trees and communities healthy

Laura Schillé[1]
Elena Valdés Correcher[1], Patricia Marzin Janvier[2], Séverine Perron[3], Jérôme Sawtschuck[4], **Bastien Castagneyrol**[1]
[1] BIOGECO, University of Bordeaux, INRAE, 33612, Cestas, France
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[4] Univ. Brest, LABERS Laboratoire d'études et de recherche en sociologie UR 3149

Abstract: Trees play a critical role in the ecological functioning of urban socio-ecosystems, in addition to being favourable to the physical and mental health of city dwellers. Tree health is therefore tightly linked to that of people in the city. But do they (people, not trees) know it? Maybe not, because trees and their ecology are poorly known by the majority of people living in cities. We engaged a network of schools in the study of the top-down control of insect herbivory in oaks (*Quercus robur*) along urbanization gradients. Our goal was two-folds: produce sound ecological knowledge on tree health and promote ecological and scientific literacy. Schoolchildren and their teachers were invited to identify trees in the immediate vicinity of the oak they selected. Additionally, they monitored trophic interactions by assessing oak leaf area impacted by insect herbivores, and by counting predation marks on dummy caterpillars they exposed in oaks for 15 days. We used the percentage of impervious surface in a buffer of 200 m radius centered upon oak trees as a proxy for urbanization. We analysed the effect of urbanization and surrounding tree abundance and diversity on the potential top-down control exerted by insectivorous birds on insect herbivores. In parallel, we collected feedback from schoolchildren and teachers involved in the project through online questionnaires and interviews.We present the results of the research in ecology as well as data illustrating the process of a school-based citizen science project focusing on urban tree health.

T4.26 Questioning Urban Forest Canopy Cover Goals - Best Practices for Setting and Achieving Canopy Cover Targets

Questioning Urban Forest Canopy Cover Goals - Best Practices for Setting and Achieving Canopy Cover Targets

T4.26 Questioning Urban Forest Canopy Cover Goals - Best Practices for Setting and Achieving Canopy Cover Targets

Justin Morgenroth[1]
[1] University of Canterbury

Abstract: Tree canopy cover (TCC) is the total area of tree crowns projected onto the ground. It expresses canopy area as a percentage of total ground area. TCC is commonly used to describe the amount and horizontal distribution of urban forest canopy within a given city. Tree canopy cover is easily understood by various stakeholders, including government, urban foresters, arborists, planners, urban designers, and developers.

Because tree canopy cover has been linked with ecosystem service provision and benefits for local communities, numerous cities around the world have set targets to increase their urban forest canopy cover. However, these global TCC targets largely appear to be aspirational, rather than being justifiably informed by current research. This panel discussion addresses the topic of urban forest canopy cover targets. A group of international experts will use their personal experiences with canopy cover, as well as knowledge of grey and scientific literature to consider answers to the question of how much tree cover is desirable, or appropriate, in the world's cities.

Early work by panel members confirms that research no longer supports a universal tree canopy cover recommendation. Instead, different canopy cover targets should be tailored to individual cities, based on local context. The international literature also shows that some cities are moving away from setting a single, city-wide, target, opting instead for different targets across electoral wards, local boards, neighbourhoods, or land uses. It's also noted that targets do not preclude cities from aspiring to greater canopy cover, though overly-ambitious targets may be unachievable and undesirable for a variety of reasons. This panel discussion will conclude with recommendations for cities to successfully set and meet canopy cover targets.

Questioning Urban Forest Canopy Cover Goals - Best Practices for Setting and Achieving Canopy Cover Targets

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Kieron Doick[1]
[1] Forest Research

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Cynnamon Dobbs[1]
[1] Department of Natural Resources and Environment, University of Connecticut

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Peter Duinker[1]

[1] School for Resource and Environmental Studies, Dalhousie University, Canada

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Richard Hauer[1, 2]
[1] CNUC
[2] University of Wisconsin - Stevens Point

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T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

Analysis of Sustainability of People's Organization: The Case of NED Landcare Association in Barangay Ned, Lake Sebu, South Cotabato, Philippines

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

Louise Bernadette Del Castillo[1]
Lorena Sabino[1]
[1] Department of Social Forestry and Forest Governance, University of the Philippines Los Baños

Abstract: The main purpose of the study was to develop an indicator for assessing the sustainability of people's organizations (POs), with a specific focus on the Ned Landcare Association (NLCA) in Barangay Ned, Lake Sebu, South Cotabato, Philippines. NLCA is a farmer-led people's organization that has been operating since 1999 owing to their natural resource management and conservation efforts despite the geographical remoteness from service providers. The rationale for this research stems from the scarcity of relevant literature concerning the sustainability of POs and their corresponding indicators. Consequently, it is imperative to identify these sustainability indicators in order to ensure the long-term viability of organizations and their programs aimed at enhancing local communities and facilitating comprehensive community development and natural resource management. To achieve its objectives, the study employed a combination of methods. A comprehensive literature review was conducted, specifically focusing on the development of PO indicators designed to assess the sustainability of POs classified into internal and external aspects, with each focusing on social, economic, and environmental factors within the context of NLCA.

The study's findings indicate that the NLCA exhibits a high level of sustainability, primarily attributed to its strong linkages and networks, effective leadership, successful projects and activities, sound governance, and clear vision, mission, and goals. However, there are specific areas of the organization's overall development and sustainability that require attention. Particularly, emphasis should be placed on membership engagement, policy formulation, livelihood initiatives, and enterprise activities. Moreover, the study reveals that age plays a significant role in influencing the sustainability of NLCA. Therefore, it is crucial for the organization to ensure that the younger generation of Landcare members actively embrace Landcare strategies and maintain collaborative partnerships with external stakeholders. It is important to continue implementing new projects and activities, enhancing governance systems, and effectively communicating the organization's vision, mission, and goals to both existing and new members. To foster sustained engagement, the NLCA should prioritize efforts to motivate members to remain actively involved in the organization's activities. By encouraging continued participation, NLCA can enhance its overall sustainability and ensure the effective implementation of its initiatives.

Assessing the community benefits of EU woodland nature-based solutions - A Systematic Review

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

TIMOTHY PITTAWAY[1]
LEANNE TOWNSEND[1], CLAIRE HARDY[1]
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Abstract: Background: Nature-based solutions (NBS) are initiatives that sustainably manage and restore natural and modified ecosystems that address societal challenges effectively and adaptively, benefiting people and nature (International Union for Conservation of Nature, 2020). Most NBS provide various co-benefits, addressing societal challenges and enhancing community health and wellbeing alongside their primary objectives. NBS locations can also offer recreational opportunities such as walking trails, bird watching and fostering social cohesion. Woodland-based NBS can impact environmental factors such as biodiversity, carbon sequestration, filtering pollution and absorbing excess water. Although there is substantial literature on how NBS can benefit human well-being, there is a limited understanding of how the NBS-enhancing community aspects differ across the EU. As countries become increasingly urban, rural settlements approach woodland-based NBS to address societal and environmental challenges. This paper will provide an overview of recent research on NBS social benefits in EU woodlands alongside findings from our research, on the COEVOLVERS Horizon Europe project, on the benefits of woodland-based NBS in Scotland. The paper provides insights into the role of NBS and related activities in community health and well-being.

Methods: A systematic literature review was conducted with a web collaboration platform across several academic and online databases. ATLAS.ti software assisted in categorising articles for easy identification and transparent methodology. Each article is screened using appropriateness criteria through a three-stage process: title, abstract, and full text, with the objective of mapping and analysing these reviews for associations between the Europe woodlands and NBS social benefits. The main themes and findings were extracted using a predefined coding strategy. The paper also presents findings from qualitative interviews and questionnaires with stakeholders of a community woodland in Scotland, exploring the benefits of nature-based activities and initiatives.

Keywords: community benefits, EU woodlands, nature-based solutions

Communal forest management in native communities in the Peruvian Amazon and its potential for implementing REDD+ initiatives

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Since 2000, the native communities of Ucayali, Peru and AIDER have been co-creating a proposal to sustainably use communal forest resources. The Communal Forest Management (CFM) proposal seeks to comprehensively manage forest resources in native community territories, taking into account the geographic, social and cultural characteristics of the different indigenous peoples, thus achieving the proposed environmental, socioeconomic and climatic objectives. It is through this holistic management of the territory, communal governance, the right of the peoples over their territory and sustainable forest management, that the benefits obtained are translated into: (i) improvement of the quality of life of indigenous peoples living together harmoniously and with social inclusion, (ii) security and diversification of livelihoods and income, (iii) recovery of the productive potential of communal forests, (iv) conservation of Amazonian forests and their biodiversity, (v) mitigation and adaptation to climate change with the reduction of greenhouse gas emissions and (vi) resilience of indigenous peoples and Amazonian forests.

The CFM allows obtaining benefits from ecosystem services, developing REDD+ initiatives thanks to the production of carbon credits in the communal forests; these credits are the financial leverage that gives sustainability to the productive economic activities implemented in the native communities. This CFM is being developed in seven Shipibo Conibo and Cacataibo native communities in the Ucayali region, where the financing obtained through the REDD+ Nii Kaniti initiative has allowed the implementation of sustainable inclusive activities and businesses that care for and conserve the forests, such as: governance, legal physical sanitation, forest control and surveillance, agroforestry, commercial forest plantations, handicrafts, fisheries management and timber and non-timber harvesting.

Comparison of Small-scale, Community, and Indigenous Forestry among the Norway, Sweden, and United States

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Hanne K. Sjølie[2], Francisco X. Aguilar[3]
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[3] Swedish University of Agricultural Sciences, Department of Forest Economics, Sweden

Abstract: Forests exist within complex socio-political-economic systems. A key component to these systems is the people who own and manage these lands as they are the ones who make the primary decisions on if and how the land should be used, within contextual political, economic, and biophysical constraints. Forest ownership histories and patterns vary across the globe, but there are many areas where cross-country comparisons can help. Such analyses may increase knowledge about the barriers and opportunities that different ownership and user communities face to progress forest management in a time with global climate change and increasing public concerns about the impacts of forest management on ecosystem services. Norway, Sweden, and the United States all have extensive forest cover and forest ownership that is dominated by private owners, 80%, 75%, and 58%, respectively. All three countries have well-established National Forest Inventories (NFIs) and national forest ownership surveys, the one in the U.S. tied to the NFI. This presentation will compare histories of forest ownership, current ownership patterns, and a more detailed comparison of the demographics, attitudes, and behaviors of small-scale, family forest ownerships across the countries. Preliminary data explorations suggest that demographics, reasons for owning, and management activities are fairly similar. Factors such as size of holdings have similar impacts across counties, but the impacts of various national and local policies and economies present substantially different constraints and opportunities for forest ownership and management. These findings have important implications in terms of understanding the future of forest ownership and forests and how policies and programs might impact these futures.

Designation of World Natural Heritage and challenges of traditional small-scale forestry in Okinawa

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Yambaru area, the northern part of Okinawa Island in Japan, was designated as a World Natural Heritage in 2021 with three other islands in the Ryukyu Archipelago. Because of its geographic and climatic significance as an isolated subtropic islands, the area is rich in biodiversity and famous for many endemic species of plants and animals. However, people have lived in this area for a long time and engaged in economic activities such as forestry and fishery. The Ryukyu Kingdom remained independent for 450 years between China and Japan, Yambaru had been continuing to supply timber and firewood to the people in the capital city Shuri and populated Naha.

This study aims to recall the historical and concurrent importance of local forestry activities in Yambaru as well as to identify the characteristics of rich biodiversity of the forest and to explore the need for its protection. Small-scale local forestry can be said to be quite powerless against major environmental movements. Even so, local forest owners' cooperatives and people involved in the forest industry have no choice but to continue the forestry business on a small-scale. The authors interviewed such forestry related people and environmental groups, and tried to consider a constructive future plan to sustain small-scale forestry against the strong pressure for protecting rare and endangered species and rich biodiversity in the World Natural Heritage and surrounding buffer zones.

Ecotourism must be an answer, but it is important to see how local forestry people get involved in tourism while continuing forestry activities including timber production and others. We are hoping to discuss with participants of the IUFRO session who have similar kind of experiences in different place of the world.

Examining space for indigenous peoples and local communities in community forestry

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: The roles of indigenous peoples and local communities in sustainable forest management have widely been acknowledged in Multilateral Environmental Agreements and national policies. Regardless, a tension persists where legal arrangements are inadequate to recognize, address and respect the rights and roles of indigenous peoples and local communities in a balanced approach in forest management. Taking Nepal's community forestry as a case, this paper aims to explore to what extent the space for indigenous peoples and local communities is accepted in policies, laws and practices for sustainable forest management. The conflicts between indigenous peoples and local communities in community forestry and other forms of forestry are also analyzed in the light of international environmental instruments, local needs, sustainable use, gender equality and space for transformative change. Literature survey was the main source of information, while some key informant interviews of indigenous and community leaders were also carried out. It was found that local communities were adequately recognized by policies, laws and programs particularly in community forestry, while indigenous peoples were slightly addressed in policies and some aid-funded projects but not in programs and practices. In rest of forestry programs, neither indigenous peoples nor local communities are recognized, respected or addressed. Marginalization of indigenous peoples from forest landscapes started long before the community forestry was initiated and institutionalized. The study also found that blaming the local communities for excluding indigenous peoples due to community forestry was not evidence-based. Instead, community forest user groups in many places tried their best in practice to address the issues of indigenous peoples within the existing policy and legal frameworks. In order to fully incorporate the rights and roles of indigenous peoples in forested lands and their tenure, a transformative revision in domestic forest laws and adequate sensitization of policy makers, forestry officials and practioners are recommended.

Forest conservation incentives and benefits distribution for Indigenous communities --a case from Peru with scalable lessons

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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[1] Michigan State University
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[4] Asociación Servicios Ecosistémicos Perú

Abstract: Forest-dwelling Indigenous Peoples and local communities (IPs and LCs) make decisions for over 36% of forests globally. Particularly in tropical forest countries, communally held land is central for the subsistence and livelihoods of Indigenous people. Major climate negotiations prominently feature forest protection as a key mechanism to reduce emissions from the land sector. However, despite an estimated USD 12 billion pledged to address tropical deforestation, only a fraction of funding for tropical forest monitoring conservation is reaching decision-makers on the ground. Best practices to distribute incentives for conservation activities to small-scale and indigenous communities is poorly understood. This research explores the strengths of mechanisms to directly transfer incentives to communities to grow equitable conservation partnerships and develop long-term commitments.

Peru holds the second largest share of Amazon Forest – locally and globally important for biodiversity, climate regulation, and carbon storage - and communal landholders make decisions over more than 65% of this ecosystem. As part of an ambitious plan to conserve 79% of its tropical forest (54 out of 68 million hectares), Peru's Ministry of the Environment (MINAM) has pursued a strategy of using incentives to shape behavior and decision-making to stop deforestation. The mechanism, called Conditional Direct Transfers (TDC, in Spanish), signed nearly 200 conservation agreements with communities overseeing 2.9 million hectares in its first 10 years, with plans for continued scaling.

Our research assessed current performance and interactions of the TDC program, including implications for long-term outcomes. We asked: How can the TDC be improved to achieve long-term conservation and development objectives?

To analyze this question, we developed a rich dataset that included interviews with qualitative and quantitative components, TDC programmatic documents (Policies, implementation guides, PGI examples, community reports, etc.), and community data from multiple public sources as well as from fieldwork. We used strategic categories in the theoretical framework—Governance, Economics, Participation, and Social Impacts—to construct research questions, identify methods, and undertake data analysis.

Our framework provides generalizable recommendations with an assessment of program implementer responsibility and best practices. In this way, we offer a strong foundation for

implementation and subsequent monitoring of forest conservation incentive programs around the world.

Forestland concession, land rights and livelihood of ethnic minorities: Evidence from the Sal forest of Bangladesh

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Forestland concessions have in the recent past been the dominant governance tool for the acquisition of state-owned forest resources in many tropical countries, including Bangladesh. The Sal forests of Bangladesh are treated as one of the most concession forests, and a number of ethnic minorities use these forests for their daily lives. Therefore, the objectives of the study were to identify the impacts of Sal forestland concessions and land rights on the livelihood development of the ethnic minority living in the Madhupur Sal forest area of Bangladesh. Using both qualitative and quantitative data collection techniques, the study found that about two-thirds portion of the original Sal forestland was grabbed by state and non-state actors. As a result, the inhabitant ethnic minorities have lost their traditional land and free access rights to the Sal forests. The process of losing ethnic minorities land and access to forests has been enhanced by the institutional arrangements of the state, which have also created severe conflicts between the forest department and the ethnic communities. The study also revealed that the land concession has negatively affected the five livelihood capitals development of the ethnic minority; consequently, their livelihood basis has shifted to non-securing jobs or poor income sources like daily wage labor. Therefore, the study would recommend to establish a legitimate process in order to settle down the issue of traditional land and forest access rights of ethnic minorities; which could also attain the conservation and development goals of the degraded Sal forest.

GOVERNANCE DYNAMICS OF COMMUNITY BASED FORESTS IN KENYA: CASE STUDY OF LOITA FOREST IN NAROK

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

Roxventa Ongugo[1]
Charles Koech[1]
[1] KEFRI

Abstract: Forests in Kenya were under traditional community management regimes up to 1891.Formal management of forests by state started in Mangrove forest along the Kenya coast at Vanga and, later the entire country in 1900. In 1997 decentralized forest governance was successfully piloted through Participatory Forest Management in Arabuko-Sokoke forest at the Kenyan coast. This informed review of the Forests Act, Cap 385 to The Forests Act, 2005 subsequently revised to Forest Conservation and Management Act, 2016. The Act has explicit sections on decentralized forest management with special focus on communities. The devolution of forest governance especially through Community Forest Associations (CFAs) has given the communities a sense of legal ownership and management. Through the CFAs the communities participate in the management of forests close to their residences. They organize themselves in groups to facilitate management and extraction of products and services from the forests. This study was carried out to document status of the management structures of Loita forests currently managed by community under traditional rules represented by the Oloibon institution. The objective of the study was to document the governance structures applied in these forests and their effect on the management of the forests including its conservation**.** Data was collected through interviews with the officials of the CFA, other organizations with stake in the forests. Results indicated that there is population increase putting pressure on the forest and its resources. There is improved infrastructure and mechanization in the area. Currently there are challenges on the governance system which poses a risk to the existence of the forest. The Oloibon institution which has safeguarded the forest is losing its effectiveness due to factors like emergence and spread of Christianity and land demarcation. There is encroachment into the forest for production of food crops and charcoal burning.

These challenges pose the question on the success of devolved structures based on community governance institutions. Another issue to address is the role of indigenous management structures in safeguarding forests and ensuring their ability to provide the required ecosystem products and services over time.

Indigenous endangered species in small-scale forest and valuing carbon stock: a success story of climate smart forest

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: This study focused on the restoration programme of small-scale forests at University of Chittagong, Bangladesh of 600 hectare of land with indigenous endangered species not only generating ecosystem services to the inhabitants of the society but act as a measure to save watershed area of river Halda, only natural breeding ground of carp fishes in the world, and a major source of water for irrigation and drinking. This study assessed the forest resources applying a spatio-temporal time series analysis of landuse changes using satellite images from 1990 to 2020 and measured tree vegetation with species composition, diversity and density of natural regeneration of tree species, carbon stock with major timber species, using field experimentations. Restoration programs on hilly part of the area with indigenous and 52 endangered species. The results revealed that plantations restricted runoff during monsoon and also be a germplasm repository of endangered species for the nation which provide positive impact on management of watershed of river Halda. Organic carbon content by six major timber species (with different age classes) namely Garjan *(Dipterocarpus turbinatus),* Mehogoni *(Swietenia macrophylla),* Shal *(Shorea robusta)* Chapalish (*Artocarpus chama), Gamar (Gmelina arborea), Akashmoni (Acacia auriculiformis)* and soil organic carbon stock were measured. Six allometric equations of stated species were developed for effective management. This reforestation program on small-scale forest and carbon valuation put forward an effective venture to the nation and earned national best award on tree plantation for 2023 as well. This approach of reforestation program with carbon management for small scale forests may provide an instrument to combat climate change and rebuild a healthy forest, may be apply to any part of the world as it has a generic nature.

Innovative ways of linking small scale forestry enterprises to markets: a review

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Small scale producers are considered the world's largest private sector, making up about 80% of forest enterprises and contributing to 50% of forest related jobs. However inadequate market mechanisms and lack of institutional instruments to connect the small scale enterprise to markets, threaten their prosperity. This article reviews and analyses innovative ways in which small and medium forestry enterprise in East Africa access markets and services for their products, as part of developing National forestry investment and innovation hubs to link producers to markets and services. We present analysis from forest producer organisations, forest dependent communities and institutions within East Africa on existing policy, institutional frameworks, support programmes and constraints in linking small scale producers to markets. Analysis uses a framework of 10 indicators on best practice in supporting small scale enterprise. Findings indicate that small scale enterprises have great potential to grow through forming aggregated groups for marketing products and improving marketing networks, diversifying distribution channels and uses of forest products and participation in various secondary processing and value addition process. However, challenges of isolation between practice and policy frameworks, limited financing mechanisms and lack of documentation of forest value chain information systems still exist. We conclude that national investment initiatives are required to connect small and medium enterprises to markets, enhance visibility of the enterprises, and provide communication channels for provision of advisory service and networking.

Key words: Small scale, forestry enterprises, market linkages, bio-economy, investment hubs

Introducing a lean forestry practice in a rural community context

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: In Sweden, there is an evident interdependence between small-scale forestry and large-scale forestry. Typically, the management systems, the technology and the logistics, primarily developed in large-scale forestry, are now also applied on small-scale forestland. The pursuit of reduced costs for timber for industrial purposes, through rationalization and simplification along the entire production chain, has resulted in a mono-measures forestry i.e. routinely; the same measures are done at all times and everywhere. Although small-scale forestry also may benefit from the rationalization gains, there are drawbacks of the "one-method-fit-all" principle that needs to be addressed. One way of doing this, is by introducing the *lean forestry* concept, which can be expressed as silvicultural measures that are as precise and resource efficient as possible, not only to minimise expenses and maximise high biomass and wood production, but also to maintain the potential for other forest ecosystem services (Rautio et al 2023). This requires exact spatial information that can be obtained by using remote sensing data from satellites or sensors on drones or attached to machines operating in situ. To explore how *lean forestry* can be applied in practice, what system and technological changes that might be required, and which gains that might be achieved, the ArcticHubs project are introducing the concept in a series of workshops with stakeholders in Malå. In this paper, the outcome of these workshops will be presented and discussed, particularly with regard to how small-scale forestry can benefit from the potential of more fine scale operations which also may support the preservation of other forest functions and thereby mitigate land use conflicts.

Key words: case study, exact spatial information, silvicultural measures, workshops

Moving towards join forest management at landscape level in Portugal: the case of Coimbra Region

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Portugal is one of the European countries with the highest percentage of private forest. Land fragmentation is dominant, where forest areas are owned by more than 400 thousand small landowners and 85% of the holdings have an area of less than 3ha. These conditions discourage active forest management and are often pointed out as one of the causes of rural fires. Nevertheless, Portugal has a significant forest area (36% of the territory) and favorable conditions for the development of forestry activity, especially in low-density territories, where growth rates of forest species and the added value of forestry are among the highest in Europe. The effectiveness of forest management in small land areas depends to a large extent on how the owners' structure and organize their joint decision-making processes. Public policies in recent decades have promoted the implementation of join management instruments to increase the scale of intervention. More recently, two legal instruments were created - the Integrated Landscape Management Areas (AIGP) and the Village Condominiums (CA), in the umbrella of the Portuguese Landscape Transformation Program (PTP). One of the goals of these recent programs is to contribute to overcome property fragmentation by developing solutions that promote land consolidation and the consequent scale increasement to promotes resilience to fires, enhancement of natural capital and rural economy. For the creation and maintenance of the AIGP and CA to be more successful, it is important to create mechanisms to monitor the different initiatives, allowing good practices to be identified and generalized. This study implemented in the region of Coimbra, integrated in the RESIST project, co-funded by the European Union, aims to: understand the acceptance by the agents involved, namely forest owners; assess the impacts on the territory arising from the adoption of integrated forest and fire management practices, including silvicultural practices adjusted to climate change; identify and propose valorization models that boost the local economy. The relationship of the new AIGP and CA structures with other past join management initiatives will also be analyzed, such as the Forest Intervention Areas (ZIF), some of which are still active in the territory.

Opportunities for cooperation in multi-objective forest management – a case study of forestry stakeholders in Finland

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Forest owners (FOs) have various forest ownership objectives, and they simultaneously face manifold external expectations related to the use and management of their forest, such as forests' carbon sequestration, preventing biodiversity loss, and conservation of ecosystems. As many ecological functions (e.g., water conservation) are not restricted by forest property boundaries, the cooperation between FOs and other forestry stakeholders could offer novel opportunities for multi-objective forest management and reconciliation of diverse objectives. In the best-case scenario, this type of cooperation could, enhance the implementing of new voluntary activities, increase knowledge about different forest management options, and produce practical benefits in ecosystem conservation activities as well as financial reward.

Yet, there is relatively limited research knowledge on forestry stakeholders' perceptions on cooperation in forest management. Thus, the objective of this study is to investigate forestry stakeholders' interest in cooperation in forest management and to examine their perceptions on the benefits, opportunities, and barriers of cooperation. The research was conducted in two phases during 2022-2023 in Finland. The qualitative data were collected through 22 forestry stakeholder online interviews and were analyzed with content analysis. The data were enriched by quantitative survey data pilot collected from FOs (n=39) that were analyzed with quantitative methods.

Preliminary results indicate that there is a willingness to increase local awareness and interaction in forestry issues among forestry stakeholders. However, more information on the benefits and possibilities of cooperation is needed. Furthermore, there is a need for a coordinator of cooperation and such FOs who have sufficiently similar objectives in terms of the management and use of forests. The quantitative results show that one third of the FOs considered cooperation as fairly or very necessary in forest management related issues (e.g., carrying out of jointly agreed practices, such as loggings). Shared experiences with other FOs, new contacts, and interaction opportunities were seen as the most important benefits of cooperation. Moreover, cooperation would likely to improve water conservation possibilities and enhance biodiversity. The findings provide tentative understanding on stakeholders' cooperation opportunities and suggest that cooperation could provide opportunities to foster more sustainable forest management and use in Finland and beyond.

Perceived Opportunities and Challenges from Agroforestry Technologies Adopted by Kapit-Bisig Farmer's Association in Atimonan, Quezon, Philippines

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: This study examined the perceived opportunities and challenges from agroforestry technologies adopted among members of the Kapit-bisig Farmer's Association Incorporated (KBFAI) which was established in 1989 and became a partner farmer organization of the Department of Environment and Natural Resources (DENR) to implement the Community-Based Forest Management (CBFM) program. This program intended to rehabilitate, improve, and manage natural resources under the Certificates of Stewardship Contracts awarded to the 331 legitimate members with a total of 2,207.3 hectares. Agroforestry farming techniques are adopted by the members within the 4-7 has of land wherein 20% of which should be timberland and the 80% for any cash crops or livestock. Among the fifty (50) active members interviewed in 2019, their memberships to the KBFAI and as recipients to the DENR-CBFM program through trainings and seminars have equipped them with the knowledge and skills to implement an agroforestry system as main source of livelihood. Majority (90%) adopted the multi-storey type of Agroforestry system for the social, economic, and environmental benefits to farmers. In 2018, KBFAI was awarded the Best CBFM Model in the CALABARZON region. Leadership skills and collective efforts among them have improved as well as linkages/networks and good rapport with other government agencies were established. Economically, agroforestry provides farmers better yield and regular monthly income from the multi-storey system since they do not only integrate forest/fruits trees and agricultural crops, but also with poultry, bees, and livestock. The "*coprahan" venture*, selling of seedlings, basket weaving and whisk broom also contributed to the income sources of the KBFAI members. In terms of its environmental benefits, members observed that trees improved soil quality, provided shades for crops and livestock, restored water supply and reduced erosion. However, a study revealed that KBFAI also experienced both successes and setbacks in implementing this practice. Many of the members are senior citizens and having trouble managing their agroforestry farms and are facing challenges in convincing their children to carry on the work. The study recommends that local governments and agricultural institutions should create programs and incentives to encourage the younger generation to sustain agroforestry in the Philippines.

Socio-Economic Contribution of Small Scale Tree Nurseries to Smallholder Farmers in Kenya

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Forests and forest-based industries are moving towards a sustainable forest-based bio-economy. Forestry is a key financial resource, and supply of raw material for small scale entrepreneurs. It is, in principle, renewable, re-usable and recyclable. Small scale tree nurseries are a lucrative source of livelihoods to numerous households. They provide planting materials for afforestation, rehabilitation of degraded landscapes for climate action, and commercial forestry opportunities. The enterprise has not been fully embraced as an investment because little information exists on costs and return on investment. The specific objectives were to: identify preferred tree species raised in tree nurseries, evaluate the monetary value for the seedlings, identify market sources for the tree seedlings, evaluate the contribution of tree nurseries as a source of livelihoods and document constrains facing the tree nursery small scale dealers. The data was collected in Nyeri and Laikipia Counties, Kenya. Random sampling of tree nurseries was done and data was collected using semi-structured questionnaires administered to 400 nursery owners. Parameters evaluated included: socio-economic characteristics of nursery owners, tree species raised, costs and returns, cash flow of the enterprise, rate of return on investment and cost-benefit ratio. The data was cleaned, coded, entered and analyzed. A total of 86.1% of tree nursery owners were between 18 and 43 years old with male dominating (78.9%). The main tree species were *Melia volkensii, Senna siamea, Grevillea robusta*, fruit tree species (citrus, mangoes, and avocado), and ornamental species. The profit of a small scale tree nursery was between Ksh 100,000 – Ksh 300,000 annually and the rate of return was 90%, with cost-benefit ratio at 2.76. Challenges faced in tree nursery investment included: water shortage 35%, lack of quality tree seeds 25%, lack of proper potting materials 15%, lack of ready markets 15%, evictions by authorities 6%, pest and diseases 2% and inadequate funds 2%. Small scale tree nursery is an economically viable enterprise hence operators should be provided with entrepreneurial skills, access subsidized costs and environment friendly potting materials from economic stimulus programmes, and trained on producing high quality seedlings.

Key Words: Small scale, Cost benefit ratio, Tree nursery, Seedlings

Sustainable Community Forestry Development in Mexico

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Climate change, biodiversity loss and socioeconomic conditions are important challenges for achieving sustainable community forestry development in Mexico. These challenges have created the need for building capacities in forest ejidos and communities (common property land), since they are who live with effects of any action in their communities. For that, it was necessary to apply a participatory strategic management model (different to traditional processes) in forest ejidos and communities for sustainable development. The integral model is based on three principles: strategic thinking, holistic vision, and participatory democracy. The model included: a) Multisearch Conference, which is a participatory and decision-making of "bottom up" process, and b) participatory strategic management model for the competitiveness of community forest enterprises. It includes strategies for designing, implementing, and monitoring strategic plans for managing sustainable forestry development. The application of the model allowed to the local people better motivation and appropriation levels of participatory decision making processes for driving their own development. Examples of outputs of this model are: a) Participatory strategic master plan for sustainable forestry development in the state of Chihuahua, Mexico; b) Integral forestry development project of the forest Ejido “El Largo and Anexas”, Madera, Chihuahua, Mexico (the largest forest ejido in Mexico), and c) Forest Productive Chain “Baja Tarahumara, S.C.”, Urique, Chihuahua, Mexico. In sum, the participatory strategic model promoted anticipatory and self-managed sustainable community forestry development. The model represents a paradigm shift in order to get sustainable community forestry development.

The De Carballo community forest, a remarkable case of sustainable self-management in north-western Spain

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Spanish communal forests are currently only found in some regions of the country, especially in the region of Galicia (NW Spain), where communal forests are of a type called "Montes Vecinales en Mano Común" (which translates roughly as "neighbourhood communal forests"), a traditional and specific type of collective form of private land tenure with high economic, social and environmental importance. The De Carballo community forest (Friol, Lugo) is a paradigmatic case of the self-management and enhancement of the multiple uses and services that forests can generate. This forest (716 ha) was managed by the Galician public forest authorities through agreements reached in 1944 and 1953 and then by a further agreement, signed in 1982, which was finally rescinded by the community owners in 2009. The community members now manage the forest by themselves, with help from a forestry consulting company. This has enabled the community to fulfil the forest management plan in relation to the traditional timber uses, as well as to launch several initiatives involving other types of use (silvo-pastoral use with native horses, pigs and goats, mushroom foraging, honey and resin production) and services (promotion of social activities, including local festive events). The De Carballo forest was the first Spanish community forest to be awarded FSC certification, and it has since also been certified by PEFC. In conclusion, the De Carballo forest is a model example of a viable community forest and of how forestry can best serve the collective needs of people through self-management and leadership involving local communities.

Twenty years' review of Community Forestry Program in Taiwan.

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: While Taiwanese community forestry program, focusing on biodiversity conservation, has been implemented for more than 3,000 projects and become an important communication tool between forestry agencies and local communities in the past 20 years, this study aims to describe its contents and contributions, and discuss its influence on community participation, empowerment, local livelihood development and the following forestry policies. We adopted literature review, participant observation and interview to collect relevant information. Totally, about 400 relevant project reports, publications and papers were reviewed, and we have been involved in 22 occasions by participant observation, and conducted 16 semi-structured interviews from 2020 to 2022.

Almost Taiwanese community forestry projects belonged to the first stage, while with original design of three stages to empower local communities for co-management and/or co-governance of national forests step by step. Only about ten cases have been engaged and three of them have completely implemented the 2nd stage projects, as there isn't any 3rd staged project. The results showed that Taiwanese community forestry program could contribute to local social and human capital but do not work well on financial capital and livelihood development. Its content mainly focused on capacity building of local people and organizations, survey of fauna and flora, and those relevant to ecotourism development, which could play some role to improve local livelihoods. The sponsored program funding was mainly used on supporting operations of community organizations, promoting the internal and external social network, and creating job opportunities. The major deficiencies or weaknesses of Taiwanese community forestry program might be limited participation of communities and local people in forest governance. In recent years, Forestry Bureau has developed several new participatory policies to increase interactions with indigenous and local communities. Nevertheless, the community forestry program still one of the most popular and effective ways for the forestry agencies to build up partnerships with local communities on site. In this regard, this study suggests that Taiwanese community forestry program could be the empowerment tool and platform to integrate with above different policy programs for the forestry agencies to engage indigenous and local communities.

Two models for organising small-scale forest owners to receive income from timber sales: A comparative analysis between Japan and Sweden

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: OECD countries in Northern Europe and Northeast Asia have a high share of privately owned forests crucial for sustainable forest management in both regions. Forest owner cooperatives (FOCs) constitute an important institutional arrangement for facilitating forest management and supporting profitability of family forestry. This study presents a comparative analysis between the economic models of organizing FOCs in Japan and Sweden.
In Japan, over 600 cooperatives largely rely on public subsidies and provide services in planting and harvesting. Most members' income comes from the standing timber sale. Their current income level is historically low and only about 30% of clearcut areas are reforested. In Sweden, forest owner cooperation is concentrated in three large-scale forest owner associations (that are in principle, FOCs), in northern, middle and southern parts of the country. Forest owner association Södra operates in the south, where the area of privately owned forests reaches 75% and 50 % of the area belongs to 52 000 members of Södra. Södra is the largest FOCs in the country and operates sizeable pulpmilling and sawmilling capacities. Having a large share of the roundwood market, Södra keeps down the standing timber price but shares the profits from the wood processing sector with its members.
The very different economic models of organizing FOCs in Japan and Sweden highlight the underlying economic conflict, when sawn timber and pulp sector strives to source logs for the lowest possible cost but forest owners try to sell their standing timber for as high price as possible. As sawn timber and pulp sector of Södra are large scale and internationally competitive, it can pass the profits from the processing to the shareholders, thus compensating the members for lower stumpage. Whereas most Japanese FOCs are primarily involved in forest management with no or insignificant own industrial capacities. Japanese FOCs have little influence on the log market due to the small scale operation per FOCs. Our comparison will highlight pros and cons for respective models, which can provide interesting lessons also for other countries.

What can transaction costs can teach us about managment structures in small-scale forests and their owners in Germany

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: It is known that small-scale forest owners fall short of their forest utilization potential. This is often reasoned by a socioeconomically driven goal of preserving the forest value for their descendants. Their behavior could also be explained by the costs they need to incur to participate in the forest market, considered as transaction costs. Transaction costs belong to any economic activity, but they are specific, individual and not easily generated – especially for small-scale forest owners. Applying the transaction cost theory on small-scale forestry could open new solutions for mobilizing forest owners. Therefore, the aim of our study is to define transaction costs for small-scale forestry, to evaluate their impact on harvesting decision-making, and to estimate them empirically.

Firstly, we performed a literature review and expert interviews to build a concept for estimating transaction costs for small-scale forestry. Next, a harvest decision model was created to estimate the impact and the relationship of transaction costs and forest owners´ behaviors. Finally, we conducted an online survey to gather empirical data on transaction costs for private forest owners in Germany.

Analysis of literature exhibited the need for an empirical study on transaction costs. The implementation of transaction costs to the model showed an apparent effect on the behavior of forest owners. Increasing costs reduce the activity of forest owners and intensify the logging measure. The online survey confirmed these results. The expert interviews showed that existing basic management structure, larger forest area per forest owner or measure, and outsourcing to professionals lead to less transaction costs for forest owners. In contrast, determinants like smaller forest estates, or less education on forestry and a "do-it-yourself" strategy promote higher transaction costs.

This study emphasizes the importance of reducing transaction costs and the improvement of market efficiency and access, especially for small-scale forest owners.

Who are the owners of private forests in Poland and what is the importance of ecosystem services to them?

T4.27 Small-scale, Community, and Indigenous Forestry: Global Challenges and Opportunities

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Abstract: Constant process of generational change among forest owners, which was further intensified after 1989 in the countries of Central-Eastern and Southern Europe by the appearance of "new owners" as a result of reprivatization processes of forest property and a new group of owners who benefited from the financial support of the Common Agricultural Policy for the afforestation of land excluded from agricultural use. The positive effect of these processes is the increase of private forest area, while the negative consequence is further fragmentation of private forest area. The social phenomenon that accompanies the described changes is the weakening of the relationship between the "new" owners and agriculture or rural areas. A large part of the owners are not interested in forest management because it is not important for them as a source of income.

Forest ecosystems, regardless of ownership or management type, are suppliers of many products and services, both market goods and public goods and services. The main difference in the provision of the latter by private forests, as opposed to public forests, is that owners must assume the obligations arising from their property rights, as reflected, among other things, in numerous programs to compensate forest owners, for example, for the costs of protecting biodiversity or for lost income due to the abandonment or curtailment of timber harvesting. Thus, if private forestry is expected to engage in biodiversity, climate, water, and soil conservation on a large scale, it is necessary to know not only the expectations of owners, but also the level of their knowledge and awareness of nature, which is shaped by the value system of forest owners that governs the implementation of forest management. Knowledge on the above scale is necessary to implement the best solutions for multifunctional forest management, whose main objectives compete with each other to varying degrees. In addition, the objectives set in both the planning and implementation phases need to be increasingly modified, taking into account the increasing impact of extreme weather events in recent years that threaten the sustainability of forest ecosystems.

T4.28 Towards quantitative explanations of forest governance and its complexity

Advancing quantitative statistics in governance research – case study examples from tropical forest policy

T4.28 Towards quantitative explanations of forest governance and its complexity

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Abstract: Different and increasingly diverse demands on forests and their ecosystem services require an increasingly complex forest policy, which usually relies on various single policy instruments. In addition, combinations of individual instruments in different mostly country specific policy mixes must be considered. These are related to and driven by different stakeholders. Governance research requires adequate methods to analyse the interplay of governance components and the effectiveness of policy instruments. Using case studies on current tropical forest policies in Ecuador, Zambia and the Philippines, quantitative approaches to forest policy analysis are presented. These rely on classical governance (field) assessment methods like literature reviews, interviews and focus group discussions which are as well widely used in qualitative approaches. However, through coding and scoring, numerical data are produced that are the basis for statistical evaluations. Selected results include examples for parametric and non-parametric comparisons of means for different governance components in order to analyse governance quality across landscapes and tenure regimes. Multiple regression analysis is applied to determine the significance of underlying (e.g. governance) and direct drivers for deforestation. In another application, preferences of stakeholders for different policy instruments and their combinations are determined by means of principal component analysis in the three study countries. Social network analysis is used to quantify the power of individual stakeholders. Relations between preferences for policy instruments and power can form the basis for recommendations for individual instruments. Based on these examples it can be concluded that such reproducible and stochastic quantitative designs are needed to allow for generalization of results. However, specifically the formulation of research questions and the interpretation of results need a deep procedural understanding, e.g. resulting from qualitative research. This shows that a polarization between quantitative and qualitative approaches is neither useful nor intended.

Assessing changes in Brazil's international forest policy engagement and capacity

T4.28 Towards quantitative explanations of forest governance and its complexity

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Abstract: In the last decades, Brazil has been under increasing scrutiny regarding its policy towards forests, especially during Bolsonaro's presidency (2019-2022). While both domestic and international forces have a considerable influence over the foreign policy of a country, Brazilian presidents have often acted as drivers of changes in diplomatic strategies, shaping them to their own beliefs and interests. Such changes in diplomatic strategies translate into issue-specific shifts in the policy capacity and engagement of the country. While previous studies showed the overarching shifts in Brazil's foreign policy under different presidencies, this study focused specifically on variations in capacity and engagement on forest issues. This was done by determining changes in resources allocated to diplomacy (as a proxy for capacity) and in the degree of interaction with other countries (i.e., engagement). To reach this goal, we carried out a quantitative analysis of the bilateral and multilateral agreements signed by Brazil from 1995 to 2022, as well as the size of delegations sent to international forums on forests, climate change, and biodiversity. The choice of the timeframe used in this analysis captures the surge in presidential engagement in diplomatic issues, and its further development throughout the terms of five executive leaders. The quantitative data were further complemented by expert interviews and qualitative content analysis of presidential declarations. Our results indicate a trend of increasing engagement and capacity, followed by a noticeable decrease during Bolsonaro's presidential term.

Comparative analysis of wildfire policies across European and South-American countries

T4.28 Towards quantitative explanations of forest governance and its complexity

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Abstract: Wildfires and societies have co-evolved during millennia, with fire being a cost-effective management tool. However, in recent decades, unprecedented wildfire seasons have disrupted the coupled human and natural system due both to climate conditions and inadequate policies, mostly targeting fire exclusion and emergency suppression as ad-hoc reactions. Wildfire policies, composed of goals, instruments and implementing actors, can be influenced by different factors, including the salience of fire as an issue, the political system of the country as well as its domestic capacities. Hence, the aim of this study is to compare and explain wildfire policies in countries with different development status, issue importance, and political system. In order to do so, following a most different research approach countries in South America and Europe were selected as cases. In each country fire policy issues were identified based on a document and media content analysis. Data was obtained from nationally distributed newspapers as well as professional journals, regulations, and programs within a specified time period. Simultaneously, actors and policy instruments were identified and characterized following Krott (2005). The identified wildfire policies were classified according to a proposed classification system that can be applicable to other cases. Data was analysed with a qualitative comparative analysis (QCA), with issue salience, policy system and the countries´ capabilities as explanatory conditions explaining the fire-policy (outcome). Our results show that wildfire policies relate to the general and issue specific countries´ capacities and polity. This study will allow us to better comprehend which factors are playing a role in wildfire policies.

Evolution of cooperation networks of forest governance system in China: Based on Bibliometric Analysis of 2571 Policy Documents, 1949-2020

T4.28 Towards quantitative explanations of forest governance and its complexity

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Abstract: Forest governance is intrinsically complex, comprising forest use and conservation and dealing with ecological and socio-economic issues from multiple levels. The independent or pluralistic cooperative relationship of forest governance authorities is an important part of the process of policy decision-making. It is of great significance to analyze the cooperation network and its evolution trends among policy-making authorities to further clarify the policy development path and improve the coordination mechanism of forest governance. Taking the 2571 forestry policy documents issued at the national level from 1949 to 2020 as research samples, applying social network analysis method, this paper analyzed the evolution characteristics of the cooperation networks of Chinese forest governance authorities and their roles in the network by drawing the cooperation networks and the two-dimensional matrix with breadth and depth of cooperation. The results show that the number of annual forestry policy documents issued at national level in China has a trend of first fluctuating upward and then slowly downward during 1949-2020, with distinct phased characteristics. The main body of forest governance has shown the characteristics of extensive and dominant coexistence, involving up to 150 departments. However, the national forestry administrative department, the finance department, the development and reform committee and the national agricultural administrative department are the leaders of forestry policy joint issuance, and the national forestry administrative department has always been the authoritative body of the forestry policy releases, accounting for 82% of the total number of forest policy documents. The cooperation among the main authorities in the network has evolved from the loose situation with the national forestry administrative department as the core to the situation with it as the core of the network and the multi-sectors partial core equilibrium. This indicates that in recent years the national forestry administrative department has been playing a dominant role in promoting the forestry development and the construction of ecological civilization together with multi-sectors in a coordinated way. In the context of increasingly prominent forest externalities and environmental problem complexity, interdependency and cooperation among sectors are effective ways to solve the environmental problems and promote the construction of ecological civilization.

Global governance for deforestation-free cocoa

T4.28 Towards quantitative explanations of forest governance and its complexity

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Abstract: As a commodity crop, cocoa has been developed globally to tackle cocoa-related issues such as price stabilization, deforestation, child labor, and smallholder farmers' living income. This study examined global cocoa rules through quantitative content analysis of global documents related to the cocoa sector. The research explores over 60 years of global cocoa rules since 1962, the year of establishing the Intergovernmental Cocoa Organization with member countries (22 exporting countries and 26 importing countries) under the auspices of the United Nations, to 2023. Global society has made efforts to reduce deforestation in cocoa production through hard and soft laws. In the 1970s and 1980s, International Cocoa Agreements by International Cocoa Organization more focused on alleviating price and market difficulties. However, starting from the 5th Agreement in 1993, the Agreements included agenda with environmental aspects and sustainable production. In the 2010s, Global Cocoa Declarations appeared as a new rule of the global cocoa sector, including the deforestation agenda. Global Cocoa Farmers Conference in 2018, organized by the International Cocoa Farmers Organization, declared farmers' participation in the global cocoa communication and decision-making processes, which included climate change, deforestation, and sustainability. The declarations also provide specific guidelines for collective action for sustainable cocoa production and forest protection. Recently European Union adopted Deforestation-Free Regulation targeting six global commodities, including cocoa. Global cocoa governance indicates the changes in the rules for controlling deforestation in the cocoa industry. Hard laws are necessary to improve the effectiveness of achieving the goal. However, this effectiveness must entail the much more precise norms adopted through the soft law institution. The cocoa sector shows a synergetic design between the hard law, including International Cocoa Agreements and EU Deforestation-Free Regulation, and soft law, including declarations.

The forest-climate interface: Exploring drivers of state participation in informal forest-related climate governance arrangements

T4.28 Towards quantitative explanations of forest governance and its complexity

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Abstract: The 1992 Earth Summit marked both the UN's failure to create a global convention on forests and its success in creating a convention to address climate change (i.e. the UNFCCC). However, years later, out of the UNFCCC negotiations would emerge arguably the most relevant international forest policy to date: Reducing Emissions from Deforestation and Forest Degradation (REDD). The REDD mechanism exemplifies how a climate-focused agreement can nonetheless have a major influence on forest governance. While forest and climate policy scholars have independently explored the specific features and challenges, as well as assessed the effectiveness of the REDD mechanism, other similar forest-related climate initiatives remain understudied. Therefore, to contribute to filling this knowledge gap, we aim to explore issue-specific explanations for state involvement in the growing number of informal forest-related climate governance arrangements (FCGAs). To achieve this goal, we will map and characterise a large number of FCGAs using the Yearbook of International Organisations as a primary source, binary code our variables of interest and (possibly) use binomial logistic regression to model state involvement. In addition, we will contrast our results with responses to semi-structured interviews with key government actors. Drawing on scholars of international relations, we hypothesise that countries with higher forest economic indicators (e.g. value of exported forestry products) will engage in more informal settings to avoid having to comply with strict forest conservation rules linked to climate change mitigation commitments.

The subnational government power influence in the management of forest protected areas in Patagonia

T4.28 Towards quantitative explanations of forest governance and its complexity

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Abstract: Protected forests are territories of power struggles between different private and state actors at different levels of governance with increasingly land use pressures. In federal countries, where forests are under a subnational jurisdiction, subnational actors have a strategic role in the management of forests, resulting in power distributions. In Argentina, the aesthetic attractiveness and environmental value of the Andean Patagonian Forests resulted in the protection of the ecosystem under different features, turning the ecological region into one of the most protected with both national and subnational protected areas. Against this background, the aim of this study was to analyse and compare the power balance of the actors involved and define the role of the subnational government in two protected areas with different jurisdictions. In order to do so two protected areas in the Andean Patagonian region were selected, in the first case the subnational government is the main authority and in the second case the subnational government shares the administration of a forest territory with the national government and indigenous communities. By applying the Actor Centred Power approach that considers the power expression into three elements: information, incentives and coercion we compared the governance structure in both areas. Our results showed that in both cases the subnational government was one of the actors with most coercive and incentive power, although the information power remained with other actors. However, subnational governments did not show enough coercive capacity to develop effective regulations to prevent the appearance of conflicts of interest.

Towards quantitative explanations of foreign forest policies

T4.28 Towards quantitative explanations of forest governance and its complexity

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Abstract: Foreign forest policies can be defined as the processes which regulate the conflicts of interests around forests having known consequences for actors external to a nation state. With globalization the capacities of central foreign bureaucracies to oversee all foreign affairs, especially issue specific ones, are exceeded allowing other bureaucracies to expand and build up own units dealing with these issue-specific international relations . Following the core theses of bureaucratic politics theory, the bureaucracies in charge of these emerging sectoral foreign policies are striving for autonomy from other sectors, including foreign affairs, with whom they must coordinate with. Countries' bureaucracies have included forests as an issue in their foreign policy agendas with forest related bureaucracies becoming increasingly relevant in foreign policy. However, the forest sector has strong relations with the environmental, agricultural and industry sectors competing but also making coalitions based on the overlapping portions of their interests. Latin America, relatively more forested than any other region of the world and containing the Amazon rain forest, has received a lot of international attention. However, most research on foreign policy focuses on developed countries from the Global North, with a lack of studies on Latin America.

In this context, bureaucracies in Latin American countries have included forests as an issue in their foreign policy agendas, with forest related bureaucracies becoming increasingly relevant. However, the importance of forests as an issue widely varies between countries, which can be assumed having severe implications on a country's foreign forest policy. This paper aims at analyzing and comparing foreign forest policies in Latin American countries. Through social network analysis, our results showed that in those countries where forests are a salient issue more actors and their coalitions were involved in the development of foreign forest policy, resulting in complex policy networks and limiting the autonomous agency the coalitions could perform. Contrary, in the countries where forests are not a salient issue, a limited set of actors and coalitions engaged, providing them with high degrees of autonomy. In all countries, however, the resulting foreign forest policy was greatly shaped by the most powerful actors in the networks.

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

Building resilience for sustainable livelihoods in forest-reliant communities: 15 years of collaborative work with Indigenous Peoples and smallholders

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

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Abstract: Local communities and Indigenous Peoples have been widely recognized as stewards of forests and their biodiversity, a fact reflected in the Kunming-Montreal Global Biodiversity Framework of the Convention on Biological Diversity. However, these important actors are usually in a vulnerable situation, struggling with their local livelihoods and poverty. This presentation synthetizes the experience and lessons learnt from 15 years of bottom-up collaborative work with Argentine Indigenous Peoples and local communities with the valuable support from the Austrian Government.

Within the framework of the 2030 Agenda for Sustainable Development, these actions promote sustainable management of forest landscapes to enhance resilient and sustainable livelihoods for Indigenous communities and creole peasants, social inclusion and women and youth empowerment, in line with sustainable development goals 1 (no poverty), 2 (zero hunger), 5 (gender equality), 13 (climate action) and 15 (life on land). They include small-scale projects on conservation and sustainable management of forests and non–timber forest products, capacity building for local production, agroforestry, traditional crafts production and commercialization, and valorization of traditional knowledge. A key enabling factor of these experiences is a robust governance, achieved through strengthening dialogue spaces among grassroots organizations and local stakeholders with an emphasis on Indigenous and peasant communities' involvement and gender-responsiveness.

These projects involve the active participation of indigenous communities (qom, wichí, mbyá guaraní, qolla, mapuche-tehuelche, diaguita), creole peasants and grassroots organizations in every step from project design to implementation, in six Argentine provinces, and joint work of these actors together with public agencies, academia, NGOs and the private sector.

Governing EU's forests on the route to Paris: identifying leverage points for the facilitation of just sustainable transitions

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

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Abstract: Following the Paris Agreement and the European Parliament's declaration of a climate emergency, the EU has developed multiple directives and strategies, including the European Green Deal, which describe EU's forests as a key contributor to the aimed for sustainability transition and agreed climate goals. In addition, the EU has made commitments that these transition processes are conducted in a just manner. We examine whether the translation of the EU's ideas around forests' roles to the national contexts of the member states create national level, tangible, leverage points for change. We aim to gain deeper understanding of differences in framings of the forest at different levels, potential synergies and trade-offs between different prescribed roles to forests at different levels, what policy instrument mixes are proposed to motivate forest owners to manage their forests so as to contribute to the fulfilment of these roles, and in what way just transition considerations, including the balancing of diverse interests, are incorporated in these policy instruments. We conduct a case study in which we analyse and compare the Paris Agreement, EU climate and biodiversity directives and strategies, and Swedish government bills, strategies, and action plans for forestry. We find that, whilst there are many roles and goals ascribed to EU's forests, there are no clear leverage points for the facilitation of a just sustainability transition in the forest sector both at the EU and in Sweden. The current setup provides opportunities for synergies in the short-term, but risks goal conflicts and trade-offs in the long-term. Furthermore, there is divergence in focus of policy instruments, where EU climate policy builds on rules and regulations and economic instruments, whilst the Swedish forestry policy focusses on social and information-based instruments. Neither include rights-based instruments and the EU's commitment to create just transitions has no prominence in the proposed policy instruments and national level policy documents. We conclude that the current translation of EU goals to the national level in Sweden provides insufficient leverage points for forest owners to engage with the sustainability transition and risks a lack of perceived legitimacy through its limited attention to considerations of justice.

Integrating Scientific and Indigenous Ecological Knowledge in Conservation of Threatened Woody Tree Species in Kenya

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

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Abstract: Integrating Scientific and Indigenous Ecological Knowledge in Conservation of Threatened Woody Tree Species in Kenya

T 4.29: Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

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Abstract

The indigenous ecological knowledge has been poorly incorporated into conservation and management of natural resources due to its perceived insignificant contribution. Lately, scientific community and policy makers have recognized the importance of integrating indigenous and scientific knowledge to address challenges in natural resource conservation as reflected in international strategies such as Convention on Biological Diversity. This study combined qualitative and quantitative approaches to identify, rank and prioritize tree threatened species through Focus Group discussions. Community members were guided to free list all the tree species known to have existed in the area. Prioritization of the species of conservation importance followed gender based Hierarchisation and prioritisation methods aligned to IUCN classification system of population trend and threat analysis against a baseline of 1970. Species with population decline of ≥ 80%, ≥ 50% and ≥ 30% were classified as Critically Endangered, Endangered and Vulnerable respectively according to IUCN category A4 population reduction class. The key drivers of degradation perceived to have contributed to species loss or population decline were illegal and overharvesting for diverse products (0.22) driven by high poverty levels (0.12). Others limitations were low natural regeneration potential for certain species and climate change. Prioritisation of species for conservation varied across gender due to differences in perceived use values and threats. Fourteen species were listed as critically endangered with population decline now and in the future of ≥ 80%. *Oldenia alpina*, *Schefflera volkensii*, Podocarpus sp and *Vepris nobilis* were among the species perceived to require urgent conservation measures. Integration of indigenous knowledge in scientific research provides a low cost and local practical solutions to biodiversity conservation.

Keywords: Biodiversity conservation**,** indigenous ecological knowledge; threatened species

Lessons from the Global South: Forest-related cooperation and the importance of local knowledge and communities

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

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Abstract: The world's forests are being devastated at a rate of 10 million hectares annually. Most of this catastrophe is occurring in the countries of the global south. Agribusiness and consumption patterns, particularly in developed countries, are of great relevance in contributing to this serious problem. International cooperation can play a relevant role in avoiding deforestation and supporting the maintenance of forest ecosystems. In this regard, this contribution, based on the author's experience working with cooperation projects, highlights the importance of focusing on local and indigenous communities to strengthen their capacities and resources. Such initiatives must be based on a participatory approach and should be characterized by absolute respect for the cultural and spiritual context and the rights of these communities. The interest of the communities in sustainably managing the natural resources on which they depend, illustrated by the concept of "the environmentalism of the poor", can also be reinforced by cooperation initiatives. Practical experience shows that this approach with a focus on supporting local and indigenous communities is a very efficient form of cooperation. On the contrary, the eventual donor country's belief in the superiority of its approach to forest management can lead to its uncritical transfer to the recipient country. This may be encouraged by the host government's perception of everything that comes from abroad, particularly from a more prosperous country, as better. The transfer of know-how from the donor country without critically assessing its possible negative impacts must be seriously questioned.

Stone enclosures in the Šumava Mountains. Mysterious structures or prosaic traces of past forestry?

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

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Abstract: The upper parts of *Šumava* (*Bohemian Forest*) in the Czech Republic and the *Bavarian Forest* in Germany represent some of the most valuable ecosystems in Europe and are protected as national parks. The mountain spruce forests here are considered to be almost pristine and unaffected by exploitation and management. However, modern airborne laser scanning (LIDAR) methods have revealed numerous surface relics of past human activity: Square or rectangular stone enclosures with edge sizes ranging from 20 to 40 m. Around 400 of these formations are currently known in an area of approx. 600 sq km, but the number is not definitive. They are all located at altitudes of around 1100 m.a.s.l.

The stone structures are difficult to see and find in the rugged mountain terrain, which, together with the loss of historical memory following the displacement of the German population after WW II, has caused a complete lack of awareness of this phenomenon. Combination of radiocarbon dating, observed age of the present-day vegetation, and historical maps allows to estimate origins of the enclosures between 1650 and 1850. Avaiable literature does not contain any data on enclosures and research in archives is at early stage.

Interpretation of the stone enclosures is therefore only at the stage of estimation, but at least the majority of them can be considered seedbeds and forest nurseries. If assumption, that the dozens of forest seedbeds in such high altitudes were founded before the great forest calamities of the 1860s-1870s, proves true it will be necessary to completely rewrite the history of forestry in Šumava and in general re-evaluate data relating to the origin of forest stands and their management in the early modern period.

This can then lead to a better understanding of - now forgotten - local practices linked to the harsh natural conditions, which were based on both indigenous knowledge and the principles of modern forestry. This knowledge, destroyed by the events of the 20th century, can at the same time contribute to improving conservation mechanisms and forest management in a region that is massively affected by the consequences of climate change (esp. bark beetle outbreaks).

The fate of Mijikenda Sacred Kaya Forests: Is there hope for their restoration in the wake of emerging threats?

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

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Abstract: *Kaya* forests, located along Kenya's coastal landscape are sacred forests of the Mijikenda community and have existed since the 16th century. In the recent years, these forests have been diminishing in size mainly due to encroachment and over-exploitation begging questions as to whether they can withstand the enormous threats over time. A study was conducted to assess the emerging threats to Kaya forests and develop strategies for their mitigation, and sustainable conservation of the forests. The study covered four Mijikenda Kaya forests namely Kaya Mudzi Mwiru, Mudzi Muvya, Bomu and Fimboni in Rabai, Kilifi County. Participatory rural appraisal methods comprising household questionnaires, Focus Group Discussions, Key informant interviews, transect walks, and oral narrations were used to collect data. Our study found that the main threats to Kaya forests are rapid population growth, infrastructural development and proximity to Mombasa city, cultural erosion and over-exploitation of forest resources which have resulted to their extensive degradation. The loss of indigenous knowledge systems that underpin the conservation of these sacred forests further compounds the threats with potential for significant negative impacts on the livelihoods of local communities who are dependent on the forests, biodiversity conservation and climate change mitigation and adaptation. The main strategies proposed for addressing the threats were community sensitization on the importance of conserving the forests, development of sustainable alternative sources of livelihoods for local communities and creation of employment opportunities for the youth to reduce degradation pressure on the forests, and establishment of a biocultural heritage territory in Rabai to enhance collective governance of the landscape by the community to reduce threats. The study findings reinforces the need to protect indigenous knowledge systems and strengthen traditional governance systems which underpin the conservation of kaya forests for enhanced conservation and socio-economic benefits.

The possibilities of using different spatial data in the mapping of non-protected cultural heritage

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

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Abstract: The description and mapping of non-protected signs of human activity in the landscape, that is, cultural heritage sites, began in Estonia in the early 2000s. For example, old farm sites, historic forest roads, stone fences and many other objects that have value to the landowner or the local community. At the initiative of the State Forest Management Centre and with support from international cooperation projects, more than 43,000 cultural heritage sites, which have been described regardless of ownership and land use type, have been entered into a database in Estonia. The prepared public map layer is in the public domain and is a source of information for both landowners and those that plan various activities affecting the landscape (mainly state and local agencies and companies involved with planning). As Estonia's forest cover has increased in the last 80 years (covering over 50 per cent of land area now), many signs of human activity that were previously found in the open landscape are now located on forested land. Logging is an important factor affecting their condition. The National Forest Register has also been established to provide information about cultural heritage sites when registering a forest notification that permits felling in an area that overlaps with records entered in the database. The object-saving working methods are part of the trainings for forest management specialists and forest workers in Estonia. There is also a subsidy for private forest owners for the maintenance and exhibiting objects of cultural heritage. The mapping work was done with the help of local people, where in addition to oral tradition and landscape inventory, historical maps and other written materials were used to find objects. In the last years it has become possible for the public to use various GIS-data created by the Estonian Land Board. The cross-use of spatial data for the pre-selection of cultural heritage objects before fieldwork in the landscape has been simplified. The article deals with the synthesized use of georeferenced historical raster maps, Lidar relief data, the Estonian Topographic Database and oblique aerial photographs for the identification and mapping of new cultural heritage objects.

Traditional forest related knowledge's contribution to rural livelihoods, food security and sustainable forest management in Africa

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

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Abstract: The rich body of traditional forest-related knowledge in Africa has been widely acknowledged as important for its contribution to current global efforts towards sustainable forest management, biodiversity conservation and adaptation to climate change. While many rural communities in Africa continue to observe their age-old traditions in relation to forests to ensure the provision of their livelihoods, other communities have lost their traditions for many reasons, including their forced or voluntary cultural alienation from forests, reduced dependence on forests for rural livelihoods, and extensive urbanization. Nonetheless, many communities throughout Africa are still living in or near the continent's diverse range of forest ecosystems and continue to depend on these forests for their livelihoods and in adapting to environmental stress. A documentation of how communities have successfully managed these forests to provide for their needs until the present day can serve many useful purposes, including for evidence-based sharing of experiences or case studies, research adoption and uptake, and knowledge transfer and training in forestry curricula. In this paper, based on a review of scientific literature on exploratory studies conducted among forest proximate indigenous people in Cameroon Ghana, Kenya and Uganda we provide a general background on traditional forest-related knowledge in Africa; its historical and present contributions to food security, and rural livelihoods; the present challenges faced by the holders and users of this knowledge; and institutions governing the use; and opportunities for its preservation, enhancement, and application to help solve pressing environmental, economic, and social challenges, including the conservation and sustainable use of forest biodiversity, and responses to climate change.

W8banaki forestry stewardship: Managing culturally keystone species on Indigenous territory

T4.29 Tradition in Transition Social and cultural aspects of sustainable forest management in the context of climate challenges

Laurence Boudreault

Abstract: W8banaki basketry is a very important practice based on indigenous knowledge and depend on black ash (*Fraxinus nigra)* availability and viability. W8banaki basketry consists of weaving strips of black ash wood and sweetgrass into baskets. This practice is intrinsically linked to a way of being. Black ash is a ring-porous hardwood, that is used for basketry and that also plays fundamental cultural importance and is tied to the cosmology of many indigenous nations, including the W8banakiak (ak indicates plural). In the context of global changes, indigenous forest users face many challenges right now. External pressures are threatening ecosystems and traditional basketry activities, and therefore all the traditional knowledge associated with it. Like other cultural keystone species, the importance of black ash is not always known, recognized, and often not taken into account by forest managers and other territory stakeholders. The implementation of adaptation measures by the Nation about black ash is also hindered by the fact that the ancestral territory of the W8banakiak is now highly privatized, which limits access to the land and the resource. The Nation has mobilized many times in history, performing acts of resurgence to maintain the relationship that unites them to black ash.

Laval's University and the Grand Council of the W8banaki Nation has partnered in order to propose black ash management tools to support the Nation's adaptation process. The first step of this project allows us to understand that to be used for basketry, annual ring of black ash needs to be of a certain width on of a certain density. They can be then transformed into very thin and flexible strips that will be woven. Those properties being influenced by climate and biophysical condition are influenced by management. Knowing the growing condition that support black ash quality and viability, we will then be able to propose innovative measures for the management of the species based on the W8banakiak stewardship vision and knowledge that can enhance and sustain both black ash and basketry has to ensure the transmission and securing of knowledge and practices.

T4.30 Urban green against air pollution and climate change

An analysis of the thermal environment of scenario-based urban greening types

T4.30 Urban green against air pollution and climate change

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Abstract: Rapid urbanization has reduced green spaces in cities, increased artificial pavements and buildings, and caused various urban environmental problems, including worsening thermal environment. Green spaces are evaluated to be effective in improving the thermal environment, such as reducing the urban heat island phenomenon. In particular, the degree of thermal environment improvement may differ depending on the types, forms, the method of construction of urban greenery. It is necessary to find the optimal green space construction scenarios for efficient thermal environment improvement. This study aims to categorize the types of green spaces that exists in urban areas, design detailed construction scenarios, simulate thermal environment using ENVI-met 5.1.5v, and suggest effective green space construction methods. This study area is Jung-gu district in Daegu Metropolitan City, which is one of the hottest cities in South Korea. An area of 1.5km*1.5km including a 10-lane boulevard and a large urban neighborhood park was designated as the analysis range. The types of urban green spaces were classified into 'roadside trees', 'urban parks and school forests', and 'greening of redevelopment areas'. Based on them, several urban green scenarios were derived to simulate their effects of degree of thermal environment improvement. By comparing the air temperature and surface temperature of each green space scenario with those of the current situation, the most effective scenarios for improving the thermal environment in the study area were derived. This study is meaningful in that it quantitatively compared the effects of improving the thermal environment according to various green space scenarios. It is expected to be used as basic data for efficient and economical thermal environment strategies and planning measures.

An analysis on cooling effects of urban forests in densely built-up areas : A case study in Daegu, South Korea

T4.30 Urban green against air pollution and climate change

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Abstract: While the thermal environment problem is serious due to the urban heat island, the importance of urban forests is increasing as a solution to this problem. As Korea's urban areas are developed with high land use density and buildings, the temperature reduction effect of urban forests in these urban areas can be greater. Many previous studies have found that urban forests cool and humidify the surrounding environment through heat exchange and form a park cooling effect. In addition, the cooling effect of parks varies depending on the size and interior factors of the park, and the diffusion intensity varies in climate and urban spaces with different characteristics. Thus, the temperature reduction effect of urban forests has been extensively investigated. However, relevant research is lacking in cities such as Korea, which are characterized by climate and dense development. While urban forest policies are being actively implemented to improve the urban thermal environment in Korea, it is necessary to establish a comprehensive plan to expand the function by clarifying the temperature reduction effect of urban forests and analyzing factors that affect the cooling function of urban forests.

Therefore, this study quantitatively investigated the effect of urban forests on the thermal environment by targeting parks located in densely built-up areas in Korea. This study aimed to analyze the diffusion range of the cooling effect of parks located in the densely developed city center of Daegu. In addition, the relationship between the various characteristics of parks and the thermal environment was identified, and plans for effective urban forest planning and park design were proposed. For this purpose, previous studies on the relationship between the characteristics of urban forests and the thermal environment were reviewed, and the factors and effects of urban forests affecting cooling were considered. The thermal environment of the park was analyzed using ENVI-met simulation and field measurement. As a result, the effect of urban forests on reducing city temperature was confirmed, and the cooling effect determined by the characteristics of the park was different. This study can be used to prepare strategic urban forest plans to improve the urban thermal environment.

ASSESSMENT OF ANTHROPOGENIC DISTURBANCES AND HEALTH STATUS OF BENGUET PINE FOREST UNDER VARYING LAND USES In BAGUIO CITY, PHILIPPINES

T4.30 Urban green against air pollution and climate change

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Abstract: Urban forests are ecosystems consist of interacting natural and anthropogenic systems. Because humans play an important role in maintaining an urban ecosystem, it is crucial to determine how various land uses affect the health of urban trees in an urban ecosystem. In the absence of studies dealing on both quantitative and qualitative assessment of health status of Benguet pines in the Philippines, this study aims to determine the health status of Benguet pines in Camp John Hay, Baguio City vis-à-vis six varying land uses and eventually, identify if there is a relationship that exist between the two. This study included 434 trees in six varying land uses, namely, recreational, residential, commercial, managed and protected forest, and infrastructure and facilities. Despite the presence of various human activities in the study site, the results positively showed that majority of the Benguet pines are not sick and/or dying, however, mostly are characterized with failure and defects in its crown which is a symptom of dieback and tree decline. Results revealed that there is a relationship that exists between land use and tree health. Data correlated that the most number of healthy Benguet pines are found in the land use with the least number of human activities which in this study is the protected forest. Soil compaction was also found to be the most common effect of human activities and influx of people in the study site. Land uses related to recreational activities were more prone to soil compaction while commercial areas were mostly affected by construction activities of buildings, infrastructures, roads, or landscapes. Residential places or land uses near residential places often exhibited failure on the trunk of Benguet pines because of intentional and unintentional mechanical injuries. Further studies that will delve on the other drivers of urban tree condition such as environmental factors are strongly recommended.

ASSESSMENT OF URBAN GREEN SPACES' POTENTIAL FOR AIR PURIFICATION AND LOCAL CLIMATE REGULATION IN WARSAW (POLAND)

T4.30 Urban green against air pollution and climate change

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Abstract: The urban heat island and air pollution are now serious threats to the health of urban residents. Actions aimed at improving life quality in cities using natural processes require knowledge of the potential of existing urban green spaces to provide ecosystem services (ES) such as air purification and local climate regulation. Warsaw, the largest city in Poland, is inhabited by nearly 1.8 million people and covers the area of 517.2 km^2. Green spaces make up almost 47% of its area and play a very important role as major providers of regulating ES. The objective of this study is to assess the potential of Warsaw's urban parks and forests for particle matter (PM) removal (in winter and summer) and air temperature regulation (in summer) using remote sensing data and long-term in-situ measurements carried out on selected test sites. The total amount of PM accumulation is largely influenced by the cover and structure of vegetation, a good indicator of which is the leaf area index (LAI) - the ratio of the leaf area to the ground area. The cooling effect of vegetation was determined using the evapotranspiration (ETA – amount of water evaporated from plant cells and soil under conditions of unlimited presence of water in the ground), selected because of its linear relationship with latent heat. Both ES indicators were calculated based on satellite data provided by European Environment Agency, in line with the verified formulas. More detailed research was done in six Warsaw's parks of different size and vegetation composition and structure. Air temperature was measured in the parks and in the neighbouring built-up areas to assess the impact of parks on people living in their vicinity (e.g. cooling range of parks). To determine the diversity of green spaces' structure, a cartographic analysis, field inventory and mapping were done. Our findings allow to point out the most beneficial features of urban green spaces to maximize the studied ES provision. The outcomes of the research can be used by city planners in developing urban greening strategies.

Comparisons of PM2.5 mitigation between coniferous and broad-leaved forest in peri-urban region of Seoul metropolitan area, Republic of Korea

T4.30 Urban green against air pollution and climate change

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Abstract: Owing to industrialization and urbanization in recent decades, fine particulate matter ($PM_{2.5}$) in the atmosphere has become a major environmental problem worldwide. This environmental issue pushed the use of forests as air purifying tools. However, there is a lack of continuous and long-term forest management to efficiently mitigate $PM_{2.5}$. In this study, we assessed the potential of different forest types to control air pollution, by measuring the seasonal $PM_{2.5}$ concentrations inside and outside the forest for one year. In addition, the $PM_{2.5}$ reduction efficiencies (PMREs) of different forest types were compared, and their relationship with stand characteristics after forest density control was analyzed. Results showed that the average PMRE inside the forest was approximately 18.2%; the seasonal PMRE was highest in winter (approximately 28.1%) and lowest in summer (approximately 9.6%). The average PMRE of the Taehwa deciduous broad-leaved forest (TDF) (approximately 18.8%) was significantly higher than that of the Taehwa Coniferous Forest (TCF) (approximately 17.5%)($P < 0.001$); the differences showed a seasonality. The PMRE was higher at TCF in spring and summer ($P < 0.001$), while it was higher at TDF in autumn and winter ($P < 0.001$). Furthermore, the PMRE of TDF was negatively correlated with the stand density ($P = 0.003$) and positively correlated with the average diameter at breast height (DBH) ($P = 0.028$). However, the PMRE of TCF did not significantly correlate with stand characteristics. This study revealed the differences in $PM_{2.5}$ mitigation according to stand characteristics, which should be considered in urban forest management.

Contribution of urban forestry in compensating the CO2 emissions in Niger: case of the city of Maradi

T4.30 Urban green against air pollution and climate change

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Abstract: The trees in urban environment play a fundamental role in the life of the city-dwellers. However, the service of sequestration of carbon and attenuation of the effects of the climatic change that they return is very little known. Conducted in the city of Maradi, the present study aims at valuating the answer of the parklands and the plantations to the broadcasts of the CO2 due to the consumption of the wood-energy of the households. The adopted methodology was based on trees inventory including the dendrometrics measurements and the survey conducted to the households. The survey listed eighteen thus (18) woody species distributed in sixteen (16) genera and fourteen (14) families with a strong preponderance of the exotic species. The species *Azadirachta indica* dominates the stand with 57,95%. The mean diameter of the population is of 22,10 ± 9,15 cm against 7,46 ± 3,13 m of mean height. The mean density of the woody species is of 97,37 ± 49,61 trees/ha for a mean base area of 3,29 ± 0,01m²/ha. The mean global biomass of the stand rises to 3,70 ± 0,04 t/ha for a mean stock of carbon of 1,85 ± 0,02 tC/ha. Also, the survey showed that the wood-energy was the main source of energy for 95,56% of the households of the city. The mean of wood consumption by household rises to 1,72 ± 0,32 t/year and 0,39 ± 0,12 t/year of charcoal for a household of mean size of 9 ± 3 people. The resulting carbon emission was 25.49 ± 12.36 tC/ha/year. This emission is very high compared to the amount of carbon stored by green spaces and households in the city. However, the contribution of these in the mitigation of CO2 emissions is far from negligible because they can offset up to 2.14% of the annual CO2 emissions resulting from the consumption of wood energy by households. It is then more than necessary to multiply reforestation, to protect the available forest capital and to substitute wood energy with other energies that do not pollute the environment and emit less greenhouse gases.

Diversity and the condition of green spaces and woody plants in 3 Lithuanian cities

T4.30 Urban green against air pollution and climate change

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Abstract: In urban areas, the ecological quality of life of the residents is determined by existing greenery. Municipalities aim to ensure that each city has a sufficient area of greenery, and that woody plants are healthy and suitable for that area.The inventory of green areas and woody plants provides municipalities with knowledge about the diversity, condition, and abundance of plant species, and helps organize management and maintenance.

The aim of the study is to assess the diversity of woody plants, health status, and abundance of greenery in 3 Lithuanian cities.

The inventory of greenery was carried out in 2022, in 3 cities located in different region of Lithuania: Pakruojis, Švenčionys and Birštonas. The area of public parks was calculated, the species and condition of each woody plant was determined, plant heights and trunk diameters were measured.

The results showed that all cities have more parks areas than the proposed minimum area. Woody plants of alien species dominate, but the number of native individuals is much higher than that of trees of alien species. Shrubs are grown less than trees. Invasive woody plants grow in all cities, of which ash maples are the most common. Most of the plants are in good condition.

Ecosystem Services of solitary city trees of four common species in Germany

T4.30 Urban green against air pollution and climate change

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Abstract: Solitary trees in a city are a key component of urban forests, and it is essential to quantify their benefits to improve the management and care of these trees. Therefore, this study quantifies and compares eight ecosystem services (ESS) among solitary trees near streets and inside parks of four common species in Karlsruhe City, southwest Germany. Additionally, the study aimed to identify the influence of growing habitat and crown pruning intensity on the variation of these ESS. We randomly selected 320 urban street and park trees consisting of Norway maple (*Acer platanoides*), horse-chestnut (*Aesculus hippocastanum*), Black locust (*Robinia pseudoacacia*), and small-leaved linden (*Tilia cordata*). Those four species represent 12% of Karlsruhe City's approx.— 150,000 trees owned by the municipality. A complete dendrometric inventory of the trees was conducted following the guidelines of the *i-tree Eco* program. The ESS were calculated by using the *i-tree Eco* program.

The carbon storage of park trees was 1.28 times higher than that of street trees. Park trees provided 24 % more leaf biomass than trees near streets. The four different tree species showed substantial variation in ecosystem services, with black locusts and small-leaved linden showing the greatest differences in provisioning and regulating ecosystem services. Horse-chestnuts were found to be the tree species with the highest air-cleaning capabilities, removing up to 50% more pollutants from the air than black locust trees. Further, comparison-of-mean tests showed that Norway maple park trees provide significantly more ESS than street trees of the same species. Tree pruning and crown dieback had a negative effect on provisioning and regulating ESS. The crown light availability positively influenced regulating ESS, like carbon sequestration, oxygen production, or pollution removal. Tree size (diameter) was shown to be a strong predictor for all ecosystem services.

The results underline the importance of balancing the conservation of large living urban trees, their appropriate crown pruning intensity, and the maintenance of taxonomic biodiversity in the urban environment, which becomes even more crucial when considering the impacts of climate change.

Effects of urban environment on BVOC emissions by street and park trees

T4.30 Urban green against air pollution and climate change

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Abstract: Urban trees can reduce air pollution by capturing particulate matter and gaseous pollutants. However, trees also release biogenic volatile organic compounds (BVOCs) that participate in the production of ground-level ozone (O_3) and particulate matter in the form of secondary organic aerosols (SOA). To quantify the net effect of urban tree species on air quality in cities, reliable estimates of tree BVOC emissions are thus needed. Yet, direct measurements of urban tree BVOC emissions are rare, and whether estimates of tree BVOC emissions in natural environments are applicable in urban environments is unclear. As one of the important roles of BVOCs in trees is stress mitigation, the stress factors of urban environments that differ in quality and quantity from those in natural environments may importantly change the BVOC emission rates and composition.

We measured BVOC emission rates and composition of five common urban tree species in parks and streets of two northern cities (Montreal, Canada and Helsinki, Finland) using shoot enclosures and adsorbent tubes analysed with a gas-chromatograph mass-spectrometer. We compared the measured BVOC emissions with earlier emission estimates from natural environments and between park and street trees, and calculated the species' potentials for O_3 and SOA formation.

Urban tree BVOC emission rates corresponded generally well with the earlier species-wise estimates from natural environments. Potentially due to the higher heat and pollution loads, street trees had generally higher isoprene and sesquiterpene emissions compared to park trees in Montreal. As expected, O_3-forming potentials were large for species with high isoprene emissions (e.g., *Quercus* species). SOA-forming potentials were important also in species with high monoterpene emissions (*Betula pendula*) and occasionally high sesquiterpene emissions (*Tilia cordata, Acer platanoides*).

According to our results, using BVOC emission estimates from nonurban conditions for modelling and species selection of urban trees may be appropriate. We however note that the applicability may depend on the degree of urbanisation – for example, the intensity of the heat island effect and pollution. Moreover, species- or genus-wise estimates are lacking for many urban species, such as *Gleditsia triacanthos* in our study, encouraging further efforts to map BVOC emissions by urban trees.

Effects of Urban Public Greenspace on Carbon and PM2.5 Reduction

T4.30 Urban green against air pollution and climate change

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Abstract: The increasing concentrations of greenhouse gases and fine particulate matter (PM) are serious environmental problems globally, and require urgent policy and scientific action. Increasing CO_2 concentrations exacerbates environmental and social systems via the impact of climate change, including sea level rise, extreme weather events, and biodiversity loss. $PM_{2.5}$ is a class 1 carcinogen, as designated by WHO, and it causes various respiratory diseases and strokes. In cities dominated with carbon and $PM_{2.5}$ emissions, urban greenspace plays an important role via the uptake of atmospheric carbon during photosynthesis and the adsorption of particulate pollutants, including $PM_{2.5}$, through its leaves, branches, and stems. However, information on the effects of urban greenspace is still lacking globally. Therefore, the purpose of this study was to quantify the carbon and $PM_{2.5}$ reduction effects of urban public greenspace, including urban parks, street trees, and forests, in Gangneung, a medium-sized city located in the coastal region of South Korea. This study sampled a total of 35 urban parks and 42 street trees. All the trees in these sample urban parks and streets were field-surveyed, and their planting structure were quantitatively analyzed. The area by type and age class of Gangneung's forests was calculated using statistical data. Annual carbon and $PM_{2.5}$ reduction of these public greenspace was calculated by applying quantitative models by tree species and size. The mean tree cover of study parks and street trees was 44.5 ± 3.0 and 11.2 ± 1.4%, respectively. Among the total forest area, mixed forests with age class IV occupied the largest area (26.3%). Total annual carbon and $PM_{2.5}$ reduction of public greenspace in Gangneung were 557.5 kt/yr and 767.2 t/yr. In addition, the public greenspace was observed to offset 31.6% and 1.8 times of the total carbon and $PM_{2.5}$ emissions in the study city, respectively. Based on these results, a greenspace planning strategy is explored to maximize carbon and $PM_{2.5}$ reductions, including conservation, improvement, and enlargement greenspace. This study is expected to be useful as practical planning to improve carbon and $PM_{2.5}$ reduction in urban greenspace projects.

Estimation of Plant Pollution Removal Based on Intensive Air Quality Measurements

T4.30 Urban green against air pollution and climate change
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Abstract: Understanding the role of vegetation in mitigating environmental pollution requires an accurate estimation of plant pollution removal. This study aims to investigate the effectiveness of various plant species in removing pollutants from the atmosphere by utilizing an existing air quality networks database.

The research methodology involved collecting air quality data from multiple monitoring stations placed in urban and suburban areas. These stations measured concentrations of air pollutants, including nitrogen dioxide (NO2), particulate matter (PM2.5 and PM10), sulfur dioxide (SO2), ozone (O3), metals, and meteorological parameters (only at specific locations).

The study is conducted in Bucharest, which is situated in a plain area and is recognized as one of the most polluted metropolitan areas in Europe. Currently, Bucharest is under an infringement procedure for PM10 pollution. However, despite its high pollution levels, Bucharest has one of the lowest tree cover percentages. Within the city limits, the tree cover is only 3%, but if all metropolitan areas are considered, including two significant forests, Stefanesti with 450 hectares and Baneasa with 800 hectares, the tree cover increases to 22%.

This study employs non-parametric methods for receptor-orientated analyses to assess and identify potentially contributing areas to air pollution in Bucharest and its surroundings, considering specific characteristics as well. Analyses based on meteorological parameters, particularly wind speed, and direction, allow for cluster analyses. The study investigates the absolute and relative comparison of air pollutant concentrations (between 2017 -2022) from sites directly exposed to pollution sources (Bucharest air quality station B1, B3, B6) or surrounded by vegetation (B2, B4, B5, Stefanesti periurban forest station), considering the phenological phase of the vegetation.

Up-to-date research indicates significant variations in the pollution removal efficiency among different plant species. Certain species demonstrate a higher capacity to absorb and reduce pollutant concentrations, thereby contributing to improved air quality in their vicinity.

Nevertheless, the objective of this study is to illustrate the quantifiable impact of plant capacities in influencing air pollution concentrations.

In conclusion, estimating plant pollution removal based on intensive air quality measurements is a

significant step toward understanding and underlining the benefits of vegetation in mitigating environmental pollution.

Evaluating Urban Green Space Governance and Management in Kenya: Unlocking the Potential of Urban Forestry for Safe, Resilient, and Sustainable Cities

T4.30 Urban green against air pollution and climate change

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Abstract: Cities globally are increasingly focusing on contributing to the Sustainable Development Goals by implementing tree planting and land restoration initiatives. In Kenya, urban forests play a significant role in meeting national and global restoration targets, such as the government's ambitious plan to plant 15 billion trees by 2032. However, several challenges hinder the sustainable management of urban green spaces, including conflicting interests, weak institutional structures, and funding gaps. A study was conducted in Nairobi, Mombasa, Kisumu, and Nakuru in Kenya to assess the status of urban forestry activities, identify challenges and opportunities, and assess policy and management options. The research employed a combination of quantitative and qualitative methods, including desk research, interviews with key stakeholders, site visits, tree and shrub identification, and data analysis. A total of 251 respondents participated in the study.The findings revealed that nearly half of the respondents (49.9%) considered shade and relaxation as the greatest benefit of urban green spaces. Other benefits cited included playgrounds, recreational sites, aesthetic value, and environmental services. To improve urban green spaces, 58.4% of the respondents suggested creating awareness about the importance of development strategies, involving urban communities in management and maintenance, and engaging NGOs, private organizations, and local communities. The survey also highlighted the need for additional green spaces in all cities due to overcrowding in existing areas. In each city, over 116 tree and shrub species were identified, indicating rich biodiversity. However, several challenges were identified, such as the absence of urban forestry policies and management plans, poor matching of trees to their planting sites, lack of protection against grazing livestock, and weak enforcement of city by-laws. The study identified opportunities for improvement, including Public-Private Partnerships for green space management and renovation, as well as integrating urban forest plans into city planning processes. The adoption of adaptive management practices was recommended to ensure continuous enhancement of urban forestry in the cities

Greenspace planning guidelines for a low-carbon city

T4.30 Urban green against air pollution and climate change

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Abstract: The potential negative impacts of climate change on the environments have necessitated the creation of low-carbon cities. Urban greenspaces can reduce the level of atmospheric carbon, a major agent of climate change. They sequester carbon during photosynthesis and avoid carbon emissions by saving building heating and cooling energy. This study proposes desirable planning guidelines to establish a low-carbon city by urban greenspace type. Urban greenspaces are categorized as streets, parks, gardens, riparian corridors, and suburban zones. In Korea, gardens on residential, commercial, and Institutional lands are characterized by small sizes and poor tree planting. In addition, urban parks are potential sources for the creation of carbon sinks through tree planting within the limited greenspace of cities. The carbon reduction of a park can vary depending on factors such as tree size, planting density, species, vertical structure, and land cover type, even if the park area is the same. Nevertheless, the extensive impervious and grass areas, single-layered plantings, and the dominance of small trees limit the carbon reduction of urban parks. In addition, the excessive annual pruning, insufficient root growth space, and inappropriate tree species of street trees limit their carbon reduction. The planning guidelines included a proper layout of trees around buildings in gardens to enhance building energy savings through shading, evapotranspiration, and wind reduction. Minimization of unnecessary impervious and grass areas and multi-layered/clustered planting were recommended as a desirable park planning. This study also suggested planting of tree species with good growth rates and creation of multilayered greenways in streets, and nature-friendly development in suburban zones to decrease carbon emissions from the damage of existing trees and soils and uses of heavy equipments. Future studies on urban greenspace should consider estimating especially the size of greenspace supply to offset carbon emissions and net carbon reduction using life cycle analysis. This study can contribute to various land use and spatial planning to help create a low-carbon city.

Particulate matters and metal elements in snowpacks of urban forests in NE China: Implications for winter air pollution control

T4.30 Urban green against air pollution and climate change

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Abstract: High latitude northern hemisphere cities usually face serious winter particulate mater (PM) pollution, and tree-species-specific PM deposition in amount and metal composition are not well defined yet. This study was conducted in Harbin city in Northeast of China during the winter heating periods, the most serious PM pollution season. We collected snow samples from seven urban forest plantations (J(*Juglans mandshurica*); Pa(*Phellodendron amurense*); Q(*Quercus mongolica*); L(*Larix gmelinii*); Ps(*Pinus sylvestris* var. *mongolica*); Pt(*Pinus tabuliformis*); Pm(*Picea koraiensis*) with full recording of all tree diameter at breast height(DBH), height, live branch height, and tree density, and one control plot.And the snowpack depth, density, snow water equivalent(SWE) were measured. Furthermore, the PM contents at different diameters ($W_{10\mu m\text{-}2mm}$, $W_{2\mu m\text{-}10\mu m}$, $W_{0.45\mu m\text{-}2\mu m}$) and eleven metal concentrations (Ca,K,Mg,Fe,Zn,Cu,Mn,Ni,Cr,Pb,Cd) in snowmelt water were analyzed. Our results showed broad-leaf forest plantations had greater snow depth and SWE than coniferous forest plantations, whereas coniferous forest plantations had greater PM contents in snowpacks than broad-leaf forest plantations (especially $W_{10\mu m\text{-}2mm}$ in coniferous forest plantations was significantly greater than in broad-leaf forest plantations. Overall, coniferous forest plantations had higher levels of metal concentration than broad-leaf forest plantations, where K, Ca, Cu and Mn had significant differences ($p < 0.01$). In addition, *Picea koraiensis* plantation forest (Pm) had higher metal concentration, as well as the larger metal storage and $W_{10\mu m\text{-}2mm}$. And it indicated that the forest opening plot had lower PM accumulation, metal concentration and storage, illuminating urban forest functions in the heavy metal deposition in wintertime. Moreover, snowpack depth and SWE showed significant negative correlation with DBH and individual above-ground biomass; but the concentration and storage of most metals in PMs with different diameters showed significant positive correlations with DBH, tree height, above-ground biomass. Our findings highlighted that coniferous trees with more above-ground biomass could favor the snow deposition of PMs in total amounts and specific metals, favoring forest-based urban air particle control in winter via snow interception.

Polycyclic aromatic hydrocarbons (PAHs) accumulation in urban areas: A study of Platanus x Acerifolia, Celtis Australis, and Tilia Grandifolia

T4.30 Urban green against air pollution and climate change

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Abstract: Accumulated Polycyclic Aromatic Hydrocarbons (PAHs) in leaves and one-year-old branches of three common tree species that were grown in middle-sized city in a moderate climate zone were estimated. *Platanus x Acerifolia, Celtis Australis,* and *Tilia Grandifolia* specimens from highly urbanized, frequent, and highly PAH-contaminated streets were compared with non-contaminated same species originated from the parks in the same urban core with the aim to define PAH profiles, diagnostic pollution emission sources, and finally to define organ- and species-specificity of PAH uptake potential as a PAHs remediation '*green tool*' in urban ecosystems.

Obtained results indicated that the leaves accumulated higher PAH concentrations up to ~20–30%, compared to branches. Also, following all three species, street trees accumulated more PAHs, while highest concentrations were observed for heavy-weight PAHs with five and six rings. Out of 17 tracked PAHs, Benzo[a]anthracene, Benzo[a]pyrene, Dibenzo[a,h]anthracene, and Pyrene were accumulated in the highest concentrations in all analyzed species and sites, and they account more than half of the total of detected PAHs.

Following Σ_{17} PAHs, *P. acerifolia* and *C. australis* have greater potential for PAHs remediation, via leaves and branches, than *T. grandifolia* whose in their leaves accumulated up to ~40% less PAHs than *C. australis*. In detail, the highest foliar PAH concentrations of trees that growth at streets were detected in *C. australis* (502.68 ng g^{-1} dry weight (DW)), slightly less in *P. acerifolia* (488.45 ng g^{-1} DW), while *T. grandifolia* accumulated the least PAHs in their leaves (339.47 ng g^{-1} DW). On the other hand, *C. australis* (414.89 ng g^{-1} DW) accumulated the most PAHs in their branches, while *P. acerifilia* and *T. grandifolia* accumulated significantly lower concentrations (327.58 and 342.99 ng g^{-1} DW, respectively). Finally, '*black box*', about species- and organ-specificity, as well as specific drivers that limited PAHs uptake capacity by trees, was opened, and future perspectives in PAHs remediation were suggested.

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The functionality of trees inside and outside cities: human and climate effects on isotopes characterization in Pinus pinea

T4.30 Urban green against air pollution and climate change

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Abstract: Cities are facing socio-environmental challenges as far as the rising trend in summer temperatures and the spreading effect of Urban Heat Island (UHI), the changes in air quality, in land use and soil sealing, in runoff control and, finally, the biodiversity loss are generating severe health and wellbeing problems to contemporary urban people. Green areas and trees can play a key role by mitigating temperature and pollution and by preserving or even enhancing the ecological sustainability and resilience of cities. In this context, urban trees' vitality and health are facing several challenges due to high temperatures, water deficit and exposure to pollutants. To assess how urban trees respond to climate variation and traffic emissions, and to understand physiological processes related to tree vitality and health, we investigated C, O and N isotopes in tree rings. The survey was carried out in Central Italy, in Pisa and Firenze, comparing an urban and a periurban site for each city. Cores samples of fifteen *Pinus pinea* trees in each site were collected and $\delta\,^{13}C$, $\delta^{18}O$, ^{15}N and ^{14}C isotopes were determined in the last seventy tree rings, from 1952 to the present. The general hypothesis is that urban sites, characterized by environmental constraints as water deficit and high temperatures, show a higher $\delta\,^{13}C$ and a lower $\delta^{18}O$ than in periurban ones. Regarding the characterization of the ^{15}N and ^{14}C concentrations in the tree rings of *P. pinea*, we assume that the signals of exposure to traffic emissions are more evident in the urban neighbours than periurban contexts. The expected results might support the crucial challenge of the urban trees health monitoring in the context of "re-greening the cities" as a win-win strategy, besides that, it could represent a useful tool for municipalities and city planners to quantify tree benefits.

Urban tree pollen as air pollution: improving allergy management through advanced pollen identification and spatial modelling.

T4.30 Urban green against air pollution and climate change

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Abstract: Urban trees play a crucial role in improving the quality of life in cities, providing numerous ecosystem services. However, they can also contribute to worse air quality through the production of pollen. Exposure to allergenic airborne pollen is a risk factor for respiratory allergies and a major public health concern, especially as climate change is lengthening the pollen season. Pollen concentrations vary spatially and temporally, which makes pollen monitoring a critical tool for research and healthcare improvement. However, little is known about how pollen levels – for all pollen types, such as grass, weeds, and trees – vary within a city and whether this variation affects the development and exacerbation of allergic reactions. Pollen concentrations are often obtained from a single station assumed to represent exposure over a large geographic area. Furthermore, due to negligible morphological differences between related species, pollen grains are rarely identified at the species level. In this project, we focus on pollen from urban trees, which are the first to bloom, collected using 25 gravimetric traps placed throughout the island of Montreal, Canada. The results of our study are based on 950 pollen samples collected between 2021 and 2023. To improve the process of pollen identification, we developed an innovative integrated approach that combines flow cytometry with machine learning enabling faster and more accurate identification of specific types of pollen at the species level. Then, we developed spatial models to enhance pollen forecasts by combining the collected pollen data with environmental predictors, such as vegetation composition and meteorological data. Our results revealed that the pollen in the air is influenced by much more than nearby trees. The distribution of airborne pollen on the island of Montreal is complex and influenced by external factors such as the weather, built density, and farther vegetation. These findings, coupled with our innovative approach, represent a major step towards better-informed, science-based urban greening plans, aiming to minimize allergy impacts.

When does a new urban forest become a real CO2 sink? A case study in Florence, Italy

T4.30 Urban green against air pollution and climate change

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Abstract: Carbon Dioxide (CO_2) is one of the most impactful greenhouse gases (GHG) leading to global warming. Trees uptake CO_2 from the atmosphere and store carbon in their tissues thanks to photosynthesis process. Therefore, planting a new urban forest can help to mitigate climate change. However, to set up a new urban forest GHG emissions occur during cultivation in the nursery, planting and maintenance operations. Within the AIRFRESH project (LIFE19 ENV/FR/000086), 170 new urban trees belonging to 4 genera (*Tilia*, *Acer, Ulmus* and *Cupressus*) were planted in Florence (Italy) to set up a new green area of 0.55 ha. To estimate their net CO_2 assimilation, we used a leaf-level approach and light response curves were carried out (PAR: 0, 25, 50, 75, 100, 200, 300, 400, 700, 1000, 1500, 2000 μmol m^{-2} s^{-1}) for each species by infrared gas analyzer (LI-6800, Li-Cor Inc. Lincoln, NE, USA). Using the measured data, a non-rectangular hyperbola function was developed in order to estimate the CO_2 assimilation with photosynthesis and carbon loss through respiration. Moreover, instantaneous measurements of net photosynthesis (A_n) were performed along the day to assess the midday depression of photosynthesis due to stomatal closure in the early afternoon. Finally, scaling-up from the leaf to tree level was accomplished considering crown size and Leaf Area Index (LAI). In addition, seasonal soil respiration was measured by EGM-4 Soil Respiration Chamber with the SRC-1 System (PP-Systems, Herts, UK). The Carbon Footprint (CF) linked to the nursery cultivation, planting and maintenance was assessed throughout Life Cycle Analysis (LCA). In conclusion, we calculated the Carbon balance of a new urban forest considering both emissions and CO_2 assimilation by trees. This study allows to determine when a new urban forest becomes a real carbon sink, thus helping to achieve the European goal of carbon neutrality.

WRF-Chem simulations at different scales for urban air quality assessment

T4.30 Urban green against air pollution and climate change

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Abstract: In the framework of the project AIRFRESH "Air pollution removal by urban forests for a better human well-being" (LIFE19 ENV/FR/00086) we used the WRF-CHEM model to estimate the impacts of urban forests on air quality and meteorology in the city of Florence and Aix-en-Provence. In particular, our aims are to: i) estimate the air pollution removal capacity by a reforested test area; ii) estimate and quantify the environmental and health benefits provided by urban tree at city-scale; and iii) propose recommendations for reforestation policies for attainment of the air quality standards in both cities.

We used the Corine Land Cover (CLC) database as initial condition for land cover, allowing to identify several urban features, like industrial areas or highly/low residential areas. These information are needed by the model when using the urban scheme over the different selected city-domains.

In our simulation we decided to use a triply-nested domain to downscale the ERA5 forcing data from a coarse domain to a fine scale city domain. The urban domain has 1 km resolution, 35 vertical levels, extending from land surface up to 50 hPa and the time period chosen for the simulations is 2019. For the European domain we also use the spectral nudging that allows transmitting forcing information not only from the boundary conditions but also and directly within the domain; this allows for a more stable model increasing the consistency with the reanalysis.

Here we present results for the Florence and Aix municipalities. To analyse the impacts of the urban forests we elaborated 4 different scenario modifying the vegetation in a circular area around the municipality of Florence of 5 km. The 4 different scenarios are: the current vegetation scenario, the evergreen and deciduous scenarios, realized replacing the 50 % of dominant vegetation of the original landcover (fraction mixed forest and crops) with Evergreen low BVOC emitting trees (Pinus Pinea) and Deciduos high BVOC emitting trees (Querqus Robur), and the no vegetation scenario realized replacing all the vegetated of the original landcover with the category bare soil or sparsely vegetated.

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

Creation of a point-based scoring system for valuating ecosystem services of urban forests and assessement of its implementation potential

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban and peri-urban forests (UPF) are crucial for human health and well-being. Tangible benefits from regulating and provisioning ES can be precisely estimated, and their economic values can also be modeled (e.g., by the *i-tree-eco* program from the US Forest Service). However, intangible benefits from cultural ES are only quantifiable qualitatively through human perceptions, and supporting ES, such as biodiversity and habitats for flora and fauna, are quantifiable as indexes (e.g., Shannon diversity index, Gini index). Moreover, cultural and supporting ecosystem services could not be realistic to assess in monetary terms. We, therefore, aimed to 1) develop a novel non-monetary and point-based scoring system that can integrate ALL types of ecosystem services under one framework and 2) analyze stakeholder perceptions on the implementation possibility of such a scoring system in urban forest management practice and planning. The study was conducted in the UPF of Karlsruhe City in southwest Germany. For the first objective, we randomly installed 201 plots (each 404m²) in size to quantify all regulating, supporting, and provisioning ES at the tree (N=2978) and city level using *i-tree-eco* and other software. The estimates of those ES were normalized scores, which can be further used to add ranks. The cultural values of forests and trees were measured in codes by questionnaire surveys (N=501) and literature research and also normalized to add to the scores from supporting, regulating, and provisioning ES. For the second objective, stakeholders' perceptions of the new concept are analyzed, interviewing stakeholders (N=21) from four stakeholder groups: Politics, Administration, Civil Society, and Experts. The questionnaire comprises several subjects that need to be discussed regarding developing the ES point system for valuing UPF. The results showed high support by stakeholders in implementing the new valuation method, considering the criteria and expected challenges mentioned by the stakeholders. A stakeholders' consensus was found on integrating cultural ES by combining qualitative and quantitative data. We concluded that political frameworks and legislation must be addressed in the next step before considering implementing a score-based system in the ES valuation in UPF management.

A Rapid Assessment of Bird Community in the Selected Areas in Calamba City, Laguna

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Birds are important indicators to determine the health and quality of habitat. This study aims to determine the species of birds and its diversity of the six selected green spaces in Calamba City, Philippines. To estimate bird diversity, a total of six transects were established randomly in the urban city. There were 105 individuals belonging to 12 genera and families recorded to include Passeridae, Apopidae, Pycnonotidae, Esrtrildidae, Laniidae, Motacillidae, Rhipiduridae, Sturnidae, Ardeidae, Acanthizidae, Nectarriniidae, and Oriolidae. Out of the 105 bird species observed, ten residents and two Philippine endemics were observed. The most abundant species were Eurasian Tree Sparrow (*Passer montanus* Linnaeus, 1758) followed by Glossy Swiftlet (*Collocalia esculenta*, 1837) with 30 and 18 individuals, respectively. Most of the species observed were commonly found in urban communities, agroecosystem, and forest edge. Diversity analysis revealed a low level of diversity with H' = 0.93 which requires more sampling effort and new technology for identification. With the presence of the endemic bird species in the sampling sites indicates the need to take into consideration the fauna and habitat conservation vis-à-vis ecotourism. We recommend to preserve and increase the green spaces, trees planted, high gardens and rooftop gardens be included in the landscape architectural design.

Keywords: urban birds, avian, diversity

Assessment of campus green space exposure and its association with university students' mental health before and during the Covid-19 pandemic

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: The mental health of university students has been widely discussed in recent times, with studies indicating that exposure to green spaces has a positive impact on mental well-being. Given that campus green space (CGS) is the primary natural environment that university students are exposed to, it is crucial to examine the health benefits associated with CGS exposure for students. Specifically, it is important to investigate how CGS exposure affects the mental health of university students during the Covid-19 pandemic. In this study, we utilized behavioral trajectory data, activity logs, and questionnaires to comprehensively assess university students' CGS exposure and its association with mental health before and during the pandemic, using the Minhang campus of Shanghai Jiao Tong University as our case study. Our results indicated a significant correlation between the two subjective indicators of CGS exposure based on activity logs and questionnaires. Additionally, subjective CGS exposure did not have a significant correlation with objective CGS exposure based on behavioral trajectory data. Furthermore, the indicator of CGS exposure based on activity logs during the pandemic was significantly and positively correlated with the mental health of university students. This correlation was stronger than the correlation between mental health and family harmony, as well as satisfaction with residential facilities and services in the quarantine residence. We also found a significant and positive correlation between the number of indoor plants and mental health. Based on these findings, we propose recommendations for constructing campus green spaces and improving the mental health of university students.

Causal network map for sustainable urban riparian management: a case from Souel of South Korea

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban riparian play a critical role in promoting ecological resilience, mitigating urban biodiversity loss and enhancing the quality of life in urban areas. Due to the intricate interplay of socio-ecological and political determinants, a systematic analysis of drivers is essential. Necessitated an understanding of not only the direct but also the indirect influences on urban riparian circularity, the visualization of causal networks becomes indispensable for facilitating this systematic analysis. This study provides a comprehensive causal network map on the multiple impacts of urban riparian that can inform urban riparian policy and response to manage sustainability. The methodology consists of two procedures. It begins with a thorough exploration of prevailing academic literature, to identify initial variables and causal relationships. Then, Delphi analysis is applied to reconcile the perspectives of various stakeholders and formulate a consensus-based management strategy. To achieve this, the SDGs-based DPSIR framework is chosen to examine the causal relationships influenced by policy responses. Relevant to urban riparian, 15, 11, and 6 targets from the SDGs are selected and used to classify factors. Previous research consistently indicated the positive impacts of urban riparian on air and water quality, water temperature, and biodiversity. Based on the findings, three key policy topics are derived as a comprehensive plan for effective urban riparian management. This plan outlines strategies including the establishment of a legal framework, capacity building initiatives for public officials associated with waterfront forests, and public outreach efforts. This study's results offer significant insights that can inform the development of city-level waterfront plans and policies, fostering a harmonious coexistence with nature. Moreover, the visualization of driver interactions provides stakeholders with valuable understanding, highlighting the most effective measures for sustainable urban riparian management.

Changes in citizen perception or urban trees 2018 - 2023

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Management of urban arboriculture elements, predominantly trees, is sometimes very complex due to the conflicting interests from various stakeholders. Main drivers of such attitude between demographics could be different perception of environmental and monetary values of arboriculture elements.

The goal of this research was to estimate if recent pandemic restrictions have influenced people's attitude and perception towards urban arboriculture elements. We have distributed the same questionnaire on perception of urban arboriculture elements and analysed respondents data on two separate occasions. Survey was conducted in Croatia in 2018 and 2023 and we have completed the 1501 individual surveys- (723 in 2018 and 778 in 2023).

Overall, in both groups, respondents perceived trees as a positive element of urban infrastructure, and for this matter we found no statistically significant differences between the two groups. The perception of quality of tree maintenance has and perception of the overall condition has slightly decreased in 2023. The importance of damage caused by trees decreased for urban inventory and physical injury decreased while importance of biodiversity sustainability increased slightly in comparison with 2018 survey results.

Inclusive governance of urban forests is a key for making efficient, sustainable and biodiverse urban environment and allowing guided citizen participation can relieve shortcomings induced by budget constraints. This study also indicates that citizens may be willing to commit their own time and effort in order to improve the state of their urban trees.

Keywords: urban trees perception, inclusive governance, biodiversity, tree risk tolerance

Comparison of the prevalence of ASaV-infected flowering ash (F. ornus) trees in two Germany Cities

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Viral diseases play a particular role in tree health as predisposing factors (Büttner et al, 2013, 2023). Therefore, the virus infection could counteract trees resilience, especially in cities with anticipated extreme climate conditions. Flowering ash (*Fraxinus ornus L.*) infected by the ash shoestring-associated virus (ASaV) develop symptoms like chlorotic ringspots, mottle and leaf deformation such as curling and shoestring (Gaskin et al., 2021). The tree species is considered as a potential "climate tree" in urban environment. In this study, we assessed the prevalence of ASaV in this tree species, which is increasingly planted in German cities, in the cities of Hamburg and Berlin.

In the vegetation periods 2019 and 2020, a survey on the occurrence of ASaV-associated symptoms was carried out in selected street sites of Hamburg considering 50 % of the 466 flowering ash trees planted in the city state. The trees were visually inspected twice per year. A selection of symptomatic and symptomless leaves was sampled and tested for an ASaV-infection by virus-specific RT-PCR.

In 2021, we examined 65% of the 1150 flowering ash trees grown in Berlin for ASaV symptoms. Visual scoring of the trees was followed by sampling of 82 symptomtic leaves. Additionally, 85 samples without virus suspected symptoms and 32 with discoloration and deformation atypical to an ASaV-infection, and 14 samples with mild ASaV-symptoms were taken and tested by ASaV-specific RT-PCR. The occurrence and distribution of ASaV-infected trees in these two cities make aware that viruses have to be listed as a considerable member of potential pathogens in trees.

Defoliation and dieback of Sitka spruce in Reykjavík, Iceland

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: The green spruce aphid (*Elatobium abietinum)* is an important defoliating pest of Sitka spruce (*Picea sitchensis*) in Iceland. A comparison of two urban Sitka stands in Reykjavík, from 2013-2017, reveals a distinct difference in defoliation due to the green spruce aphid between trees located near a main road (94% defoliated) and several hundred meters away from heavy traffic (47%). Chemical analyses of the spruce needles demonstrate substantially higher nitrogen ratios in trees near traffic. Furthermore, the recently warming winter temperatures promoted larger overwintering aphid populations since 2003, as well as a shift of mass outbreaks from autumn to spring, accompanied by distinct growth suppressions one year after an aphid population spike in the post-2003 tree-ring data. The results of this study indicate that the mechanisms triggering Sitka spruce dieback in Reykjavík include a combination of increasing winter temperatures, more frequent and severe green spruce aphid outbreaks, as well as elevated N values in the needles of urban trees. During recent years the Sitka spruce stands have partly recovered from the defoliation.

Dynamics of Street Tree Populations in Urban Areas: Understanding Mortality Rates and Associations with Age and Size Classes

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: ***Keywords:*** *Urban Trees, Urban Tree Mortality, Street Trees, Tree Growth*

Urban green spaces (UGSs) play a critical role in mitigating the climate change challenges by offering multiple ecosystem services, such as regulating air quality, increasing shade, cooling, and air humidity, enhancing biodiversity, and offering erosion control. Trees are a vital component of UGSs and provide significant environmental, economic, and human health benefits in urban ecosystems.

Our study focused on understanding the dynamics of street tree populations in urban areas, which are built through cycles of planting, growth, death, removal, and replacement. In this study, we used the cadaster dataset of 12 cities in Germany with 5-10 years of street tree monitoring. Our research objectives were to a) calculate annual mortality rates for the most common urban tree species; b) analyze the association between mortality rate, age and Diameter at breast height (DBH) size classes with multivariable logistic regression models.We hypothesized that the mortality rate varies across species. Furthermore, the mortality rate is associated with age and DBH size classes, with high mortality rate for young and small classes and low mortality rate for middle, large age and DBH size classes.Annual tree counts and mortality observations were used to calculate the elements of the street tree demographic modified balancing equations, and to determine annual mortality rate and population growth.

Since demographic concepts, such as survivorship and mortality curves are useful to analyze urban tree mortality rates, we will assess the size and age-based shape of the street tree mortality curve in the next phase of the study. By analyzing the mortality curve, we aim to identify the factors that contribute to high mortality rates and that change as the trees age and grow.

Our study provides a framework for future urban tree mortality research and may fill the knowledge gap on mortality rates of urban trees, aiding in the design of effective urban forestry strategies. It can be replicated in other cities with similar climates for further comparisons.

Environmental DNA Analysis as a Supporting Tool for Assessing Soil Biodiversity Changes in new Urban Forests

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: The growth of urban populations and associated development has profound effects on biodiversity. Urban forestry and green spaces are imperative to improve the quality of life in urban areas. In this context, urban and peri-urban forests hold particular significance to provide essential ecosystem services such as biodiversity improvement. Indeed, the recovery of biodiversity, encompassing fauna and flora, can be significantly aided by establishing new tree plantations in urban regeneration projects. The AIRFRESH project (LIFE19 ENV/FR/000086), supported by the LIFE 2019 Environment and Resource Efficiency sub-programme, aims to reduce air pollution through the planting of a new urban forest in Florence, central Italy and Aix-en-Provence in South-eastern France. The project includes a total of about 2 ha experimental green area hosting 170 and 400 trees in Florence and in Aix-en-Provence respectively, belonging to highly performing genera (e.g. *Tilia*, *Acer, Ulmus*) in the absorption of pollutants. Concurrently, faunistic surveys have been conducted to monitor changes in biodiversity throughout the project duration, using direct observations, camera traps, and bat boxes. Initial results from observational surveys have indicated an increase in faunal biodiversity, particularly birds and mammals. However, soil diversity has not been assessed yet, although it may represent a pivotal element in determining the local environmental quality. Thus, with this work, we collected soil samples before/after and inside/outside tree plantations and we performed environmental DNA analysis with a focus on soil organisms. This method has gained popularity in environmental sciences and biodiversity conservation, providing valuable information for monitoring rare, threatened, or invasive species and studying organismal ecology and ecosystems. Furthermore, we also used environmental DNA as an alternative method to the Qualitative Biological Soil Assessment (QBS) for studying soil arthropods and beneficial soil bacteria involved in promoting plant growth. In conclusion, eDNA constitutes an important tool to evaluate in a reproducible and objective way the improvement of biodiversity in new urban green areas.

Equitable Climate Action: leveraging open-source tools to integrate forests and trees into local land use planning

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: World Resources Institute, ICLEI – Local Governments for Sustainability, and several partners are equipping community leaders with the tools they need to plan for and monitor locally-led nature-based solutions and equitable programs for climate change mitigation. Cities, counties, and landowners are taking proactive steps to mitigate climate change and build resilience, but to do so they need reliable and consistent information on how tree canopy is changing over time and the related the greenhouse gas (GHG) impacts of land management decisions. The LEARN (Land Emissions and Removals Navigator) tool is a free platform which provides automated spatial analysis of the GHG impacts of urban trees and forests within a community or area of interest. LEARN enables land managers to make data-driven plans for urban forests and efficiently monitor the implementation and impacts of those plans over time. The tool analyzes national datasets from the U.S. Forest Service (USFS) and U.S. Geological Survey to derive spatially explicit estimates of carbon emissions and removals from land cover change, forest disturbances, and changes to tree canopy on non-forest lands. A key feature of LEARN is the disaggregation of tree canopy and tree canopy change data by land use type, which is critical for community planning. High resolution (1-meter) tree canopy change data is also available for the Chesapeake Bay watershed, which provides users in the eastern U.S. with enhanced analysis capabilities, particularly for urban areas. Several anticipated updates to the LEARN tool would improve user experience and content while helping communities understand and act on mitigation and adaptation opportunities across forests and trees. Priorities for updates include disaggregation by census block and socioeconomic information, expansion of high-resolution tree canopy coverage, and functionalities for planning and decision-support. Another key improvement may involve working with the USFS to dynamically integrate with the Forest Inventory Analysis database to improve carbon estimation. Through continual updates and improvements to the LEARN tool, we are easing the burden on local and regional governments and accelerating the transition from planning to implementation on the ground.

From Ecosystem Service Prioritization to Species Distribution: selecting native street tree species for ecosystem service optimization in Ethiopia

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban street trees (UST) provide multiple ecosystem services (ESs) against multi-scaled problems facing urban areas associated with climate change, pollution, and health. Selecting the right tree species providing the needed ESs, while matching urban site conditions can maximize ESs delivery and thereby improve the quality of life for the urban population. There is political and scientific recognition of the role that urban greening and urban trees have in enhancing urban resilience, towards climate change. However, the growth behavior of USTs, prioritization of ESs from UST, and preferences for UST species remain unstudied in many parts of the world, including East Africa as shown in a systematic literature review. The primary aim is to present the methodological approaches that will be used to evaluate USTs suitability and immunity to environmental stress, and preliminary results for a range of native Ethiopian species. Once we identified the potential USTs, leaf morphological, and chemical functional traits: leaf area, specific leaf area, leaf water content, specific leaf dry mass, specific leaf nitrogen, phosphorus, and carbon content, specific wood density, and leaf turgor loss point are measured to evaluate and compare their adaptation strategies. For better adaptive species, drought, and waterlogging resistance thresholds will be determined under greenhouse experiments in early 2024. Our findings of both the field measurement, laboratory measurement, and greenhouse experiment will be discussed about the challenges facing UST selection and how different native species could be used to deliver cooling services in the warmer seasons of Ethiopia and/or in general tropical cities.

Growth and cooling potential of urban trees across an imperviousness gradient

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: The Urban Heat Island phenomenon, primarily caused by increased impervious surface cover replacing evaporative vegetation surfaces, has contributed to increased heat stress experienced by city dwellers. Climate change forecasts indicate that the UHI effect will worsen in the future, which will have a profound impact on human thermal comfort and could pose a public health threat. Urban trees, which cool the environment through shading and evapotranspiration, are an effective tool to mitigate the heat stress. However, their cooling potential is highly influenced by ecological characteristics, above and below ground conditions. Furthermore, the impact of impervious surfaces on tree growth and cooling potential across a range of urban environments remains largely unexplored. Our study addresses these knowledge gaps by comparing the growth rates and cooling potential of four different urban tree species along a eight kilometer transect which covers highly densified, city center to less impervious sub-urban areas in Munich, Germany. By assessing the impact of imperviousness on microclimatic regulation and growth patterns, we sought to provide insights into the selection and deployment of tree species to enhance thermal comfort. A field campaigned was carried out in the summer months where various parameters relating to the microclimate, tree morphology and physiology, dendrochronology and human thermal comfort of 38 tress of four different but contrasting species were measured. Results showed significant differences among the different tree species with regards to growth, vitality and cooling potential. Notably, dendrochronological analysis revealed that trees in low impervious zones (LIZ) exhibited larger sizes on average compared to those in high impervious zones (HIZ) of the same age. The light-demanding, fast-growing species,*P. x acerifolia*, exhibited the highest growth rate across all impervious zones. Furthermore, the cooling potential varied considerably among species, with diffuse-porous *P. x acerifolia* and *T. cordata* outperforming the ring-porous *R. pseudoacacia* due to higher stomatal conductance, transpiration rates, and leaf area index (LAI). The findings from our work can guide urban planners and landscape architects to select those species that are particularly effective in certain areas when the aim of planting is to improve human thermal comfort.

Health status of the street trees along the Urban – Rural gradient in the Garden city of Bengaluru, India

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban forestry deals with the management of the trees in the urban environment to improve and provide ecosystem services to the residents in the urban set-up. Trees play a crucial role in improving urban biodiversity and ecology, mitigating greenhouse gas emissions, reducing urban flood, and modifying local climate by reducing urban heat island effects. In addition, trees in urban ecology provide aesthetic benefits and enhance functional diversity. They also contribute towards economic benefits like attract tourism, increase property value and investments. Our study was focused on determining the tree health status in urban environment since they are constantly exposed to different anthropogenic pressures. For the study, 23 plots were selected in northern and 25 plots in southern transact of Bengaluru city in which trees with dbh $\geq$ 10 cms were taken for study. The size of each plot was one ha and the plots were classified as urban, transition and rural based on the percentage of tree cover and built-up. Common tree species from each domain were selected for Air pollution tolerance index in both transacts. The fresh leaf samples collected from the plots were analyzed for p^H, ascorbic acid content, relative water content and chlorophyll content. In addition, the trees' interior health was checked through Electrical Resistance Tomography which is a non-destructive method aiding to understand the sapwood, heartwood, stress and decay in the living trees through coloration. The finding from our study helps the urban decision makers, including planners and administrators, to plan and maintain the street trees in a holistic manner.

How do the increases in air temperature affect the cooling delivery of trees?

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Rising air temperatures and the urban heat island effect are causing public health concerns worldwide. Green infrastructure provides cooling benefits to urban environments by absorbing radiation, using this energy for transpiration, and by direct shading. In the UK, 30% of urban areas comprise domestic gardens, while 90% of the population live in urban or peri-urban areas. Within gardens, trees play a central role in providing environmental cooling benefits. However, there is a knowledge gap on responses of common garden trees to increases in air temperatures associated with climate change, and uncertainty regarding recommendations of tree species appropriate for a variety of environmental conditions in gardens.

To provide gardeners with species-specific information on ecosystem service-delivery by trees during warmer periods, transpiration in response to meteorological fluctuations was monitored on a variety of tree species common to UK gardens. A 2-year replicated field trial was carried out on nine different species of containerised garden trees, maintained under irrigated conditions. Measurements included continuous assessment of sap flux, substrate moisture, tree growth, leaf area index, crown volume, leaf gas exchange and summer leaf water potential. This paper reports on data obtained during the warmest month of the study period (July) for the two consecutive years of the study. A mixed model was applied to assess responses of sap flux to meteorological conditions.

Eight out of nine species displayed maximum transpiration when air temperatures were between 28-30˚C (±3), however maximum transpiration for the *Prunus* was beyond the observed temperature (up to 37˚C). For relative transpirational cooling potential (accounting for size), the *Crataegus persimilis* was most promising up to a certain threshold (33˚C), while the fast growing *Pyrus calleryana* delivered most transpirational cooling in absolute terms (largest tree, up to 33 ˚C). Findings suggest that the tree species tested will continue to deliver a cooling service during the majority of future UK summer temperatures, providing they have access to sufficient soil moisture. However it also indicates that the majority of tree species are increasingly hitting their upper thresholds in terms of transpiration potential under warming UK summers.

Incorporating tree structural complexity and neighborhood effects into urban forest monitoring systems

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Trees and forests in urban areas provide critical ecosystem services to support human well-being worldwide, yet urban-forest specific tools for monitoring are lacking, compared to those for other (rural) forest types and plantations. For example, the Forest Inventory and Analysis (FIA) program of the U.S. Forest Service has been monitoring US forests for about a century, yet have only implemented urban forest inventories in the last decade (Urban FIA). Further, urban forest monitoring systems typically rely on models of trees developed for trees growing in rural landscapes. It is important to understand how trees of different species are adapting to urban environments and how these environments affect tree form, function, and production of ecosystem services, such as mitigation of urban heat islands and carbon sequestration. Here, new data and models are presented to show how tree 'neighborhoods' in cities effect tree structural complexity, branching architecture, volume and surface area growth and biomass allocation, and how this knowledge can be incorporated to improve urban forest monitoring systems, such as Urban FIA. The potential of non-destructive methodological approaches derived from ground-based lidar are emphasized in both data collection and modeling approaches.

INEQUALITY IN THE PROVISION OF ECOSYSTEM SERVICES FROM URBAN FORESTS ACROSS DIFFERENT NEIGHBORHOODS IN ONE JURISDICTION. CASE STUDY OF LUJÁN ARGENTINA

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban forests play a crucial role in maintaining favorable environmental conditions for public health. They provide essential services such as improved air quality, climate regulation, and biodiversity promotion, contributing to healthier and more sustainable urban environments. However, ensuring equal access to these ecosystem services across different neighborhoods is essential to address potential inequalities. This research presents a case study conducted in Luján, Buenos Aires Province, in Argentina focusing on the access to urban forest ecosystem services and highlighting the importance of equity in their provision. The study employs a combination of methodologies to assess the distribution and fairness of ecosystem services provided by the urban forest in each neighborhood. By examining residents' connection with urban trees, their engagement in governance models, and disparities in accessing these services, this research aims to inform strategies for reducing social inequalities and enhancing residents' quality of life in Luján. It identifies and quantifies various ecosystem services, including air quality, climate regulation, biodiversity, and access to green spaces. To gather comprehensive data, official documents related to urban planning and green space management are analyzed to understand existing policies and regulatory frameworks. We conduct perception surveys among residents to obtain information about their connection to urban trees and their involvement in natural resource management. Additionally, the study uses the Normalized Difference Vegetation Index (NDVI) as an indirect indicator of urban forest ecosystem services, integrating it with economic and biophysical valuation. The research sheds light on social dynamics, perceptions, and utilization patterns of urban forests in Luján's neighborhoods. Findings reveal significant variations in residents' access to ecosystem services, emphasizing the importance of residents' connection with urban trees in both public and private spaces. The study also explores residents' potential participation in the governance and management of urban forests through various models. As the result, this research provides a foundation for creating more equitable and resilient urban environments, ensuring that all residents in Luján can fully benefit from the ecosystem services provided by urban forests.

Influence of urban expansion and land use/cover dynamics on ecosystem service value trade-offs and synergies in Tigray, Ethiopia

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Understanding the influence of urban expansion and LULC dynamics on ecosystem service values (ESV) is an important basis for incorporating ecosystem services and their trade-offs and synergies into urban green infrastructures (UGIs) planning and decision-making processes. Proper UGI planning can help maintain the health of urban ecosystems and their services. In this study we evaluated the impact of LULC change, urban expansion and landscape dynamics on ESVs and their trade-offs and synergies in Mekelle, Aksum and Shire-Indasilassie cities of Tigray in Ethiopia. Landsat satellite images were used to analyze LULC for the years 1984, 1994, 2003, 2014 and 2020. Fifteen ESs were selected for analysis. We used global and local ESV coefficients to estimate ESV using benefit transfer technique. In 1984, farmland represented the most dominant LULC class covering about 80% (25,739 ha), 73% (2537 ha), and 66% (2294 ha) in Mekelle, Aksum and Shire-Indasilassie cities, respectively. While built-up land had the lowest coverage in all areas during this period. However, built-up land has been increasing with an increasing trend from 1984 – 2020 at the expense of farmland and UGIs. The study shows ESV reduction of 15.6% (Mekelle) and 18.98% (Shire-Indasilassie) but an increase of 2.75% in Aksum when using the global ESV coefficients. Based on local coefficient ESV decreased by 19.9% in Mekelle but increased by 13.6% in Aksum and 26.25% in Shire-Indasilassie. While based on estimates of local coefficients, provisioning ecosystem services value decreased by 31.2% (Mekelle), by 20.2% (Aksum) and by 38.7% (Shire-Indasilassie). Food production, biological control and pollination ecosystem service values had decreased through time. From 1984 – 2020 the per-capita ESVs decreased by 86.5% in Mekelle, 73.95 % in Aksum and by 93.86% in Shire-Indasilassie. The decrease in the ESV is probably contributed by urban expansion. The variations in the trade-offs and synergies of the ESs were significant, indicating the need for area specific UGIs planning and monitoring. Long-term monitoring of ES trade-offs and synergies would be essential for making policy decisions and land use planning and management improvements in urban areas.

Mapping preferred positions of visitors in an urban garden: an analysis of correlation with green structures

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: The behavior of people visiting green spaces is affected by several factors. An important aspect is the horizontal and vertical spatial structure of the vegetation, with respect to the accessibility and other features of the green area. In this work we tested a framework for real-time geolocation and mapping of visitors of an urban garden that is part of the VARCITIES project, Villa Revedin Bolasco. An app was developed for smartphones that are given to volunteers that visit the garden. The app is very light in terms of memory footprint and records every second the spatial coordinates of the device, sending it in real time to a server that collects the information in binary format in a file. The app can also be used offline, in case of low or absent connectivity, it will store the coordinates in the phone memory, and then sync whenever the connectivity is available. Data are visible online on a web-gis portal. The collected data are used to assess which areas are significantly more visited, and thus reasonably provide to visitors an added sense of wellness. This part, that is more related to the psychological aspect, was tested by a dedicated team from the Psychology department. Initial analyses related to the identification of clustering and spatial patterns have highlighted that there are two / three areas in the urban garden that seem significantly more visited than others. These areas are in more quiet parts of the park and in more pleasant scenery. To cross-validate these assumptions, a group of volunteers was also asked to take pictures of the areas that they preferred, and the spots that were photographed had a high correspondence to the hotspots of visitors positions. At this stage the correspondence was evaluated visually, but the next step is to assign similarity indices to the two heatmaps to objectively assess common hotspots and diverging results, in order to provide a more rigorous assessment of the output.

Microhabitat provision of solitary city trees of four common species in Germany

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Today's cities need sustainable planning to address the challenges of our time, such as climate change, ongoing urbanization, and the loss of urban biodiversity. Assessing biodiversity provision is essential in this regard. Large trees contribute significantly to biodiversity as they support the life of numerous other species. Therefore, inventorying, and monitoring tree-related microhabitats (TreM) can be a promising approach assessing urban areas' biodiversity. This research aimed to investigate the abundance, richness, and diversity of TreMs in common broadleaf urban tree species in Karlsruhe City, southwest Germany. Additionally, we aimed to identify the influence of tree-related variables, such as growing habitat and crown pruning intensity, on the occurrence of TreMs. We randomly selected 320 urban street and park trees was selected, consisting of Norway maple (*Acer platanoides*), horse-chestnut (*Aesculus hippocastanum*), black locust (*Robinia pseudoacacia*), and small-leaved linden (*Tilia cordata*). TreMs were recorded and inventoried, alongside a complete dendrometric inventory of the trees.

We found that small-leaved linden trees had a high abundance but low diversity of microhabitats. Park trees of Norway maple exhibited a greater microhabitat richness than street trees of the same species. Individual tree microhabitat groups such as cavities and fungi were less prevalent on black locusts, whereas rot holes and nests were more frequent on this species.

The frequency and diversity of TreM increased with tree size (diameter), which is a good predictor for the occurrence of microhabitats. Increasing pruning intensity and crown dieback had a positive influence on microhabitat occurrence. Growing habitat positively influenced TreM abundance in park trees of horse-chestnut. Comparison-of-mean tests showed that TreM richness and diversity were higher in park trees than in street trees of the horse-chestnut.

The results highlight the need to balance the conservation of large living urban trees, their appropriate management, and the maintenance of taxonomic diversity of trees in urban areas while considering diverse growing habitats such as parks and streets. Maintaining this balance becomes even more critical to minimize the trade-off between a healthy urban tree population with high leaf area versus trees with microhabitat structures for flora and fauna.

Monetary evaluation of multi-ecosystem services in an urban park designed for countering the adverse effects of climate change in Bangkok, Thailand

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Thailand is a sought-after tourist destination, with an expansion pressure on this metropolis apart from a rapid urbanization. However, the expansion in green spaces has not been able to keep pace with this urbanization. Due to high population density and land prices in downtown, new urban parks are almost impossible to establish. Fortunately, a small park, named CU 100 Park, was established with an area of 4.48 ha in 2016 with a design to mitigate the effects of climate change. However, the important lingering question about the feasibility of such parks is "Can such a small park provide any ecosystem services (ES) to humans?". To answer this question, we conducted a study which focused on quantifying and evaluating the ES in terms of monetary value, as such a quantification can be conveyed easily to everyone from commoners to policy makers. Even for a relatively small sized park, the CU 10 Park provided all four services, including provisioning, regulating, culturing, and supporting services, which amounted to a total monetary value of USD 303.925. the most contributed ES was to the cultural services (46.79%), as the perspective of most people for coming to the park was of recreation. This was followed by provisioning services (27.81%), from the timber price, as the park manager intentionally selects the high value timber species. The contribution to supporting services was estimated at 19.86% of the total evaluation. These services are important to maintain the biodiversity of an ecosystem by providing habitat for organisms and genetic diversity. Interestingly, the least contribution was to the regulating services at 5.54%, even when the park was specifically designed for microclimate regulation. This could be due to the tree canopy being of a small size such that the leaf area index was not large enough for regulating the microclimate. It is proved that the specifically designed parks based on microhabitats are in need to provide various ecological function to attract and ensure adequate resource sharing by the flora and fauna apart from facilitating human community services related to physical activities and social interaction are crucial even with the small park size.

People's Perception on Use and Management of Urban Green Spaces of Gurugram, India

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban Green Spaces are considered to be beneficial for health and wellbeing of urban residents. The need for more Urban Green Spaces is worldwide high on the policy agenda of the cities. Urban Green Space includes parks, community gardens and cemeteries, but also rooftop gardens and vertical gardens, meadows and woods. Urban Green Space is also referred to as blue-green zone, because urban water such as ditches, canals, inland waterways and rivers and riverbanks, is considered as Urban Green Space. Urban Green Space reduces the risks of flooding in cities, cools the city in the summer and provides biodiversity. UGS contributes to the well-being of cities and its residents, to better health, and social cohesion. Besides these regulating and provisioning services urban greenery also provides a gateway to enhanced socio-cultural bonding to its users. World health organization has highlighted the delicate link between green spaces and mental health.

There are about 1200 small and big city parks in the city of Gurugram located in North Indian State Haryana. There are other green spaces like bundh, biodiversity park and nature trails created on waste and open lands which are being used by people of the city for vsrious purposes. A study was carried out in three big parks and one nature trail created on a bundh to know the users' perception on use and management of these green spaces. The responses were received from males, females and children of various age groups on social-economic matters, purpose of visit of green spaces, time spent, frequency of visit etc. and management related issues in parks.

The results of the study will be presented in the Congress.

Quantifying the aboveground proportion of sapwood-heartwood volume of urban trees with the use of terrestrial laser scanning technology.

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Estimating the aboveground sapwood and heartwood volume is important for evaluating wood utilization and monitoring tree health and internal decay patterns in urban trees. However, quantification of the wood composition of trees is challenging because they typically must be harvested to obtain the data. Previous studies have primarily focused on the main stems of rural forest trees, excluding the branch component, but branches make up a major portion of urban tree wood. Here, we demonstrate a method for estimating total tree sapwood and heartwood volume, using a model of sapwood and heartwood distribution in stems and branches, combined with terrestrial laser scanning (TLS) technology, which provides detailed three-dimensional point-clouds of trees that can be used to quantify their aboveground woody volume in a non-destructive manner. Twenty-four urban *Gleditsia triacanthos* trees were laser scanned in leaf-off condition on the Michigan State University campus. TLS point-clouds were used to generate quantitative structure models, which provided detailed quantification of the woody volume of main stem and branches of the study trees. To calibrate models of heartwood-sapwood distribution a subset of the study trees were destructively sampled after scanning, and woody disks of stems and branches were collected. The resulting models provided estimates of total tree, stem and branch sapwood and heartwood volume and showed opposite patterns of vertical accumulation of heartwood and sapwood volume for stems versus branches. The method developed in this study has broader implications for monitoring the growth and the wood quality of urban trees. Future studies should explore the use of main stem increment borer samples, combined with branch disks of urban trees that are regularly pruned, because tree harvesting for model calibration may not be applicable or desirable in urban settings.

Remote sensing monitoring of urban canopy dynamic across heterogeneous urban habitats

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban trees are receiving increasing attention from both scholars and policy-makers to serve as a green prescription for addressing various challenges facing human society. The canopy development of urban trees is an indicator of their physiological health. Adequate monitoring of canopy dynamics based on remote sensing can help to detect plant growth in different urban habitats in order to inform management practices to maximise the benefits of urban trees. Using the Kowloon Peninsula, Hong Kong, as a case study site, this study explores tree canopy dynamics in four habitats, including road verges, residential lands, parks, and natural terrains. Four approaches are compared to segment adequately individual tree canopy using WorldView-2 remote sensing data. Then the individual tree canopy is combined with freely available Sentinel-2 satellite data to obtain canopy growth dynamics for each season from 2016 to 2020. The three indicators representing leaf chlorophyll density, density of woody branches and twigs, as well as canopy water content are applied to reflect tree canopy status. This study reveals that urban trees show varying canopy growth trends, the poorer status of trees in three urban habitats relative to nature land, indicates the inhibition of trees' natural growth by the urban environment. Additionally, two super-typhoons during the study period also provide evidence for urban tree resilience in different habitats, of these, the trees in road verges are the least resilient and in natural lands the most resilient. This study also finds that urban tree canopy preferentially recovered leaf after suffering losses from typhoons, while the recovery of non-leaf woody parts and water content lagged behind. This study demonstrates how remote sensing data can be used to provide a better understanding of long-term tree canopy dynamics across different urban habitats, which is key to monitoring urban trees' dynamics and incorporating management practices to maintain the health and growth of urban trees.

Remote sensing-based tree species classification for estimating ecosystem services

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban trees play a vital role in enhancing community health and well-being by providing environmental, social, and economic functions, collectively known as ecosystem services. Urban tree growth models have attempted to estimate the extent of these ecosystem services using allometric equations, growth factors and physiological functions. Nevertheless, these models require detailed information on individual tree characteristics, particularly tree species. Traditional data collection methods for tree attributes can be expensive and time-consuming. This study proposes a cost-effective approach utilizing remote sensing products, specifically multi-temporal satellite imagery and a canopy height model with very high spatial resolution, in conjunction with machine learning techniques for single tree classification.

Our object-based classification method incorporates various features, including vegetation indices, spectral, geometrical, and phenological attributes to differentiate the most common tree genera in Munich, Germany. To enhance classification accuracy, we adopt a hierarchical approach that considers land use, physiological characteristics, genus, and species. The model was applied over a large-scale area, successfully classifying more than 160,000 trees. Evaluation of the results revealed variations in classification accuracy based on land use and tree genus, achieving an accuracy of up to 88.9% for certain species. Our results are further validated for the estimation of ecosystem services by testing our tree metrics in the CityTree model.

This research demonstrates the efficacy of remote sensing and machine learning techniques for accurately classifying urban trees and obtaining detailed tree attributes necessary for ecosystem services models. The findings contribute to a more detailed understanding of urban tree dynamics and provide valuable insights for monitoring urban trees and their ecosystem services.

Seasonal dynamics of the Leaf Area Index of selected tree species in urban environments

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: The leaf area index LAI is one of the most important parameters for the acquisition and calculation of ecosystem services (ESS) of vegetation such as carbon fixation, cooling by evapotranspiration or shade density. These ESS are important aspects of urban greening in cities to naturally reduce human heat stress and mitigate climate change. In this context, different species and vegetation types show different EES depending on age, vitality, crown size and season. The present study deals with the variation of the LAI of different urban tree species at several public places in Munich over the course of a year. Thereby, both the "branching index" before leaf emergence, the increase of the LAI with leaf unfolding and the maximum foliage were recorded, as well as the decrease of the LAI in autumn.

In this study, the LAI was determined non-destructively using the indirect method of hemispherical photography. A total of 111 urban trees of six different species (59 *Tilia cordata*, 38 *Aesculus hippocastanum*, seven *Acer pseudoplatanus*, five *Platanus acerifolia*, and two *Robinia pseudoacacia*) were studied in six public places within the city of Munich. The 14 recording dates span from the end of March to the end of October 2019.

The results showed species-specific developments of the leaf area index. Thus, *T. cordata* and *A. pseudoplatanus* showed the highest LAI, while *P. acerifolia* displayed the lowest LAI values. The LAI curve of *R. pseudoacacia* developed significantly different from all other species with a late leaf emergence, sharp increase in summer and strong decrease afterwards. Leaf emergence happened similarly for all diffuse-porous, shade-tolerant species (*T. cordata, A. pseudoplatanus* and *A. hippocastanum*) between 09.- 16. April, while it was much later for light-demanding, ring-porous species *R. pseudoacacia* and the late leaf sprouting species *P. acerifolia* (after 30. April). Further analyses also revealed the relation between LAI and the degree of soil sealing and tree phenology. The obtained data can be used as a basis for the determination of the LAI and the ESS of different tree species in the city and thus be used for a more sustainable tree management.

Shrinking urban green spaces, increasing vulnerability: Solving the conundrum of demand-supply gap in fast expanding urban area in Global South

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urbanization is fast-growing still, urban green spaces (UGS) are observed to be cushions to many urban risks and issues that are not limited to pollution, habitat and disaster risk reduction. Unplanned and exponential urban growth in the Global South in last few decades been mammoth has led to loss of large area of UGS, associated ecosystem services and interlinked urban resilience. Urban growth in India faces continuous pressure from unprecedented expansion, immigration for livelihood opportunities leading to substantial loss of UGS. We attempted to understand and capture the relevance of public UGS because of ease of access to all. Dynamics of declining UGS due to rampant concretisation to address the demand-supply gap for urban green spaces was explored taking in Nagpur has a model city. GIS tools were used to assess decadal land-use change (1990–2021) in the city's buildup area and its impact on the urban green and blue spaces. Urban blue-green ratio was also assessed as an indicator for increasing flash flood risk and loss of habitats for water birds. A participatory survey approach was used for understanding the urban risks, relevance of UGS and local perspectives regarding their benefits based on accessibility to the urban green-blue spaces and continously widening demand-supply gap. Results clearly reflected that UGS were far behind WHO and National standards. The blue green ratio was insufficient to support benefits of UGS for reducing air, noise and ground water infiltration issues that are now emerging as obvious scenario for many fast sprawling urban areas in Global South. Per capita public UGS shortage can compromise resilience and will be insufficient to support the further urban sprawling. Investment in urban areas through the provision of creating efficiently planned healthy green spaces have clear evidence to ensure successful adaptation and mitigation for anticipated climate vulnerability. Suggestions on relevant trees for reducing air, noise and ground water issues will be discussed followed by their integration in site specific plantation along with enforcement of policies to keep 30% of each city area green as a strict compliance to improve urban resilience.

Social Media-based Analysis of Recreational Trail Use: A Case Study of a Protected Forest in Suburban Japan

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Research on the recreational use of forest trails has been the main topic in greenery areas. With social media's widespread adoption, including platforms allowing users to share location-tagged content, new opportunities emerged for analyzing trail usage. However, previous research has been limited to specific social media platforms, such as Twitter or Flickr, and has provided a comprehensive analysis mainly in a larger area, such as at the national scale with national parks. This limited scope hinders a detailed understanding of recreation hotspots and preferences at the local scale (e.g., within urban green spaces). To address the gap and provide regional scale analysis, we focus on evaluating recreation hotspots along trails in a suburban forest. We collect data from multiple social media platforms to know recreational activities, visitor preferences, and the effects of various environmental factors along trails.

The study site is the "Ushiku Nature Sanctuary," located in Ibaraki Prefecture, the suburbs of the Tokyo Metropolitan Area, Japan. The sanctuary, previously a forest intended for resource supply to rural villages, has now transitioned its focus to biodiversity conservation under the management of the local government. Citizens can engage in non-destructive recreational activities, including walking, jogging, and birdwatching.

The methodology involves collecting and analyzing user-generated content, mainly photos, to gain insights into the activities and locations along the trails. We categorized landscape elements depicted in the pictures. Furthermore, we explored the relationship between the number of social media posts and various environmental factors associated with the tracks, e.g., zoning and management conditions, sky view factor, slope gradient, proximity to roads and parking areas, and the distribution of tourist facilities.

Our approach enabled a more detailed understanding of the specific activities and features that attract visitors to particular segments of the trails. We found hotspots of recreational activities along the tracks, indicating areas in high demand and appealing. Furthermore, we established correlations between environmental factors and the volume of social media posts, providing valuable insights for developing management strategies for enhancing visitor experiences and conserving natural resources.

Socio-economic value of cultural ecosystem services in urban green landscapes: evidence from a metropolitan public park

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban green landscapes provide urban dwellers with a wide range of ecosystem services, including cultural ecosystem services (CES), such as leisure, cultural education, aesthetic appreciation, and spiritual needs, but also physical and mental health, group identity, and social integration. Due to their intangible nature, evaluation of CES is less advanced than that on other ecosystem services, even in urban areas. However, estimating the monetary value of these benefits is essential to monitor the efficiency of public spending on urban green space management. The objective of this study was to analyse the CES provided by Parco Colonnetti, an urban green space of almost 40 ha, located in the Southern districts of Turin (Italy). This extensive area includes over 3,000 trees and shrubs, and three ponds. It is equipped with children's play areas, 150 benches, educational, gymnastic, and cycling paths. The specific aims of the research were to profile the park users based on the main benefits received and to estimate the use value visitors place on the park's CES. The survey was carried out through face-to-face interviews to 400 park visitors. Visitor profiles were defined using the principal component analysis (PCA) technique. The use value of the CES provided by the park was estimated with the Contingent Valuation method. Three main user profiles emerged: spiritual and convivial, stressed health-conscious, and parents seeking mental well-being. These profiles entered as explanatory variables in the model used to estimate the visitors' willingness to pay (WTP) function. More than half of the respondents stated a positive WTP to ensure the use of the park. The visitors' average WTP is about 50 euro/year corresponding to a mean value of 1.68 euro per visit, showing that local users seem to be aware of the benefits provided by the park and of its capacity to ameliorate the quality of city-life. These outcomes contribute to increasing the caseload of studies on CES in urban contexts worldwide, providing comprehensible information to policy makers, citizens and other stakeholders on the proper allocation of public resources for urban green landscapes.

Soundscapes and human well-being: acoustic indicators according to vegetational structure and site conditions in an urban historical garden

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Natural sounds improve health, wellbeing, and positive emotions, and lower stress and negative feelings. Urban green landscapes such as gardens and parks represent places to listen to natural sounds and be exposed to less anthropogenic noise. The balance between natural and human-sourced noise can influence the experience of visitors. Vegetation plays an important role in shaping soundscapes, both by creating sound and attenuating noise from natural and human sources. The present study explores the spatial and temporal characteristics of the urban tree vegetation soundscape of the historic garden located in Castelfranco Veneto (TV, Italy) by setting up fix recording devices in multiple monitoring points for periods of 3 weeks during different seasons in 2022 (spring, autumn and winter). The acoustic indices (AI) such as Acoustic Complexity Index (ACI); Acoustic Diversity Index (ADI); Acoustic Evenness Index (AEI); Bioacoustic Index (BI); and Normalized Difference Soundscape Index (NDSI) have been computed for each point and for each single audio recording of 10 minutes per hour, for a total of about 6300 entries. The heights, basal area and density of the 1,299 trees in the historic urban garden are measured using a laser rangefinder and standard trigonometric methodology, while models for canopy height, cover and volume are derived from drone borne LiDAR data. Simulations of direct and diffuse solar radiation according to the canopy cover are assessed using a 3D point cloud model from LiDAR survey, considering the daily and hourly weather conditions reported by the local measuring station.

The responses of the AI to the vegetation-related variables are assessed considering covariates' effects in the analysis, in order to understand the role of tree vegetation in attenuating noise and creating hotspots for natural sound sources such as wild birds and fauna in an urban environment.

Monitoring the changes in the proportions of noise and natural sounds provides insight into biodiversity and the human experience of an urban ecosystem. Our analysis can inform urban planning that focuses on managing green areas while maximizing natural soundscapes to enhance human health and wellbeing.

Strengthening collaboration and knowledge exchange: Exploring synergies between Urban Forestry and Agroforestry

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: In recent years, the fields of urban forestry and agroforestry have gained significant attention for their potential as nature-based solutions to provide environmental, social and economic benefits and achieve more sustainable and resilient societies. While urban forestry primarily focuses on trees and green infrastructure within urban areas, agroforestry explores the integration of trees into agricultural landscapes. And although urban forestry and agroforestry share common objectives, such as enhancing biodiversity and ecosystem services, they often operate within distinct research domains. Our study identifies several key areas where urban forestry and agroforestry converge, fostering opportunities for collaboration and knowledge exchange, as well as highlights the different emphases that characterize each discipline.

First, we explore the interactions between trees and their environment, including the roles of trees in mitigating climate change and delivering multiple benefits to the local communities and society at large. Second, we delve into the crucial topics of monitoring and operational management of trees and green infrastructure in both urban and agricultural contexts. We highlight the importance of species selection and adaptive management strategies to address the challenges of changing environmental conditions and urbanization. Furthermore, we investigate the governance and planning frameworks of urban forestry and agroforestry, emphasizing the need for integrated approaches that consider both urban and rural landscapes, the significance of multi-stakeholder involvement, and the potential for transformational change in achieving sustainable urban and agricultural systems.

Our work serves as a call to action for researchers, practitioners, and policymakers to foster greater collaboration and synergy between the urban forestry and agroforestry communities. By facilitating closer collaboration and knowledge exchange between urban forestry and agroforestry, we can capitalize on their strengths and expertise, leading to enhanced research outcomes and innovative strategies to address complex environmental challenges. Through collaborative efforts, we can unlock the full potential of trees in transforming our cities and landscapes, ultimately improving the quality of life for both urban and rural populations.

The 3-30-300 rule in practice

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Based on the importance of viewing greenery, living amongst greenery, and using greenery, and the scientific evidence that lies underneath, Cecil Konijnendijk introduced the now world-famous 3-30-300 rule for greener and healthier. The rule states that everyone should see 3 trees from there home and workplace, have 30 % canopy cover in every neighborhood and live not longer than 300 meters (328 yards) from a greenspace.

So, how can this rule be implemented and used when working with urban trees and greenspaces? This presentation will present several cases where the rule has been used in e.g. communication with politicians, policies, protection of trees during construction, and how a whole region in Sweden has now been analyzed to see how well all larger towns and cities are following this important rule.

Cecil Konijnendijk has written the following regarding the 3, 30 and 300:

3 trees visible from every home, school, and place of work. Every resident in a city, town, or even village should be able to see at least three trees from their home, school, or place of work. These trees should ideally be well-established. Fewer large-sized trees impacted resident mental health more positively than a larger number of small ones.

30% tree canopy cover in every neighborhood. Based on current research, at the neighborhood level a 30% canopy cover should be a minimum, and cities should strive for even higher canopy percentage when possible. Note that the 30% is not at the city level, as this can result, for example, in an uneven distribution of trees over the city. Thus, every neighborhood needs to be targeted, as well as all new housing developments where there are opportunities to integrate trees from the beginning.

300 meters from the nearest park or green space. In line with research and with the World Health Organization recommendations, every citizen should have a large public green space within 300 meters, approximately a 5-minute walk, from their home. WHO suggests a public green space of at least 1 ha.

THE EFFECT OF URBAN AFFORESTATION ON WILD POLLINATORS - AN ONGOING MONITORING

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Pollinators are important biodiversity indicators and offer key ecosystem services. There are several studies on the effects of urbanization on pollinators which show the importance of having green areas in cities. However, not much is known about the influence of urban afforestation on wild pollinators.

Afforestation in urban environments offers various ecosystem services and an increasing number of cities are investing in these projects. But how are urban forests and pollinators linked? How do the abundance and the diversity of pollinators change with the age of the urban forest? How does forest structure interplay with the role of floristic composition of adjacent meadows? Is functional diversity of both plants and pollinators a better indicator of such dynamics than specific diversity?

To answer these questions, in spring 2023 we started a monitoring project in the metropolitan area of Milan, Italy, by sampling hymenoptera, hoverflies and beetles using pan traps and capture with an entomological net. We monitored twelve sites located in meadows near forests planted in different years between 1984 and 2014 in Parco Nord Milano, a site of active and ongoing urban afforestation on former abandoned agricultural fields. Other five sites were located west of Milan in areas that will be reforested between 2023 and 2024 and represent the control.

We will show the results of the first year of monitoring. We expect: 1) a better understanding of the links among pollinators, forest structure and flora; 2) to observe a difference in the specific composition of pollinators between the two types of sites, with the presence of species that nest in woods in sites near forests; 3) to detect a time-dependent change of richness and diversity among forests planted in different years, which could be mirrored in the five new afforestation areas for the next several years.

The European urban tree inventory: differences in tree composition are crucial for the establishment of invasive forest pests

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Most invasive forest pests are first introduced in urban or peri-urban environments before they spread further, making urban trees potential bridgeheads for pests of trees in other cities or surrounding forests. Species composition of urban trees therefore has an influence on how likely an invasive species can establish after introduction. Consequently, the biosafety of both urban trees and surrounding forest trees is influenced by which trees are planted in cities.

In Europe, urban tree composition is highly diverse and varies among cities, with many more tree species in urban environments than in surrounding forests. The differences in tree composition in European cities is driven by climatic and cultural factors. To map these differences and how they can affect susceptibility to tree pests, we collected European urban tree inventories as part of the eCOST-action ub3guard. We obtained tree inventories from >170 cities across Europe with a total of >8.5 million individual trees from >3500 species. Most trees planted in European cities are native European species but there is also a wide range of non-native trees.

To examine what the extraordinarily high species richness of urban trees means for biosafety, we explored how many of these urban trees are hosts of quarantine pests as defined by the European and Mediterranean Plant Protection Organization (EPPO). We found that there are considerable differences in the number of suitable hosts for quarantine forest pests among European cities. Considering the potential damage that can be expected from invasive forest pests on urban and forest trees in Europe, we suggest greater consideration of potential invasive pests when choosing urban tree species for future planting.

The forest cemetery in Stockholm – eternal forest bathing

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: One of the few UNESCO world heritage cemeteries in the world exists in Stockholm, Sweden. The whole cemetery is designed in close connection to the forest and thereby the cemetery shifts with the seasons and continuously when the trees grow and are field.

Even though this cemetery gets the highest of attention from managers the Swedish UNESCO counsel and many more, the cemetery faces sever challenges. Some of the most important areas of the cemetery is built around elms which are threatened by Dutch elm disease. The large pine forest are showing severe decline due to a combination of pathogens, stress and suspected root damages, and the spruce are being devastated by insects.

The cemetery administration has therefor contracted a consultant network to do a full review of the historical, current and future management. The work focuses on pests and pathogens, climate change, biodiversity and replanting. This presentation will give an overview of all the issues the cemetery is facing together with how these challenges will be analyzed and the suggested changes in management to preserve this world-unique cemetery for future generations.

The importance of monumental and protected urban trees: a comparison between different European contexts

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban trees can be protected through planning instruments, which is particularly true for monumental trees. Monumental trees are defined based on different criteria, and vary between countries and cities. In this contribution, we present results from the MONUVERSITY "MONUmental and urban trees for biodiveRSITY: improving our knowledge on their origin and microhabitats" project and, specifically, we analyse and compare protected and monumental trees in the Veneto region, and the cities of Grenoble (France) and Helsinki (Finland). The presentation first focuses on similarities and differences in terms of criteria adopted as well as other relevant data for monitoring and biodiversity (e.g., tree species). Second, a specific analysis of tree-related microhabitats will help in understanding the potential role of these trees in urban biodiversity. This analysis focuses on the frequency and variability of tree-related microhabitats considering different types of protection and of monumental trees. This study provides a contribution to biodiversity monitoring in urban areas as well as further deepening our knowledge of monumental trees. These results may also orient urban planners to better integrate biodiversity in their management plans and daily treatment of urban trees.

The Influence of Urban Park Characteristics on Recreational Vitality

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban green landscapes play a crucial role in providing recreational opportunities for residents and are considered important indicators of high-quality urban development. However, the specific characteristics of urban green spaces that influence recreational utilization remain largely unexplored. This study aims to investigate the factors influencing recreational utilization in 10 urban green spaces in Shanghai using social media data. By employing OLS and GTWR regression models, we analyze the relationship between recreation utilization and both internal spatial characteristics of green landscapes and external environmental factors. Additionally, on-site investigations provide data on recreational activities, allowing us to examine the relationship between green landscape characteristics and recreational activities using regression models, focusing on 3 urban parks. The results reveal the following key findings:(1) Recreation utilization of urban green spaces exhibits temporal variability and spatial aggregation, with significant spatial and temporal heterogeneity in the influence of green space characteristics on recreation utilization. (2) Indicators such as recreation facility density and lawn coverage positively influence recreation utilization, while the influence of water coverage and normalized vegetation index varies spatially and temporally. The number of roads and the ratio of residential-commercial land use significantly and positively affect green space utilization, while the effects of the number of subway lines and bus stops exhibit significant spatial variation. (3) Certain urban green space characteristics, such as convex terrain, vegetation coverage, planting design pattern, green vision rate, seasonal plant proportion, and accessibility, exert a significant positive influence on recreational activity density. However, connectivity and the number of streetlights have a negative impact. The area of activity venues, grassland types, and land use diversity in the surrounding areas of the park significantly contribute to activity diversity. These findings provide a theoretical basis and empirical evidence for the organic renewal and enhanced utilization of high-density urban green spaces, thereby improving the social services provided by such spaces.

Tree-related structure variables for biodiversity and ecosystem service provision: a comparative framework for urban and rural forests

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: As a consequence of climate change and habitat loss, sufficient biodiversity levels and broad ranging ecosystem service (ES) provision are currently heavily threatened on local, national and global scales. Both urban and rural forested landscapes are of key importance in solving this crisis. A central challenge is how to manage forested landscapes in a way that enhances biodiversity levels and balances between provisioning, regulating, supporting and cultural ecosystem services, rather than favouring only few ES. Although extensive literature exists on the topic, many studies are limited to either rural or urban forests and only deal with a single or few ESs. Hence, there is a lack of studies that take a holistic approach to sustainable tree management by including both rural and urban forested landscapes and their potential complementarity in terms of biodiversity support and broad and balanced ES provision.

The literature was searched for review articles dealing with urban or rural temperate or boreal forests in the northern hemisphere to explore which tree-related 'structure variables' that support biodiversity and provide which ES and ecosystem disservices (EDS). Based on this, a comprehensive framework of structure variables for biodiversity support and broad and balanced ES provision in both urban and rural forested landscapes is presented. The structure variables 'multi-layered vegetation', 'old trees', 'broadleaved trees', 'dead wood' and 'horizontal variation within the area' were found to support biodiversity and lead to the highest number of ES in both urban and rural forests. Further, the placement of the structure variable seems to be of greater importance in cities, in order to provide ES of importance on local scale and not to cause EDS to local green space users.

Urban forest EDS mainly matter on local scale, affecting urbanites where they live, and e.g. include pollen emission leading to allergy, dense vegetation making green space inaccessible and danger from falling branches. There are fewer rural forest EDS compared to urban ones, mainly since rural forests are less populated than cities. For biodiversity support and broad ES provision, local authorities could focus on the central structure variables identified here when managing urban green spaces.

Unsupervised Remote Sensing-Based Assessment of Complex Green and Grey Infrastructure in Rurban Environments

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Trees play a pivotal role in urban green infrastructure, providing various ecosystem services crucial for enhancing the quality of life in urban areas. Conversely, grey infrastructure consists of built-up areas characterized by impermeable surfaces. The interplay between urban green and grey infrastructure influences the overall quality of urban life and the ecological value of urban spaces. However, the conventional dichotomy of separating urban and rural contexts is inadequate for comprehensive assessments in rapidly urbanizing Global South regions.

This study presents an unsupervised remote sensing-based approach to categorize the complexity of green and grey infrastructure in rurban environments. Using Bengaluru, India as a case study, we integrated 3D information and identified five distinct categories that describe the composition and configuration of green and grey infrastructure. Our approach offers a quantitative characterization of these rurban configurations, providing valuable insights for effective planning and management of rapidly urbanizing regions. By bridging the urban-rural divide, our methodology facilitates a comprehensive understanding of the intricate relationships between green and grey infrastructure elements, contributing to the sustainability and livability of urban environments.

Unveiling the Swedish Urban Forest's Hidden Treasures: Decoding Forest Owners' Mindset towards Uneven-Aged Forestry.

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Sweden is characterized as having a worldly renown forestry model that goes back to the mid-1800s since the creation of the Swedish forestry act. The purpose of this law has changed through time – from a production perspective to a more holistic approach that is conscious of the impact that the forest sector has on society, nature, and climate.

Different forest management methods have been proposed in the last decades, with clear-cutting being the most popular one up to date. However, there is interest in looking for alternative management solutions if we are to meet SDGs, biodiversity goals, and solve climate change. Methods such as Continuous Cover Forestry have gained the interest of various stakeholders in Sweden, as a way to preserve forests with the premise of having a productive forest land while protecting biodiversity.

This research intends to provide updated information on uneven-aged forest management methods available in Sweden. Specifically, identifying the challenges of implementing techniques such as Continuous Cover Forestry in Urban forests, while understanding the behavior of both forest owners and visitors. The project consists of different stages with the first one being to identify which methods are currently being used in Sweden's urban forests. The later stages seek to interview both forest owners and visitors to find valuable insights that can support the transition to an uneven-aged forestry model.

This study addresses the challenges surrounding the analysis of urban forests in the Swedish context, specifically focusing on the pressing need for a unified and specific definition of the term "urban forest." Our findings aim to shed light on the dynamics of forest ownership observed throughout the country, while also providing valuable recommendations for effectively integrating various management approaches to enhance the recreational value of urban forests.

Urban trees under drought: stem growth monitoring in two temperate cities with contrasting climates

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Urban trees are usually associated with the increasing quality of life in the cities, in particular, when they grow old and healthy. The ecosystem services that urban trees provide can help mitigating the urban heat island, reduce air pollution and contribute to lower the steady rising global temperatures of the last decades. At the same time, urban trees suffer from the climate change conditions of more frequent heat waves and drought events, causing changes in tree growth and therefore quantity of ecosystem services. To better manage and plan sustainable cities, changes in growth must be precisely assessed. In this study, tree growth and drought response of commonly planted urban tree species *Tilia cordata, Acer platanoides* and *Robinia pseudoacacia* are analysed in two temperate German cities: Munich and Würzburg by using dendrometer and dendrochronological data. Dendrometer data have been collected in ten different locations among the two cities since 2018, while we used increment core data of over 100 trees for the City of Munich. Growth trends and ecosystem services linked to the urban climate and to drought are analysed by linear mixed models, considering the development over the years, as well as within years, e.g., to link the length of the growing period with the seasonal climate. First results show species-specific growth trends during and after the dry years 1992, 2003 and 2015; as well as differences linked to growing location (urban vs. suburban) and analysed period of growth (1980-1999 vs. 2000-2019). Significant better growth was measured for *A. platanoides* and *T. cordata* in suburban areas, while *R. pseudoacacia* did not show strong differences linked to the growing location. Significant lower growth after the year 2000 was observed for *R. pseudoacacia* (over -40%) and *A. platanoides* (-36%) compared to the twenty years before, indicating a negative effect of recent climate change for these species. Combining these dendrochonological and dendrometer data as well as different data resolutions can increase the quality of monitoring of tree response to the urban climate during climate change.

Using airborne laser scanning data to assess the number of trees visible from the window

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: In the urban space, highly transformed by man and with a substantially reduced natural areas, people have limited opportunities to interact with nature. Therefore, each, even seemingly shallow, interaction with the living world takes on a special meaning. One of the examples of possible everyday interaction with nature in the city is experiencing/observing it through the window. Research clearly shows that the presence of nature in the window view, in particular trees, significantly increases the level of satisfaction with the place of residence and general well-being, and also promotes faster recovery (see the '3-30-300' rule).

The aim of this study was to assess the provision of aesthetic experiences and opportunities promoting health, recuperation or enjoyment through passive interaction with urban trees from the place of residence or work. An indicator dedicated to the local scale and local spatial planning was developed, showing the number of trees visible from the windows (5 m facade segment) on the top floors of buildings. To calculate the indicator, LiDAR-derived high-resolution digital elevation and terrain models were used, as well as vector layers of buildings and tree crowns. The preliminary analysis was performed for all residential and commercial buildings located in six selected housing estates in Warsaw, Poland: two tenement, two single-family and two large-scale multifamily.

The mean number of visible trees ranged from 8 in the tenement housing in the downtown to 277 in the large-scale housing estate on the outskirts of Warsaw. The obtained highest number of visible trees per window was 906, however, in every housing estate except one, windows located on the top floors of buildings, from which no trees were visible, were recorded.

It can be concluded that the use of trees to generate aesthetic experiences and promote health, recuperation or enjoyment is the highest in large-area housing estates, slightly lower in single-family housing estates, and the lowest in the areas of tenement housing. Nevertheless, the high variability within these residential types indicates that the land use in a given neighbourhood, related both to buildings and greenery, can substantially affect access to this ecosystem service.

"Quantifying Private Urban Trees: A Study of Berlin's Hidden Greenery"

T4.31 Urban trees & green landscapes: Monitoring and management for providing multiple services

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Abstract: Berlin is renowned for its greenness and abundance of trees, which provide a multitude of essential ecosystem services and significantly enhance the urban experience. Trees in public spaces, i.e. streets and parks, are regularly catalogued in a database and are thus well-documented.

However, the number of trees on private property and their development over recent decades remains largely unknown. These areas include private property owned by individuals and housing cooperatives, as well as allotment gardens and other private land. The inclusion of this significant number of trees is crucial for urban planning and management.

Our study aims to address this knowledge gap by quantifying the total number of trees and their coverage in private spaces, and by examining changes that have occurred over the past two decades.

Since 2005, aerial surveys have been conducted at regular five-year intervals to evaluate the condition of Berlin's urban trees in public spaces. The digital imagery is freely available and forms a robust database for our analyses. Concurrently, deep learning approaches have made significant advancements. Techniques such as DeepForest now enable large-scale segmentation of tree crowns using high-resolution aerial imagery. Our study applies this algorithm to digital aerial images from 2005 and 2020 to address our research question. We will present the results of our study providing deeper insights into the entirety of Berlin's urban trees. Our analyses are supported by a large number of validation and in-situ data.

T4.32 Valuation of water and biodiversity co-benefits in carbon forestry schemes

Creating investor value from forest landscape restoration through integrating carbon, forest products, water, biodiversity and community benefits

T4.32 Valuation of water and biodiversity co-benefits in carbon forestry schemes

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Abstract: Markets for forest-based mitigation activities to meet emissions reduction targets are driving significant investment in landscape change through afforestation and other forms of landscape repair. However, concerns about the integrity of sequestration outcomes and a desire to contribute to other sustainable development goals such as improving water, biodiversity and local community benefits, are placing greater attention on the potential value of these co-benefits for carbon projects investors.

This paper explores different ways in which the value of these co-benefits is being captured for private sector investors using examples from forested landscapes, including those developed by the Landscape Finance Lab. This same methodology is being applied for landscapes in other habitats such as peatlands and river systems. This innovative funding approach bridges the gap between investors and land managers by supporting practitioners and investors to incubate sustainable landscape solutions that will generate impacts at scale and restore watershed functions or protect threatened biodiversity. Good project design is critical to avoid perverse water and biodiversity outcomes from climate mitigation investment. This begins with structuring landscape investment portfolios and investment vehicles and building blended finance models drawing upon different sources of finance: philanthropic, impact and full commercial. Suitable tools, guidance, training and knowledge are required to value different benefits and share this value equitably among project partners, value chain participants and stakeholders across the target landscapes. Effective tools for assessing value will be described including a landscape scorecard and the '4 Returns Framework' methodology that provides a common language and practical instrument to halt and reverse the losses from landscape degradation and stimulate thriving landscapes and communities at scale. A key shift is to move beyond valuing specific returns on a per hectare basis to generating multiple returns at a landscape scale.

Impacts of co-benefit accounting for nature-based project in voluntary carbon markets: examination of risks and benefits

T4.32 Valuation of water and biodiversity co-benefits in carbon forestry schemes

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Abstract: Voluntary carbon markets (VCMs) are an important tool for achieving climate change targets and are expected to rapidly scale-up over the next decade. Nature-based solutions (NBS) are among the most cost-efficient means of producing the mitigations that VCMs trade as credits and represent a growing proportion of market activity. However, NBS projects' impact go beyond mitigations to include so-called co-benefits such as improvements for livelihoods, biodiversity, and water availability and quality. Various VCM schemes attempt to account for these co-benefits. This additional information on co-benefits affects several aspects of VCMs from project design and development to the pricing and sale of credits. However, co-benefit accounting is highly variable across projects and credit standards, creating issues around market information asymmetry and risks to project operations and reputation. This suggests co-benefit accounting can be either a benefit or liability to projects and further refinement of approaches is needed for VCMs.

This research examines different forms of VCM co-benefit accounting and implications for project risk and outcomes as well as how they can be improved. Specifically, it looks at how different co-benefits and associated availability and quality of data affects credit pricing. It further considers how credit pricing impacts project finances and translates to perceptions of project quality. Several NBS, primarily forestry-related, projects at different stages of development were selected to examine. Early-stage projects rely on projections, while more developed projects utilize VCM standards' methodologies for accounting and in some cases, are subjected to third-party credit rating agencies. The research considers how these different approaches impact data availability and quality.

Though preliminary, initial findings generally indicate that the number of co-benefits and robustness of accounting correlates with higher credit prices. Though, the consistency and magnitude of price increases varied across accounting approaches and stages of project development. It further suggests that these projects better manage risks related to securing capital investments, maintaining stakeholder buy-in, and accusations of greenwashing.

Quantification of Co-Benefits by the Agroforestry Carbon Project at Primary Schools in Arid and Semi-Arid areas (ASALs), Kenya

T4.32 Valuation of water and biodiversity co-benefits in carbon forestry schemes

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Abstract: There is a large area waiting for re/afforestation in Arid and Semi-Arid areas (ASALs) in Africa, while majority of the investments are distributed to relatively humid and fertile areas considering the profitability and risks. The lack of sufficient rainfall during the past three years since 2020 has led to the death of 2.5 million livestock and malnutrition among some 940,000 children under the age of five in Kenya (UNICEF 2022). There is an urgent need to mitigate the negative impacts of climate change in those disadvantageous areas. By evaluation of co-benefits, such projects in ASALs can be regarded as more attractive to support.

A pilot carbon project by agroforestry was started in 4 primary schools in South Kitui, one of the driest areas in Kenya in 2023. The schools selected to grow indigenous tree species which shows a high tolerance in limited hydrological environment; Baobab (*Adansonia digitata*) and African Mahogany (*Melia volkensii*) in combination of legume crops such as cowpeas. Young leaves of baobab are used for school lunches as they are rich in iron, calcium and vitamins. African mahogany is grown to supply school desks and chairs that are always not enough for all children. An appropriate planting-harvesting rules as for the carbon project is applied. With the increased water supply and improved land management methods provided, the agroforestry methods including terracing enriched hydrological and nutrition cycles in the soils. The project is expected to enhance resilience and adaptative capacity of the school children and surrounding communities to the changing climate.

The authors will display the quantifiable methodologies to evaluate these co-benefits such as studying hydrological status of soil, crop-diversity enhancement and nutrition improvement of children as well as financial benefits by the project. Their associated SDGs contribution potentials and monitoring methods including day-to-day monitoring by school children will also be shared. In combination with the co-benefit values which is in line with the modality stated in the UNFCCC decision of 18/CP.21 on non-carbon benefit, it will be expected higher valuation as forest carbon projects and will be useful to be diffused to wider ASALs Africa.

The Climate Credit: a new concept to boost and value the interlinked benefits of forest management on carbon, water and biodiversity

T4.32 Valuation of water and biodiversity co-benefits in carbon forestry schemes

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Abstract: In Catalonia, a new voluntary market for Climate Credits is being developed to promote improved forest management (IFM) in private forests. Although inspired by current carbon markets, the Climate Credit market aims to go beyond carbon and beyond tree planting, addressing 3 key forest ecosystem services (ES) in an integrated way: carbon (including fire prevention), water supply and biodiversity. To this end, we have established a methodology for the ex-ante estimation of the impact of IFM on these 3 ES.

Regarding water supply, we assume that forest management, by temporarily reducing forest cover, can increase blue water. We built a new methodology from previous data on exported water values (m3/ha and year) obtained after applying a water balance model (MEDFATE) to the NFI plots. Regression equations were obtained by relating these values to a structural variable that is easy to measure, such as basal area (BA), which is indicative of forest management and correlates well with the leaf area index (LAI). Different equations were obtained as a function of the moisture index (HI) -based on the P/PET ratio- to include variations due to the location of the forest, and of the type of forest (coniferous/broadleaf) to reflect the different responses of the tree species.

Regarding biodiversity, the Climate Credit methodology quantifies *ex ante* the impact that the IFM has on biodiversity. To do so, we chose the Potential Biodiversity Index (IBP) methodology due to its cost-effective and non-expert implementation. The IBP is a proxy indicator of a forest's capacity to support biodiversity, based on field assessment of 10 key structural factors of the forest. It focuses on the stand scale and the ordinary taxonomic biodiversity (not rare or endangered species).

We propose the forestry projects participating in the market are develop from a bottom-up participatory landscape approach. This helps to address the trade-offs between different ES and to have a greater impact by prioritizing forests with a large supply of these ES or at higher risk.

The value of Ecosystem Services: A quantitative estimation from the Kakamega-Nandi Forest landscape

T4.32 Valuation of water and biodiversity co-benefits in carbon forestry schemes

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Abstract: Natural forest ecosystem landscapes are important to human well-being, however, they are not appreciated and hence not considered in public policy decisions and do not receive adequate public support in resource allocations due to the undervaluation of economic contributions to human populations. To ensure justification, it is necessary to value the tangible and intangible values of forest ecosystems. This paper presents the results of the valuation of the monetary value of goods and services provided by the Kakamega-Nandi forest ecosystem landscape in Western Kenya. Primary data was collected from 480 households using structured and semi-structured interviews. Secondary information was obtained from service providers, other published/ unpublished sources and discussions with experts. Market prices, Contingent valuation, Cost-based and Benefit Transfer (BT) techniques were applied in estimating total economic values. Economic benefits generated from the selected forest ecosystem services in the Kakamega-Nandi landscape were about KES 9.1 billion per year (approximately USD 85.3 million). The bulk of the total benefits (48.3% (KES 4.4 billion per year or approximately USD 41 million) was from regulating services with carbon sequestration service forming 47.8% with a value of KES 4.37 billion annually (USD 41 million). The value of regulating and supporting services was estimated to be about KES 4.12 billion per year (approximately USD 41.2 million). The products and services enjoyed by local adjacent communities are about KES 3 billion (USD 28 million). These values are conservative estimates and may vary with changes in the market prices used to make the assessments. The study demonstrated that the forested landscapes provide substantial economic benefits to the local people and people adjacent to these ecosystems. These values can be applied to creating awareness of the importance of forest landscapes and for articulating the incentive mechanisms for local communities to conserve forest landscapes for sustainable flow and benefits of forest ecosystems. Resource managers/planners and policy-makers can apply the estimates in cost-benefit analysis and in support of appropriate conservation decisions. The estimated economic value of the ecosystem services provides a strong rationale for the need to conserve protected areas and the ecosystems they contain.

Towards a Woodland Water Code: encouraging Tree Planting for Water Quality, Flood Risk attenuation and Water Cooling benefits - a UK perspective

T4.32 Valuation of water and biodiversity co-benefits in carbon forestry schemes

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Abstract: As a commitment to ending the UK's contribution to global warming, in 2019 the UK Government adopted a binding target of achieving 'net zero' emissions by 2050, with an interim target of a 78% reduction by 2035 set in 2021. Recognising the need for land use change to help meet these commitments, the Government aims to treble tree planting rates in England by 2024, with woodland expansion targets to increase woodland cover from 15% to 24% in Wales, and from 17% to 25% of land area in Scotland by 2050. The aim is to plant an additional 30,000 ha of UK woodlands (90 million to 120 million trees) each year by 2025.

Government support for woodland creation includes funding in England to promote tree planting and underpinning research and development from a £750m Nature for Climate Fund. Drawing upon the pioneering example of the UK Woodland Carbon Code (https://woodlandcarboncode.org.uk) introduced in 2011 to underpin investment in woodland creation for carbon sequestration benefits – and widely viewed as very successful, there is increasing interest in developing a novel Code to cover water-related benefits of woodland creation. One of the Nature for Climate Fund projects led by Forest Research aims to develop a Woodland Water Code as a crediting mechanism covering water quality, flood risk attenuation, and water cooling (aquatic habitat) benefits.

This paper outlines recent progress on the new Code, including creating look-up tables quantifying the water benefits, developing methods and rules that fit well with those under the UK Woodland Carbon Code, and facilitating stacking carbon and water benefits while ensuring additionality. The paper traces the origins of the initiative to develop a Woodland Water Code building on the findings of the PESFOR-W COST Action - a network of researchers and practitioners from 40 countries interested in woodlands for water Payments for Ecosystem Services led by Forest Research. We conclude by describing next steps prior to the planned launch of an initial version of the Woodland Water Code covering water quality benefits in early 2025.

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

A novel indicator-based approach for capturing the multiple community-forest relations in a Canadian context

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Forest-based communities share intricate complex relations marked by their attachments to the forest environment. The notion of sense of place identifies the social and natural components that forge these relationships, and the modalities of attachment to the forest biophysical environment. Sense of place research considers that a forest territory encompasses socio-natural dimensions that are difficult to separate and cannot be captured in isolation. Results from this literature also emphasize that natural dimensions such as the biophysical environment as well as social interactions are equally important for feelings of well-being and quality of life linked to attachment. Sense of place studies have thus shown that multitude of values, embedded in a territory, can characterize the community-forest relationship.

In Canada, national-level sustainable forest management (SFM) criteria and indicators aiming at describing the state of forest-based communities are mostly driven by economic values. There are two main limits to this preponderance of economic values in the conceptualization of SFM criteria and indicators for forest-based communities. The first is that it offers a limited comprehension of forest-based communities attributes. The second is linked to the context of climate change. Forest communities are undergoing complex socio-ecological changes that jeopardize the multiple values (not just economic) associated with the forest. The impacts of mountain pine beetle and spruce beetle epidemics, drought and increased forest fires have been well documented in the Canadian context.

This presentation highlights a new method that captures a wide range of forest-related values to better characterize community-forest relationships at a national scale. Using indicators developed with a combination of socio-economic census data (Statistics Canada) and geospatial data, it is possible to better capture the cultural, social, economic, and traditional values associated with the forest. The clustering analysis performed with those new indicators allowed to identify six types of forest communities. Analysis of the vulnerability of these six types to climate change demonstrate the relevance of innovative approaches to SFM criteria and indicators.

Balancing Sustainability and Legal Frameworks: Resolving Conflicts at the Urban-Rural Frontier caused by Urban Expansion in Sweden.

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: The development and implementation of alternative forest management methods in rural areas with extensive forest land have received significant attention. The Swedish government recognizes the importance of exploring different approaches to forestry and the management of Ecosystem Services in order to achieve Sustainable Development Goals. Our research argues that it is crucial to focus on urban areas as well, especially on the border between urban and rural forests. This area serves as a perfect example of how growing urbanization can impact forest management and the challenges faced by forest owners in an urban context. Therefore, we conducted an analysis of the Swedish legal framework to assess the country's preparedness to address these governance challenges that will inevitably arise as populations and cities continue to grow.

As cities expand, conflicts arise between individual forest owners and urban forest owners, as municipalities encroach upon rural forest areas over time. The Swedish law of free access raises expectations regarding the preservation of recreational values on forested lands and with that higher expectations towards forest owners. This analysis challenges the notion of seamless integration between cities and nature, highlighting the tradeoffs that occur when both cities and urban forests expand. It also presents opportunities to maximize recreational values by adopting a different approach to forestry compared to the traditional methods used in non-urbanized forest lands.

This research emphasizes the need for city planners and the government to reconsider the way cities grow in order to avoid future governance issues. An alternative solution would involve adapting the Swedish law to effectively address these forthcoming challenges.

Beyond bio-physical inventory: human dimensions to plan for sustainable forestry

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Forest inventory has in various countries long and strong traditions and offers a wealth of information to infer forest conditions, from the property to the national level. Also, much thinking has been placed on the need and the possibilities to harmonize forest inventory data across political boundaries to facilitate regional initiatives advancing sustainable forestry. However, the human dimensions of forests, reflecting on the people who depend on, and whose actions are shaped by and shape forests, are crucial for understanding the larger set of drivers steering forest conditions as well as well-designing forest policy. Despite efforts of integrating socio-economic and biophysical data, the systematic forest inventory programs are in many countries not paralleled by data gathering of human dimensions or data are not gathered in conjunction. These limitations have several consequences. First, in many countries, the forest landbase is divided between ownership types whose strategies and management objectives vary widely. Management objectives and forest conditions may have two-way causality, making localized socio-economic and biophysical data integration necessary to infer relations. Without such information, there is a risk that the effectiveness of policies will not reach the desired goals. Second, forest conditions and forestry change due to multiple sources. Climatic factors amend the biophysical base while policies to support sustainable forestry, a green bioeconomy, and climate mitigation and adaptation are constantly developing at the same time as forest owners' attitudes are evolving. In order to advance complex objectives related to socio-economic wellbeing and forest sustainability, more data to draw substantiated links between the bio-physical and human factors are needed. At its core, forest planning whether at a property, national or global scale is intrinsically a human-centered process, and inclusion of socially-inclusive and representative data a necessity for driving sustainable forestry. We compare the biophysical-human forest inventory data gathering across countries, point to gaps and suggest steps to help our current generation of researchers and practitioners meet the needs and expectations of the future.

Exploring conflicts over forest futures: Methodological reflections on interweaving conflict analysis and conflict management

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Forests are currently undergoing unprecedented change. Against the backdrop of climate change and its manifold negative impacts on forests, conflicts on how to manage and conserve these ecologically, economically, socially and culturally significant landscapes in the future are intensifying. A deeper understanding of how different stakeholders envision the future of forests could contribute to addressing this issue.

In our presentation we show results from an inter- and transdisciplinary project on cooperative processing of forest-related negotiation processes in the context of climate change in Germany. In particular, we investigate the relation between future imaginaries and (un)certainties in negotiation processes about forest futures. By means of ethnographic fieldwork in two local case studies in Germany, we elaborate on how actors from forestry and nature conservation imagine forest futures, which forest-related (un)certainties they perceive, which practices they use to counter (un)certain forest futures and to what extent these aspects have an impact on the negotiation processes.

In our contribution, we will present first results from the constructive dialogues with relevant stakeholders and the application of formats such as roundtables, focus groups and conflict mediation. The conflict dynamics in these dialogues will be examined from an anthropological perspective. For this purpose, we conduct participant observation and in-depth interviews.

Our contribution will focus on a methodological reflection to discuss the potentials and challenges of interweaving conflict analysis and conflict management. This reflection is important in order to show to what extent transdisciplinary approaches can be fruitful in this context and to provide inspiration for upcoming research projects on forest futures.

Forests are also good to think with: the pluriverse and anthropology's methodological legacies

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Ways of being pluralist are becoming popular in discussions of environmental matters – 'multiverse', 'polycrisis' and 'pluriverse' being just three examples. At the same time, sustainable futures, though locally experienced, are highly dependent on global processes. This acknowledges that environmental damages and responses to them involve a single arena of activities and processes. But does this require a correspondingly uniform epistemology for ensuring its sustainable management? I propose it does not, based on an anthropological methodology that constantly travels between the proximate (or local) and the distant (or global).

Drawing from anthropological approaches to humans in their environments, I focus my discussion on what Arturo Escobar has popularised as pluriversal thinking as a methodological principle for research on forests and people. Above all, pluriversal thinking affirms ways of knowing that have been marginalised in modern times, and it foregrounds the 'radical interdependence of all that exists'. The level of holism that this implies has troubling implications for western epistemological practices and institutional structures, based as they are on historically constructed but often black-boxed notions of specialist expertise. When it comes to forest-proximate populations however, the critical comparative outlook embedded in the concept of pluriverse is quite good at producing evidence of (supposedly) non-modern or pluriversal ways of knowing even in unlikely places such as Finland, where people are committed in general to modern identities and, on the whole, modern science, including its black boxes.

As a methodology, the pluriversal approach can be elaborated as a derivative of anthropological ways of exploring knowing, doing and feeling, all at the same time, and adapting a point that anthropologist Claude Lévi-Strauss made decades ago: "animals / things / forests are good to think with". Perhaps this is particularly the case when the thinking involves complex problems with multiple and complicated drivers and indeterminate points of origin.

Forests as providers of cultural ecosystem services – an arts studies perspective

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: How nonhuman nature influences human creativity has been a much studied topic within the environmental humanities, resulting in conceptualisations such as *ecopoetics*, *storied matter* and *nonhuman agency*. Interestingly, nature's contributions to cultural creations are nowadays also acknowledged within environmental policy via the ecosystem services (ES) framework. Cultural ecosystem services (CES) are defined as the nonmaterial benefits people obtain from ecosystems (MA 2005). While the concept of CES emphasises interconnection between natural and cultural processes, the CES approach has raised little interest within the environmental humanities. This is lamentable, since environmental humanities scholarship is acutely needed to analyse and communicate the importance of nature's contributions to cultural practices and ideas.

In my presentation I ask, how the idea of forests providing cultural inspiration appears in current Finnish art and environmental policy. I will first provide a review of recent research on CES, and then proceed to the case study, consisting of two types of data: Finnish contemporary forest poetry, and Finnish governmental strategies concerning forests, biodiversity and ecosystem services. With a thematical analysis of the strategies and an ecocritical close-reading of the poems, I will demonstrate the ways inspirational services of the forest are acknowledged in the data. After the analysis I will discuss the applicability of the ES framework in addressing the inspirational value of forests in environmental policy. I suggest that despite of its problems, the ES framework has potential as an exercise in communicating even the most private, experiential-inspirational meanings and values of forests.

Integrating Physical and Social Variables to Enhance Understanding of Urban Forestry key-Indicators: Insights from a Socio-Cultural Forest Monitoring

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Urban forestry plays a crucial role in enhancing urban residents' well-being and providing essential ecosystem services. This study integrated physical and social variables to comprehensively understand socio-cultural indicators related to urban forestry. Key indicators examined included visitation frequency, recreation satisfaction, scenic beauty, forest care and management, and the feeling of health. Data from Switzerland's 3rd socio-cultural forest monitoring survey were utilized.

A public-participation GIS module allowed respondents to map their frequently visited forest recreation spot. They were then surveyed about visitation motives, infrastructure and forest preferences, and the meanings associated with their chosen location. Physical forest characteristics and relevant infrastructure aspects were considered as variables and intersected with mapped coordinates for regression models.

Results revealed significant relationships between the implemented variables and "scenic beauty," "recreation satisfaction," and "forest care and management." Variables like "visitation frequency" and "feeling of health" were accurately predicted. These findings highlight the importance of incorporating non-ecosystem services, such as landscape and forest meanings, in future urban forest monitoring. These variables particularly demonstrated strong explanatory power for aesthetic attributes.

Successful urban forest monitoring initiatives should consider ecological and socio-cultural aspects. Recognizing the meanings people attach to urban forests enables policymakers to align strategies with community preferences and enhance residents' experiences. Findings also inform forest management practices, promoting visually appealing and sustainable urban forests.

Furthermore, these results have implications for ecosystem services provision. Prioritizing socio-cultural indicators like scenic beauty and recreation satisfaction leads to a holistic approach to urban forest management. Urban forest policies that consider socio-cultural dimensions better meet diverse needs and values, resulting in healthier and vibrant urban environments.

In summary, this study emphasizes incorporating physical and social variables, including landscape

and forest meanings, for a comprehensive understanding of urban forestry's socio-cultural indicators. Considering these factors in urban forest policy and management facilitates the creation of sustainable and inclusive urban forests that promote human well-being and ecosystem services.

Knowledge co-creation and co-research in social scientific natural resources governance studies

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: By applying action learning via knowledge co-creation and co-research methodologies, I have studied natural resources governance with my research group and our inter-action partners in Global North and Global South. During our different research projects, we have generated a set of novel research methods during real-time co-creation of social innovation rooted in principles of reciprocity. While social innovations are co-created through action research case studies and via "going back" method, we have implemented the following tasks: 1) Co-creation of knowledge through pre-study or fact finding missions, in-depth interviews and World Café workshops; 2) Development and implementation of a "going back" method with co-researchers through participant observation, autoethnography and field research diaries 3) Processing of co-created knowledge through participatory workshops, course series and writing workshops. Yet the current natural resources governance studies have underestimated the power of co-creation and active role of inter-action partners in social innovations and collaboration. Natural resources governance does not mean strict control of all areas of life, nor does it require accurate information about future changes, but rather implies a flexible, responsive and adaptive governance model and social learning. The key question in this paper is how us as researchers could support collaborative and deliberative natural resources governance via our research approaches such as action research, co-creation and co-research.

Negotiating the understandings and impacts of the ecocrisis in forest dialogues

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Eeva Houtbeckers, D.Sc. (Econ.&Bus.Adm.), is a scholar-activist working on sustainability transfornations. As part of their postdoctoral project (2017–2022), Eeva volunteered for a citizen forest movement that organized forest dialogues with various forest related stakeholders in Finland. Eeva's work in the field of human-forest relationship focuses on negotiating the understandings and impacts of the ecocrisis in the forest dialogues and the citizen movement.

Phenomenological approach to the ways of knowing about multiverse of human-forest relationships

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Tuulikki Halla, MSocSci, Forest engineer works as project and doctoral researcher in the Finnish Academy UNITE Flagship Program coordinated by the University of Eastern Finland. In her research, she has contributed the conceptual development of human-forest relationship concept and studies these relationships within Finnish forest practitioners applying interpretative phenomenological method (IPA). She is also a board member of the scientific Human-Forest Relationship Research Club of the Finnish Society of Forest Science. in this T4.33 session, she acts as one of the session moderators.

Research strategy of an interdisciplinary case study when studying the developments in the value creation logic of the forest sector

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Numerous phenomena, such as sustainability challenges and the increasing importance of knowledge and digitalisation, have tremendous impacts on the global socio-economic system. These phenomena affect the dynamic and complex business environment where different actors from various sectors interact with each other. Responding to the phenomena and changes in the business environment pressurises established business sectors, such as the forest sector, to reconfigure their networks and value creation logic, i.e., the ways how actors perform value-co-creating activities.

In this dissertation, I investigated how the value creation logic of the forest sector is changing when entering the sustainable circular forest-based bioeconomy. The research design followed a qualitative theory-guided interdisciplinary case study strategy. I analysed scientific and non-scientific documents to determine the past and currently occurring adaptations within the forest industry's value creation logic. I conducted interviews to identify the possible future value creation logic of forestry service providers and the readiness of forest owners to respond to the occurring changes.

According to the findings, the forest sector's value creation logic is incrementally changing towards holistically sustainable, collaborative and cross-sectoral value co-creation logic. The sector has been able to reconfigure its networks and value creation logic in the past and it seems that the sector's actors have understood the importance of cross-sectoral collaboration and intangible resources in the sustainable value-creating activities. They have acknowledged that their attitudes and actions will affect the future value creation within the sector. To reach holistic sustainability, all actors within the sector need to consider the whole forest ecosystem as a capital and a resource base from where value and benefits for the common good are co-created in a forest-based sector.

Roundtable organisator / Spatial frames regarding forests, future and society

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Maija Halonen, PhD, Human Geography, is a postdoctoral researcher in the Department of Geographical and Historical Studies, University of Eastern Finland. She is an organiser of the T4.33 Roundtable. Halonen is currently conducting research on Sixth Cycle in the Periphery – financed by the Kone Foundation (2020–2024). In her research, she has contributed to the understanding of relations between sustainability transitions, forest peripheries, and socio-economic development. She is interested in different spatial frames through which people approach the forests, future, and society. Halonen is also a board member of the scientific Human-Forest Relationship research club of the Finnish
Society of Forest Science

Roundtable organizator/biography

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

Annukka Näyhä[1]
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Abstract: Annukka Näyhä holds a Ph.D. in Corporate Environmental Management and a MSc. degree in Biology. She works currently as an Academy Research Fellow at Jyväskylä University School of Business and Economics (she is on leave from senior lecturer position 2021-2026). Her research interests include the transition to the circular bioeconomy; forest-based sector; sustainable, collaborative business models; strategic change management; and corporate foresight and future studies. Her ongoing Finnish Academy research fellow project
(https://www.jyu.fi/jsbe/en/research/projects/busut)
aims to answer the question of how the sustainability transition could be facilitated by future-oriented collaborative business models. The project is designed to respond current major societal challenges – the lack of sustainable, shared value creation, participative foresight and aligned efforts to advance transition – both in forest-based sector and in other natural resources-based sectors.

AnnukkaNäyhä is an organiser of the T4.33 Roundtable.

Stakeholder views on the future of Finnish forest utilization and new wood-based products

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: Forests are an integral part of the Finnish society and culture. Still, the human-forest relationships in Finland are diverse, as all individuals have their own forest-related values and attitudes that fluctuate over time. It is generally understood that in the transition from our current fossil-based economy towards a sustainable circular bioeconomy, forests, wood and wood products play a key role. Especially novel, innovative products could be a part of the solution. However, there is not one universal, shared vision of the future of the Finnish forests and their utilization. Exploring the future visions of different stakeholders is crucial in creating consensus and supporting collaborations between various actors towards a sustainable future. The aim of this study is to explore i) how forests and their utilization is currently perceived in Finland, ii) what are the desired futures related to forest use and what are the pathways to these futures, iii) what is the perceived role of new and emerging wood-based products in the sustainability transition. To this end, we interviewed 65 stakeholders along the forest value chain and networks in Finland. Moreover, Finnish media sources were analyzed to comprehend the public discussion on how forests are perceived in the society and how the new wood-based products are presented in the discussion.

The preliminary results show that forests are perceived through various lenses depending on the stakeholder group in question, and the visions of the desired future for Finnish forests differ. By some stakeholders, forests are primarily seen as a source of raw material, income and employment, but others see them mainly as biodiverse ecosystems or targets of conservation efforts. Still, novel wood-based innovations are in general believed to have high potential in the future bioeconomy. In order to create a shared understanding of the future of Finnish forests and to support the sustainability transition, more collaboration is needed.

This study is a part of the "Future-oriented collaborative business models as a remedy for the sustainability transition: Finnish forest-based sector as an empirical arena for the creation of a transition framework" project funded by the Academy of Finland, project no. 340756.

The role and possibilities of Finnish forest nature in the Finnish social and health service system

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

Kati Kiiski[1]
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Abstract: Many of the human physical and mental health challenges probably stem from our alienation from our natural environment. Alienation from nature and health challenges are part of the wicked problems we live in the midst of. At the same time, our social and healthcare system is in crisis.

There is some national and international research on the health and well-being effects of nature. The effects have been shown to be mostly positive. Harnessing the health and well-being effects of Finnish forest nature as part of the Finnish field of social and health services and increasing the well-being of the population has not yet been implemented on a large scale.

However, the concept of planetary well-being and planetary health has emerged in Finland recently. Intervention studies investigating the health and well-being effects of nature have been ongoing for ten years. With the help of these, the applicability of the services from the point of view of individuals (and certain customer groups) has been investigated, and the experiences of the target persons (customers) with nature-based services have also been studied. More research is still needed on this whole to assess how Finnish (forest) nature can be suitable as an effective part of the Finnish social and health service system.

The ongoing research project investigates the effectiveness of nature interventions in the rehabilitation of people who have experienced a brain stroke. My role in the research is to investigate professionals' perceptions of the suitability of nature interviews for rehabilitation.

The implementation of services occurring in nature as part of social and health services solves ongoing wicked problems from the perspective of sustainable well-being. It is an interview study based on which the aim is to find solutions for promoting sustainable well-being through structures.

The strength is in diversity. Qualitative methods as trespassers between disciplines in forest research.

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

Stephanie Bethmann[1]
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Abstract: New theoretical perspectives and empirical challenges have stirred discussions about “new ways of knowing and studying forests and our interactions with them”. In this endeavor, there is much to be gained from considering the immense variety of methodological “schools” in diverse disciplines and adapting these to new, transdisciplinary contexts and questions. Based on an (SSK) analysis of qualitative research practices in sociology, and reviving the integrative impetus of Grounded Theory, I rethink qualitative methods as ideal trespassers between the disciplines. These trespassers provide new angles on the research problems that we articulate, but also come with challenges of (epistemological) translation.

Transformative Research and Methods for responsible forest resource management

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

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Abstract: In this presentation, I will present different possibilities for doing transformative research from a geographical perspective. Some initial questions are covered, starting out with considering time and spatial scale as important point of departure for discussing issues of sustainable development and climate change for instance. The key question here is how we can produce knowledge that is relevant and will create the desired impact as soon as possible at every geographical level. Following on to that is how do we identify leverage points to make recommendations policy-relevant and effective for quick implementation at the desired level (industry level, public level, and individual level)? what research practices for transformative research will be best at different geographical and political levels, and how can local knowledge and practice inform organizational changes on other administrative levels in order to increase the value-added of the forest in terms of its contribution not only to the bio-economy in a traditional sense but also in more innovative and explorative ways?

‘Ways of Knowing about a Multiverse of Human-Forest Relationships’ session organizer

T4.33 Ways of knowing about multiverse of human-forest relationships: methodological approaches for sustainable futures for the forests

Eeva-Lotta Apajalahti[1, 2]
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[2] Human-Forest Relationship Researcher Network

Abstract: Eeva-Lotta Apajalahti, Dr.Sc. (Econ. and Bus. Admin) is an Assistant Professor of Energy and Society at LUT University, Finland. She is a member of the human-forest relationship research network in Finland and is interested in various ways of doing research on the human-forest relationship, human and non-human relationships, and the affects of wood cutting. She is currently doing research on energy transition, societal impacts of energy systems change and renewable energy, as well as system interlinks of energy, transportation, and food sectors. With the roundtable session in IUFRO, she is expecting inspiring discussions on different ways of knowing and doing forest research.

T4.34 Work and employment in the forest sector: challenges and opportunities

Climate-Smart Forestry Education for Livelihood and Sustainability in South Africa (FOREST21)

T4.34 Work and employment in the forest sector: challenges and opportunities

Tatenda Mapeto
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Abstract: In South Africa, the forestry sector is critical for livelihood development, given the youth population bulge, high unemployment rates, the need to address global sustainability challenges and the potential of forestry to advance South Africa's National Climate Change Adaptation Plan. Higher Education Institutions (HEIs) should therefore naturally take a lead in preparing graduates to create sustainability-aligned economic opportunities. There is however a substantial discrepancy between what the forestry industry in South Africa sees as the key skills for future foresters, and what is being taught in HEIs offering forestry education. In 2019, a project (FOREST21) to develop and improve the constrained capacity of South African HEIs to prepare professional foresters of the future that can sustainably leverage forestry for livelihood development was conceptualised. The FOREST21 project is co-funded by the Erasmus+ Programme of the European Union and comprises five HEIs in South Africa and three HEIs from Finland and Norway. The project which is running from 2020 to 2024 seeks to promote climate-smart forestry and entrepreneurial innovativeness in forestry education that will lead to job creation as well as mitigation of climate change. FOREST21 is implemented through reforming the curricula in forestry education to equip graduates with problem-solving skills, an entrepreneurial mindset and climate-smart thinking. Problem-based learning (PBL) methods and students-centred teaching are the core of the project. Students learn through solving real-life business challenges in the field in international teams. FOREST21 is built on close collaboration with the industrial sector as well as academics and the managerial staff in partner HEIs. This paper presents the workings of FOREST21 by examining some of the educator and student development workshops and student challenges that have been part of the project. Opportunities and challenges encountered in the development of innovative approaches to develop 21st century foresters through the project's mechanisms are expanded. The future of South African forestry education in moving from teacher-centred knowledge sharing to knowledge co-creation through discovery as essential for climate smart forestry, mainstreaming climate issues in core courses and developing graduates that can leverage this knowledge for developing, exploiting, and growing sustainability-related forestry opportunities are discussed.

Current situation and future issues of forest-related work by persons with disabilities in Japan

T4.34 Work and employment in the forest sector: challenges and opportunities

Takuo Nagaike[1]

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Abstract: Sustainable Development Goals (SDGs) aim to realize a sustainable, diverse, and inclusive society that leaves no one behind. The forest and forestry sector can contribute in order to achieve the many goals of the SDGs. Forest-related workforce as a decent work could contribute the goals, In Japan, compared to agriculture-welfare collaboration (AWC), forest-welfare collaboration (FWC), which was forest-related work by persons with disabilities, has only just begun. In promoting FWC, I clarified the current situation and future issues of FWC in 47 prefectures in Japan. For industry types of FWC, mushroom cultivation was the most common, followed by woodworking. There is no correlation between the number of workplaces for AWC and that for FWC. As an exception, Mie Prefecture, where forestry is active in Japan, had the highest number of both AWC and FWC. FWC is the "main task" of the Forestry and Forestry Management Division of the Mie government office. Most of the welfare workplaces was mushroom cultivation and woodworking, and producing broad-leaved tree seedlings was also raised. In Nagano Prefecture, which belongs to the cool temperate zone, although AWC was moderate, FWC was high. In addition to that, there was a lot of production and sales of firewood. There were also activities that took advantage of the characteristics of the prefecture, such as processing deer-related products and cultivating medicinal plants. In other prefectures, conifer seedlings were also produced in FWC (Hokkaido, Akita, Yamagata, Oita, and Miyazaki), as progressing reforestation and labor shortage in Japan.

Governmental collaboration through vocational training for nature conservation and forestry

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: In Sweden, the Swedish Forestry Agency, The Swedish Public Employment Service and the County Administrative Board have a long tradition of working together to combine vocational training and nature conservation. This presentation will detail the working mechanisms and success factors for a sustainable collaboration that moves people into employment, meets the European commitments of nature conservation, and supports public health and the integration of newly arrived in Sweden. It draws on a three-year evaluation of the program that included a mixed methodology of in-situ participant observation, interviews with trainees (n=29), working groups leaders (n=5) and stakeholders (n=5) as well as surveys with validated questioners for trainees (n=214). Through this collaboration, the organisations support each other in achieving their goals. The Swedish Public Employment Service provides trainees to the vocational program, the County Administrative Board is responsible for planning the nature conservation tasks and the Swedish Forestry Agency carries out the practical tasks of nature conservation in Skåne/Scania. Altogether, the work covers 350 nature concervation sites and three national parks. The organisations offer training programs for long-term unemployed Swedish residents (24 months), and since 2016, the program is also open to newly arrived migrants (12 months) needing vocational training. The nature-based vocational training includes practical and theoretical courses on nature conservation, forestry and urban green space management. The mixed working groups of Swedish and migrant participants provide social and cultural exchanges which evolve over time, and for the migrants, the work offers scenario-based language learning as well. This long-term organisational collaboration has all the major attributes of a successful partnership structure, such as transparency and effective flow of information across the partners, respect and alliance throughout. However, to maintain and secure the collaboration long-term funding is warranted. A few examples of this long-term and strong governmental collaboration in Sweden exist. Through this collaboration, nature conservation is carried out at regional and local levels so that European-level nature conservation commitments are met, and participants gain a wide range of benefits that can support them in finding future work.

Health and Safety requirements in Forest Stewardship Council (FSC) standards

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: The 2019 'ILO Report for Discussion at the Sectoral Meeting on Promoting Decent Work and Safety and Health in Forestry' highlights that the sector has relatively high accidental rates with notable differences between and within regions. Some Europe countries report that one in eight forestry workers suffer an accident every year, while others report less than one accident in 200 forestry workers / year. FSC certification requires that certified forest management operations "shall maintain or enhance the social and economic wellbeing of workers" (FSC Principle 2 of 10). One of the six criteria under Principle 2 requires that Health and Safety (H&S) practices are implemented, which meet or exceed the ILO Code of Practice recommendations. Regular office audits and consultations with forest workers have to be undertaken by auditors, and workers have to receive regular job specific H&S trainings, and the use of personal protective equipment appropriate to their tasks and use of personal protective equipment is enforced. Beside H&S, workers wellbeing is enhanced through FSC Principle 2 criteria which addresses decent work deficits in areas such as upholding the fundamental rights at work, promoting gender equality, wages paid meet or exceed minimum wages, workers have job specific trainings and mechanisms for resolving grievances and for providing fair compensation are established. In some cases, FSC requirements for risk assessments and better signage of work zones has improved public safety.

Review on research papers show that overall, FSC has proven to be a powerful tool for improving H&S while strengthening workers' rights and working conditions in certified operations. In addition, based on FSC internal analysis of public forest management certification reports, we will show how certification has led to improvement of H&S legislations in some countries, including the provision of better equipment and training, use of safety procedures, and the reliance on properly qualified forest workers. We will also show how and when the research community can efficiently engage in the development of further improved criteria and indicators for working conditions and workers' H&S and safety consciousness.

Is employment in the forest sector automatically a green job? A systematic literature review

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: Employment in environmentally friendly and green economies are potentially green jobs. However, these jobs can only be called "green" if they provide good and decent work. The forest sector performs essential environmental services and manages vital natural resources, therefore is a green economy. But clear evidence about the quality of these jobs is lacking. Is employment in the forest sector automatically a green job? To answer this question, a systematic literature review was carried out, following the Reporting standards for Systematic Evidence Synthesis (ROSES). Science Direct and Google Scholar (first 100 search results) were the search engines utilized to capture topic-related literature written in English, German, Spanish and Portuguese. Only studies reporting employment in the forest sector and green jobs in the American and pan-European regions were considered. After a systematic search, two additional "inclusion criteria" were applied to select the final literature sample. One question aimed to identify (1) if there are indicators to recognize green jobs in the forest sector. Another question sought evidence (2) if there are incentives to foster green jobs in the forest sector. Only the literature fulfilling at least one of the inclusion criteria was considered in this review study.

A total of 43 documents were systematically reviewed and showed that the forest sector has great potential to provide green jobs. An emerging forest sector with cross-sectoral enterprises has provided good jobs in alternative forest-related economies. However, there is no clear evidence that employment in the traditional or emerging forest sector is automatically a green job. At the present moment, no indicators for identifying or assessing forest-related green jobs' quality are available. Forest certification was appointed as a "shade" of green for forestry jobs, because it follows labour standards, ensuring minimal working conditions. It was observed, that political actions aiming at developing rural employment or improving working conditions created jobs in the forest sector. However, no information about the quality of created jobs was available. In conclusion, it is highly recommended to collect data on job quality to design solutions that guarantee increasingly forest-related green jobs.

Mass redundancies in state-owned forest management - is there an impact on private forestry?

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: Estonia is a high forest cover country (53 %, 2.3 million ha) with even public-private ownership share at 51:49. Within last 30 years, reforms of state forest management (in 2008 and 2013) led to mass staff reductions.

Parliamentary elections in 2007 led to re-structuring of the State Forest Management Centre (RMK) in 2008. The main objectives of the re-structuring were to create a more efficient organization and to decrease staff numbers. The entire restructuring process and associated discussions have been highly controversial and emotional. Staff reductions caused 193 forestry specialists and administrative staff had to leave the organization: 140 made redundant, 50 retired, and 3 found other jobs.

Forest management was again re-structured in 2013, when RMK merged the responsibilities of local forest area managers and forest surveyors. As a result, another 23 qualified foresters were dismissed, because they did not hold a certificate of approved forest surveyor as required by the Forest Act.

The presentation introduces the results of a longitudinal study related to the 2013 reductions. The first survey was conducted a few days before the terminations in 2013, where foresters involved were mainly interested in finding alternative jobs in state-related institutions. Only a few foresters intended to establish their own companies or to find an occupation in private forestry. The study also analyses the opinions of colleagues of the foresters made redundant, concerning the potential of finding jobs elsewhere in forestry, of being self-employed, or other options.

Four years after the redundancy in 2017, all the former forest area managers were questioned. The aim was to find what they were doing 4 years after leaving; did they stay in the forest sector or move to other sectors, was there a desire to work in the private sector or to be an entrepreneur, how long did they stayed unemployed, did they participate in any educational programs, would they have done anything differently given knowledge of past layoffs (e.g., 2013) and the likelihood of more in 2017. The final survey is planned to be carried out in 2023, 10 years after redundancy, to find out the long-term impact of redundancies.

Navigating societal transformations: insights from work organisations in the Austrian forestry sector

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: The Austrian forestry sector, like many other national forestry sectors around the globe, has a long tradition of facing societal transformations, and is currently facing them in a more rapid way. These societal transformations include the effects of the climate crisis, urbanisation, migration movements, and social insecurities. Additionally, the public opinion is shifting towards the protection of forests. In turn, this influences the balance of prioritising environmental issues in relation to production in forestry.

As a consequence, work organisations in the forestry sector face the challenge of having to adapt to these new conditions. The aim of this study is to investigate how practices regarding hiring, promoting and valuing the work of their employees are carried out in light of the transformations the sector is facing. By doing so, this study adds to the understanding of how the societal and discursive transformations are understood by the organisations. Additionally, a more comprehensive ambition in this study is to explore whether these shifts have had an influence on gender equality and diversity strategies and measures, both already in place and newly introduced.

This study is based on a series of interviews with representatives of management and human resources of organisations in the Austrian forestry sector as well as a qualitative analysis of policy documents and mission statements of those organisations.

When traditional forestry is challenged, it might shape work, organisations and strategies in different ways. Looking at work organisations, the study connects the basis for their actions, and use of different tools, with their perception of the changes "needed" and their own understanding of the organisations. It additionally looks into the prevalent work identities and into who is impacted by the adaptations of the organisations, and discusses how this relates to potential power relations.

Promoting gender equality and decent work: Cases from the Mekong region's small-scale forest sector

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: The European Forest Institute (EFI) has worked with close to 400 wood-based household businesses in Lao PDR, Myanmar, Thailand and Viet Nam. The main objective of the work is testing solutions to challenges that smallholders and MSMEs face to participate in legal and sustainable timber supply chains. EFI has been working directly with smallholder tree growers, furniture business owners and workers as well as local and national authorities, industry associations, financial institutions, vocational training schools and academia.

EFI has been training micro and small wood processors and tree growers on key technical topics ranging from continuous improvement and occupational health and safety to complying with laws and regulations and improving silvicultural practices. EFI is using a variety of strategies and approaches to support smallholders and MSMEs such as technical workshops, customized coaching, study tours to larger enterprises, on-the-ground engagement of local authorities, policy makers and financial institutions, the establishment of associations, etc.

EFI has been coaching women-led enterprises and strengthening the role of women in tree growing communities and wood-based micro and small businesses. EFI is integrating gender aspects into technical trainings for private sector actors and conducting multistakeholder trainings and workshops on gender. This has generated interest among MSMEs and in some cases empowered women to engage more strongly in the businesses. It has also generated interest among the authorities and industry associations who are now more willing to promote gender equality in the forest sector.

EFI's presentation will share lessons from these strategies distilled from direct observations and reflections in working with tree growers, MSMEs and partners. It will discuss approaches and methods to promoting equality and women's economic empowerment in the small-scale forest sector and improving working conditions and occupational health and safety in wood processing workshops. Finally, the presentation will discuss obstacles and incentives to formalization.

Social sustainability in the forest-based bioeconomy: Challenges from micro-entrepeneurs' perspectives in Finland

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: In the face of increasing environmental challenges and socio-economic pressures, forest-based businesses play an important role in creating well-being in rural areas. At the same time, social sustainability issues, such as poor working conditions, challenges in time management and dissatisfaction, have raised in various forest-based sectors. To increase understanding of such issues, collective action framework has been applied to explain complex interactions of socio-ecological systems. The collective action refers to the actions of a group of people whose goal is to improve their state and achieve a common objective through cooperation and joint benefits.

We investigate social sustainability through the lens of forest-based entrepreneurs in two different regions in South-East and North Finland. A thematic content analysis was employed to analyze qualitative data from forestry, wood transportation, tourism, natural products and heating sector. The results not only increase understanding of incumbent collective action between entrepreneurs, but also present novel practices to enhance social sustainability. In addition, differences between the regions in terms of cooperation and raised social sustainability issues are derived.

Intensive cooperation among diverse forest-based businesses exemplifies collective action and is greatly linked with social sustainability. The relationships of workers and collaborative partnerships between small entrepreneurs and organizations forms a social foundation for forest-based bioeconomy in Finland. More accessible open data provided by forest-related organizations, such as The Finnish Forest Centre, same-sector, and cross-sectoral partnerships are seen as an opportunity to strengthen social sustainability of people involved in forest-based businesses. Collective action framework offers relevant approach to analyze causalities of social sustainability in the context of forest-based bioeconomy.

Soft Skills Training Curriculum for Liberia's Forest Sector Workforce

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: Liberia is a biodiversity hotspot and aspiring leader in community, commercial, conservation, and climate/carbon forestry, as well as One Health coordination. However, the forestry workforce faces major challenges, including poor working conditions, gender biases, and lack of sufficient coordination with other sectors. Integrating soft skills into forestry education will ensure a prepared and resilient workforce. Soft skills are personal, social, communication, and higher order thinking competencies that enable people to work more effectively. Through a collaboration between several Liberian and U.S. institutes of higher education (IHEs), we are building a model national curriculum to provide soft skills training for Liberian forestry students. Our team conducted several forms of assessments of existing training strengths, needs, and priorities for different soft skills. These included (a) interviews and conversations with key informants from government, NGOs, and IHE faculty and administration; (b) semi-structured interviews with leaders and residents in forest- dwelling communities across Liberia; (c) qualitative and quantitative elicitation workshops with faculty and students at University of Liberia and the Forestry Training Institute of Liberia; (d) in-class observations, (e) desk research, and (f) a synthesis Working Group with representatives from multiple sectors. Our assessments found that, while the term "soft skills" was unfamiliar, the underlying concepts were both familiar and widely recognized as critical training needs for Liberia's forestry sector. All stakeholder groups emphasized needs for soft skills to improve national progress in the areas of community forestry, forest conservation, and sustainable livelihoods. The workshops and Working Group found that training modules should be embedded in multiple contexts: forestry classes, training events, and real-world practical contexts. The curriculum rollout process entails presenting a draft curriculum to all stakeholders for review and revision, with a full model in December 2023. Addressing the current challenges and future aspirations for Liberia's forests and people requires an inclusive workforce with strong competencies in leadership, teamwork, cultural sensitivity, communication, conflict resolution, systems thinking, and strategic innovation. Creating a national model soft skills curriculum will facilitate Liberia's IHEs in implementing evidence-based training to build those capacities and ensure the longevity and recognition of the sector's contributions

The establishment of Indigenous forestry cooperative to manage the forestry

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: For the current forestry rejuvenation, it's crucial to develop the value of numerous enterpries in Taiwan's public and private forests. The "Forestry Sustainability and Diversification Guidance Program" was introduced in 2018, and the Forestry Bureau declared it to be "the first year of domestic timber" since 2016. Through the cooperation of expert teams and forestry experts, diversity and friendliness are both essential values to direct forest owners and cooperatives. The majority of the afforestation, maintenance, and management work in Nantou Forest District Office of Taiwan is carried out by contracted manufacturers. Most of the jobs were done by the indigenous people with little wages and the contractors own the actual profits. So, it is important to improve the current operation and management status and provide economic benefits for indigenous people to prevent being exploited by outsourced manufacturers and to encourage indigenous people to manage their own forests and to develop the forest sector. The best stragegy to assist indigenous people to organize and obtain the forest management contract from Nantou Forest District Office is to help them to establish forestry cooperatives. Everyone is the boss in forestry cooperatives, so it will improve the economic conditions of local indigenous people. The purposes of this study is to (1) investigate the indigenous people who are willing to establish forestry cooperatives within the juristiction. (2) Guiding them to establish forestry cooperatives , and assisting in the planning of follow-up operation. (3) Train local people to participate in cooperative operation. (4) Arrange a field trip to exchange experience of peer cooperatives. Literature review, cases study, in-depth and focus group interview were used to establish indigenous forestry cooperative. Finally, the indigenous forestry cooperative was established on May, 2023.

Towards a safer and healthier working environment in forestry

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: Forests provide livelihoods, food and a range of environmental services for populations around the world, including for the at least 33 million people employed in forestry. Despite efforts and some improvements over the past decades, forestry remains a dangerous sector for its workers, who face numerous occupational safety and health risks and hazards. While many of those relate to "traditional" aspects such as use of machines and tools, falling trees, working in remote and isolated locations, and natural and biological hazards, there are changing and new safety considerations in forestry work, impacted by trends in the world of work, such as technological developments, climate and environmental change, and demographic shifts, among others.

In 2022 the International Labour Organization (ILO) included "safe and healthy working environment" in the framework of the fundamental principles and rights at work. This means that all ILO Member States, even if they have not ratified the now fundamental Occupational Safety and Health Convention, 1981 (No. 155) and the Promotional Framework for Occupational Safety and Health Convention, 2006 (No. 187), have an obligation arising from the very fact of membership in the ILO to respect, promote and realize the principles concerning the fundamental right to a safe and healthy working environment.

This paper looks at the opportunities and challenges for promoting safety and health and decent work in forestry in the changing world of work. It will assess the implications of the elevation of safe and healthy working environment as a fundamental right at work to forestry and discuss specific safety challenges for workers in the informal economy, women, and young people, among others. It builds on the joint FAO-ILO-UNECE paper on "Occupational safety and health in the future of forestry work" and is further guided by the ILO's work on the topic, including the process of updating the Code of practice on safety and health in forestry work.

Understanding Diversity in the U.S. Forest Sector: An Analysis of Employee Data

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: Understanding diversity is crucial for sustainability transitions, as employees play a pivotal role in shaping these transitions. Consequently, it becomes essential to examine the participation and potential influence of employees in determining future pathways. While employee data is collected by various organizations to assess risks, impacts, and interdependencies related to representation and well-being, data accessibility remains limited, hindering the establishment of standards beyond individual entities. Furthermore, identifying the producers and users of such data poses challenges due to their scattered and heterogeneous nature.

We explored the diversity of the U.S. forest industry and its sectors based on the North American Industry Classification System (NAICS) to better understand how employee diversity could impact sustainability transitions and identify any opportunities or challenges related to our work. The sectors we analyzed included the forestry and logging, wood products manufacturing, and paper manufacturing sectors.

By focusing on race/ethnicity, gender, age, native- and foreign-born status, and immigration within specific occupations, we highlight the current status and trends on diversity in these sectors and provide evidence on the current state of diversity. We discuss the implications of our findings for achieving the United Nation’s Sustainable Development Goals (SDGs) and informing research and industrial practices. We also provide insight on the implications of diversity and societal vulnerabilities, while also addressing the ethical considerations of existing monitoring systems from an environmental justice perspective.

Who will do the work in the future? : The current status of self-employed forestry contractors in Japan.

T4.34 Work and employment in the forest sector: challenges and opportunities

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Abstract: Although forestry has begun to be known as a growth industry since the 2010s, many problems remain, such as low profitability, working conditions, and occupational injuries. Forestry Agency has held education and support policies for newly employed workers since 2003 to compensate for labor shortages. However, self-employed contractors are not captured even in the statistics.

Therefore the questionnaire research was conducted in West Japan from February to August 2023 to clarify their working conditions and safety measures. As a result, 550 questionnaires have been sent or handed out through forestry self-employed workers' organizations for workers' accident insurance, and 194 were responded to by the end of May; the questionnaire sheet is still collecting. The survey items include years of experience, previous jobs, the scope of work, machinery, client, and safety.

As a result, the median age of respondents is 64 years old, and only 6% of respondents are under 40. Compared with the national aging population rate, self-employed forestry contractors are tremendously aging, the over-65 years old rate in Japan is 28.9% in 2021, and the rate of respondents is 49.5%. Regarding occupational safety, respondents' casualty rate during the past year was 16%, and 5% were hospitalized for more than four days. However, the casualty rate per thousand people of employed workers in forestry in 2021 is 24.7, and it can be said that self-employed workers have more than six times the risk of occupational accidents as employed workers. About 60% of fatal occupational injuries in forestry happened during chainsaw work. Although the Occupational Health and Safety Regulations have required wearing chainsaw protective pants since 2019, 16% of respondents still don't wear protective pants. Chainsaw protective boots are known as high protection, but they are not required. Only 11% of respondents use those, most of whom wear spiky tabi: Japanese split-toed heavy cloth boots or rubber boots, and 47% wear them without tiptoe protections.

In conclusion, many firms rely on the labor of self-employed contractors. However, their problems are grim as no able to replace generations and should be solved by policy support.

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

Machine Learning alternatives to assess individual tree mortality: a performance comparison

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Tree mortality is an important process in forest dynamics and a key component of growth simulations, but the complexity of the effects affecting it makes that process hard to predict. One of the common techniques applied to that field is Logistic binomial Regression (LR), but the increase in the computing power of the last decades promoted a higher popularity of using Machine Learning (ML) techniques, which started to be applied to different forest modelling topics, including the prediction of tree mortality. However, a comparison between them to know their classification ability in that field is lacking. In this work, we compare the performance of the Logistic Regression (LR) as a reference approach to six different ML techniques (Decision Trees, Random Forest, Naive Bayes, K Nearest Neighbor, Support Vector Machine and Artificial Neural Networks) to estimate the individual tree mortality probability. We selected *Picea abies* pure stands established under different plantation and silviculture treatments, comprising 97 permanent plots located at 8 different study areas in Bavaria (Southern Germany). Each tree was studied individually in its neighborhood, and features concerning tree and stand sizes, vigour, growth, competition, density and climate were selected as candidates due to their importance to explain tree mortality. Different feature combinations were used to develop LR and ML models, highlighting the ones which provide better classifications from each technique. Their performance was studied through different metrics (Area Under Precision/Recall Curve, Matthews Correlation Coefficient, Cohen's Kappa Coefficient...) appropriated to deal with imbalanced data sets (8.87% mean mortality rate). Preliminary results demonstrate the potential of ML to assess tree mortality, showing comparable performances to the obtained with LR. Among them, Random Forest showed the
best overall performance. However, even in the cases when ML techniques can provide better predictions, difficulties in their biological interpretation and longer training periods must be considered when those techniques are pretended to be used. When ML techniques don't outperform LR, the interpretation difficulties make those methods less useful.

Aboveground biomass prediction of arid shrub-dominated community based on airborne LiDAR through parametric and nonparametric methods

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Aboveground biomass (AGB) of shrub community in desert is a basic quantitative characteristic of desert ecosystem and important index to measure ecosystem productivity and monitor desertification. Accurate and efficient method of predicting AGB of shrub community is essential for studying the spatial patterns and ecological functions of the desert region. Even though there are several reports on the AGB prediction of desert shrub community using remote sensing data, the applicability and accuracy of airborne LiDAR data and prediction methods have not been well studied. We first extracted the elevation, density and intensity variables based on the airborne LiDAR, and then sample plot-level AGB prediction models were constructed using the parametric regression (nonlinear regression) and nonparametric methods (Random Forest, Support Vector Machine, K-Nearest Neighbor, Gradient Boosting Machine, and Multivariate adaptive regression splines). We evaluated accuracies of all the AGB prediction models we developed based on the fit statistics. Results showed that:1) the elevation, density and intensity variables effectively predicted AGB of the desert shrub community at sample plot-level, 2) the kappa coefficient of nonlinear mixed-effects (NLME) model obtained was 0.6977 with improvement by 13% due to random effects included into the model, and 3) the nonparametric model, such as Support Vector Machine showed the best fit statistics (R2=0.8992), which is 28% higher than NLME-model, and effectively reduced the heteroscedasticity. The AGB prediction model presented in this paper, which is based on the airborne LiDAR data and machine learning algorithm, will provide a valuable tool to the managers and researchers for evaluating desert ecosystem productivity and monitoring desertification.

Assessing biotic and abiotic effects on tree species richness in uneven aged and mixed forests using machine learning approaches

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Forest ecosystems play multiple important roles in meeting the habitat needs of different organisms and providing a variety of services to humans. Biodiversity is one of the structural features in dynamic and complex forest ecosystems. One of the most challenging issues in assessing forest ecosystems is understanding the relationship between biodiversity and environmental factors. The aim of this study was to investigate the effect of biotic and abiotic factors on tree diversity of Hyrcanian forests in northern Iran. For this purpose, we analyzed tree diversity in 8 forest sites in different locations from east to west of the Caspian Sea. 15,988 trees were measured in 655 circular permanent sample plots (0.1 ha). A combination of machine learning methods was used for modeling and investigating the relationship between tree diversity and biotic and abiotic factors. Machine learning models included generalized additive models (GAMs), support vector machine (SVM), random forest (RF) and K-nearest–neighbor (KNN). To determine the most important factors related to tree diversity we used from variables such as the average diameter at breast height (DBH) in the plot, basal area in largest trees (BAL), basal area (BA), number of trees per hectare, tree species, slope, aspect and elevation. A comparison of RMSEs, relative RMSEs, and the coefficients of determination of the different methods, showed that the random forest (RF) method resulted in the best models among all those tested. Based on the results of the RF method, elevation, BA and BAL were recognized as the most influential factors defining variation of tree diversity

Discrimination of leaves in a multi-layered Mediterranean forest through machine learning algorithms

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Terrestrial Laser Scanning (TLS) systems precisely characterize standing trees with millimetric resolution. To accurately calculate the leaf area index (LAI), a crucial indicator of trees' photosynthetic activity, using TLS point clouds, it is important to distinguish between timber and leaf components. This study aims to evaluate the performance of six machine learning algorithms in discriminating timber and leaf points using TLS point clouds, with a specific focus on eight Mediterranean tree species. The findings revealed that random forests, deep learning, gradient boosting machine, and stacked ensemble algorithms achieved the highest accuracies, with the maximum accuracy reaching 0.96. The machine learning models demonstrated accurate discrimination, supported by their AUC values, with the highest accuracy reaching 0.99. The observed and predicted data showed moderate to high agreement, with average Kappa values ranging from 0.67 to 0.76. The accuracy of timber-leaf discrimination varied across species, with Italian maple, European Beech, Hazel, and Small-leaf lime achieving an average overall accuracy exceeding 0.90. Various factors influenced the contrasting response patterns among tree species, including bark and leaf traits, bark defects, lianas, forest structure, occlusion caused by small trees or shrubs on large branches, reduced accuracy of laser beams in intermediate and overstory layers (particularly for tall trees ranging from 6 to 30.7 meters in height), and the presence of dense stems (672 trees per hectare). Nevertheless, the best machine learning models exhibited reasonable computation times of 8 to 37 seconds for discriminating timber and leaf points from 2 million data points. Future studies are encouraged to utilize the obtained leaf area estimates to derive LAI for individual trees of each species.

Estimating canopy cover of natural forests using airborne laser scanning (ALS) data: A case from Alabama, USA

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Canopy cover (i.e., crown closure) is defined as the area of tree crowns, projected vertically from a horizontal plane, as a fraction of the total ground area of a forest stand. It is a valuable forest attribute used in forest management planning, especially for estimating growing stock, stratifying large forest expanses into homogeneous stands, and evaluating the necessity of thinning operations, among other purposes. Canopy cover can be measured by using a tape or densiometer from the ground perspective and by sampling or other assessment methods that use optical data such as aerial photography and satellite imagery. However, three-dimensional LiDAR (light detection and ranging) point clouds have recently gained popularity and are increasingly being used instead of, or in conjunction with, optical data in forestry research. While many studies have focused on deriving various canopy metrics from LiDAR data, typically based on the ratio of LiDAR returns above a specified height threshold, these metrics are primarily related to canopy density rather than the specific definition of canopy cover stated above. Therefore, the objective of the present study was to develop a simple workflow for estimating the canopy cover ratio of stands in a federal forest in Alabama based solely on airborne laser scanning (ALS) data collected between 2020 and 2021. The accuracy of the approach was evaluated using visual assessments (NAIP orthophotos) and field data from 255 sample plots. The results suggest that the canopy cover ratio of pure and mixed plots could be estimated with a root mean square error (RMSE) of 14%. The correlation coefficient (Pearson's r) between the observed and estimated ratios was 0.77. Whereas the canopy cover estimates for pure conifer plots tended to be slightly underestimated, canopy cover estimates for broadleaved plots were virtually unbiased, despite the ALS data being collected during the leaf-off season. As this project is still ongoing, stand-level estimates and a canopy cover map of the entire study area will be provided at the conference. The findings of this study may serve a blueprint for researchers and practitioners working with LiDAR data in their everyday efforts related to natural resources management.

Impact Assessment of Forestry Machines on Mountain Forests using Deep Learning to Develop a Severity Index based on Wheel Rut Depth and Erosion Risk

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Mountainous regions are prone to large-scale disturbance events such as wildfires, landslides, and windstorms, which can significantly impact forest ecosystems. Forestry machines, like harvesters and forwarders, are crucial for post-disturbance forest management and recovery. However, their passage can lead to additional surface disturbance enhancing soil compaction and erosion, further aggravating ecological vulnerability.

This study aims to assess the impact of forestry machines and salvage logging operations in mountain areas following large disturbance events, with a specific emphasis on developing a severity index based on wheel rut depth and the exposure to potential erosion risks. The methodology integrates LiDAR data for pre-event analysis, close-range photogrammetry from drones for the post-event scenario, and deep learning techniques for accurate wheel rut detection and depth estimation.

To quantify the impacts, LiDAR data will be used to reconstruct pre-event forest structure and topography. Close-range photogrammetry from drones, along with deep learning approaches, will enable the identification and measurement of wheel ruts accurately in the post-event scenario. Convolutional neural network (CNN) models will be trained using a large dataset of drone images to automatically detect and classify wheel ruts, providing a quantitative measure of soil compaction and disturbance severity.

Additionally, a simple hydrological model will be employed, incorporating parameters such as slope, soil type, vegetation cover, and topography to evaluate erosion risk in the affected areas. By integrating the severity index based on wheel rut depth and erosion risk exposure, a comprehensive assessment of the impact of forestry machines and salvage logging operations will be achieved with respect to changes in the micro-topography.

This study will contribute to understanding the ecological consequences of post-disturbance forest management in mountainous regions. The severity index, derived using a deep learning approach for wheel rut depth estimation, will serve as a valuable tool for assessing the extent of disturbance caused by forestry machines. Moreover, the incorporation of a hydrological model identifies areas at high risk of erosion due to machine passage, aiding in the development of sustainable management strategies to mitigate environmental degradation.

Integrating high- and low-frequency forest monitoring data into AI models for climate sensitive tree growth

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Traditional statistical modeling approaches are limited in capturing the complexities of tree growth and its response to the increasing occurrence of climate extreme events. Moreover, the increasing availability of tree monitoring data in high temporal and spatial resolution requires new modeling approaches.

The present project employs a combination of AI and traditional statistical models, such as Long Short-Term Memory (LSTM) and Generalized Additive Models (GAMs), to develop a comprehensive modeling approach for tree growth. LSTM models are utilized to capture temporal dependencies and patterns in tree growth data, while GAMs provide interpretability and account for non-linear relationships between growth and climate variables.

The project utilizes detailed long-term datasets from the ICP forests monitoring network. Hourly single tree growth data enable the analysis of physiological processes and interactions with climate variables, while periodic stand characteristics provide insights into long-term development and carbon sequestration. Terrestrial laser scanning (TLS), along with satellite-derived parameters, are integrated into the models to capture high- and low-frequency features, especially individual competition factors. Our analysis aims to identify growth parameters and should aid the further development of monitoring setups. By combining AI techniques with explainable error analysis, we strive to enhance our understanding of tree growth and optimize forest ecosystems' resilience in the face of changing climate conditions.

Linked Open Data: a tool for foresters on their artificial intelligence journey

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: By opening forest data and facilitating their use we promote forest management transparency, support the participation of different stakeholder profiles in decision making processes, and increase productivity in the forest sector, and promote the awareness of society on forest ecosystems and forest resources. Semantic technologies are part of the symbolic artificial intelligence (AI) and are particularly adequate to organize information, facilitate interoperatibility, search and expert systems. On the base of specially developed ontologies and Linked Open Data (LOD), our group developed Forest Explorer (https://forestexplorer.gsic.uva.es) that it is a web based tool that allows users to access dendrometric and land use data for forests in Spain and Portugal. The data in Forest Explorer comes from the National Forest Inventories and forest maps from Portugal, IFN6 (Inventário Florestal Nacional) and COS (Carta de Uso e Ocupação do Solo de Portugal Continental) and Spain, IFN3 (tercer Inventario Forestal Nacional) and MFE50 (Mapa Forestal Nacional). These resources have been converted to RDF and annotated with a dedicated forest ontology. Since Portuguese IFN6 was only partially disclosed, the data from Spain are more extensive and detailed than the Portuguese data. Forest Explorer caters to a diverse user base, ranging from lay users to professional foresters, each with different requirements and objectives. Forest Explorer offers raw dendrometric data at plot and tree level, providing controls to filtering by location, forest cover and species composition. This information can be used by professional foresters to inform their decision-making and support sustainable management alternatives, opening opportunities to insight on current and forecast species composition distribution, feeding forest simulators (as SIMANFOR: www.simanfor.es), and allowing users forecast forest stand dynamic and the impact of management actions and climate change. Forest Explorer offers the opportunity to access dendrometric data that can combine with other data sources to train, validate, and test AI algorithms.

Machine Learning for landscape level forest inventory: extract 3D attributes from 2D data

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Modern forest inventory records not only the dimensions of individual trees but also their location. Positioning trees from georeferenced data is a simple task irrespective of the type of data (i.e., 2D or 3D), but extraction of relevant tree attributes depends on the available information, as various heights require 3D data. Because the ubiquity of 2D representation of the Earth's surface, it is desirable to estimate tree height from orthophotos. Therefore, in this study, we aim at positioning and estimating the size of individual trees using high-resolution imagery. We selected as study areas two regions from Wheeler County, Oregon, USA, each of approximately 1600 ha. The dominating species in the area are western juniper (*Juniperus occidentalis* Hook.) and ponderosa pine (P*inus ponderosa* Douglas ex C.Lawson). We executed the forest inventory in two stages, each using a dedicated neural network. First, we identify individual trees by segmenting high-resolution multispectral images using a Faster Region-based Convolutional Neural Network, and second, we compute the tree heights from a canopy height model created using a Generative Adversarial Network. The Generated Adversarial Network was trained using lidar-derived digital elevation models. We compare our method with the multiscale watershed segmentation algorithm of Wang et al. (2004) applied to the generated canopy height model and the original imagery. The multiscale watershed segmentation algorithm exhibited a precision of at most 75% and recall of 81% (precision in this case was just 53%), with the smallest omission error of 22%. Our implementation of the Faster Region-based Convolutional Neural Network algorithm identified the trees with a precision of 91%, a recall of 73%, and an omission error of just 7%. The heights supplied by the Generative Adversarial Network were not significantly different from the values derived from lidar. Our results show that accurate spatial explicit maps of the trees can be obtained from 2D products, orthophotos and digital elevation models.

Machine Learning of Tree Height-Diameter Relationships – Data Dimension Perspectives on Selecting an Appropriate Modelling Approach

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Various machine learning algorithms have been applied to regression and classification of tree and stand parameters over the last decades. We claim that performance comparisons between methods could be considered more successful if they qualitatively considered the fitness of the selected machine learning method to the available amount and type of data in addition to model fitting and accuracy statistics in an application. To demonstrate this, we evaluate the learning process of tree height-diameter relationships based on linear and nonlinear regression, mixed effects, nearest neighbor, random forest, and fully connected and convolutional neural networks in settings with varying data availability.

Height-diameter modeling is a well known and well studied problem. Due to the measurement of trees within plots and plots within stands, the data are nested with a hierarchical error structure. A general recommendation is to use a mixed effects modeling approach to deal with the hierarchical errors, but also because in a practical case the parameters associated with the random effects are unknown and need to be predicted. The ability of the algorithms to predict the random stand effects, or to calibrate the predictions with a limited number of observations, would have resulted in a comparative evaluation taking into account all the possibilities of the modeling methods in a practical situation.

We use a total of 299 permanent plots measured at three time points, additional data from about 2,000 plots from one time point, and various related geospatial data from a test area in Central Finland. We observe the learning of tree height-diameter in different situations and evaluate the implications for the derivation of volume from diameter and height using different strategies. By testing different extents and selectively selected data, we evaluate the transferability of the model through different calibration and transfer learning approaches. While the height-diameter relationship can be learned by all approaches with fundamentally similar population accuracy, the mixed-effects modeling approaches offer undisputed advantages due to their calibration capabilities using Best Linear Unbiased Prediction. We discuss the strengths and limitations of the different approaches and the implications for stand, holding, and regional decision making with different objectives.

Machine learning prediction of tree species diversity using forest structure and environmental factors: A case study from the Hyrcanian Forest of Iran

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: The Hyrcanian Forest is an ecologically important region with diverse flora, but its tree diversity has been significantly impacted by human activities. To address this issue, we conducted a study using three machine learning methods, i.e., linear regression (LR), random forest (RF), support vector machine (SVM), to assess and predict tree species diversity within the forest. To do so, we collected an extensive dataset of forest structure and environmental factors from 2725 sample plots located throughout the forest. The Shannon-Wiener diversity index was used to quantify the tree species diversity for each plot. We found that basal area, tree density, and height of trees were the most important predictors of tree diversity, followed by diameter at breast height, elevation, slope, and aspect. We measured the performance of the models using the coefficient of determination (R^2), root mean square error (RMSE), and percent of relative error index (PREI), and found RF as the best-performing model in both the training (RMSE = 0.143, R^2 = 0.94, PREI = -0.088) and validation (RMSE = 0.146, R^2 = 0.94, PREI = -0.094) phases. RF was able to generalize effectively to new data without losing much accuracy or explanatory power. SVM demonstrated a moderate performance training (training phase: RMSE = 0.230, R^2 = 0.57, PREI = -0.178) and (validation phase: RMSE = 0.365, R^2 = 0.34, PREI = -0.207) among the models, while LR performed the worst (training phase: RMSE = 0.406, R^2 = 0.13, PREI = -0.195) and (validation phase: RMSE = 0.414, R^2 = 0.11, PREI = -0.357). These findings have broad applications beyond this specific region and can contribute to promoting sustainable land use practices and conservation efforts in other ecosystems facing similar challenges.

Mapping forests matching to sites by linking potential productivity with distribution suitability based on machine learning in northeast China

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Matching tree species with sites is a basic principle in forest management. This matching was conventionally achieved through site quality evaluation based on site index by tree species. Developing site index model through empirical growth model is necessary for this. In this study, a novel methodology was developed for matching tree species (mixture) with sites, which produced a happy tree index (HTI) combing potential productivity with distribution suitability using machine learning algorithms and multiple environment variables including soil, topology and climate. The data were from 2825 sample plots of national forest inventory in northeast China, 1km resolution climate and 250m resolution soil database. Potential site productivity (maximum annual volume increment) was produced for 13 tree species (mixture) through stand growth model and optimization algorithms. Distribution suitability for 13 tree species (mixture) was produced from assemble species distribution models. HTI for all plots was firstly attained and then trained by random forest for generalization at large scale. All models showed good generation capacity with R^2 larger than 0.70. Based on the trained model, HTI for all grids across the region was generated with the input as soil, topology and climate variables for all tree species (mixture). Our study provided useful tools for mapping forests matching to sites which is important for afforestation, degraded forest restoration and forest management decision-making. The advantages and challenges for using machine learning at large scale with multiple variables were discussed.

Modeling Height—Diameter Relationship Using Artificial Neural Network for Durango Pine species in Mexico

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: The relationship between tree height (*h*) and diameter at breast height (*dbh*) is important for forest management and planning. Various approaches have been used to study the height-diameter (*h—dbh*) relationship across different species worldwide. Nonlinear mixed effect modeling (NLMEM) has been widely utilized, and recently, the resilient backpropagation artificial neural network (RBPANN) approach has gained attention for modeling this relationship. In this study, both NLMEM and RBPANN approaches were employed to model the *h—dbh* relationship for Durango pine species (Pinus durangensis Martínez) in a mixed-species forest in Mexico. The dataset consisted of 1,000 randomly selected plots (11,472 measurements) from 14,390 temporary forest inventory plots. The dataset was divided randomly into two parts, with 50% allocated for training and 50% for testing. To analyze the dataset, a cluster analysis was performed using the *k*-means clustering method, grouping the data into 10 clusters. Plot variables such as density, basal area, mean *dbh*, mean height, quadratic mean diameter, altitude, and aspect were considered in the clustering process. The RBPANN approach was applied using tangent hyperbolicus (RBPANN-tanh) and logistic function (RBPANN-logistic) for the cross product of the covariate or neurons, along with the weights for the ANN analysis. For both the training and testing stages, 10 classical statistics, including RMSE, R2, AIC, BIC, and logLik, were computed to evaluate the performance of the approaches in modeling the *h—dbh* relationship. The results showed that the ANN approach outperformed the NLMEM approach in both training and testing. Thus, the ANN method was found to be more effective for modeling the *h—dbh* relationship for Durango pine species in the mixed-species forest of Mexico.

Modeling productivity–diversity relationship using artificial neural networks and parametric models in typical uneven-aged and mixed forests

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: The relative importance of different biotic and abiotic variables in determining productivity remains unclear for many forest ecosystems around the world. This article investigates the productivity–diversity relationship in typical uneven-aged and mixed forests in northern Iran. Using a large dataset from 258 forest monitoring permanent sample plots distributed across uneven-aged and mixed forests in northern Iran, we tested the relationship between tree species diversity and forest productivity and examined whether several biotic and abiotic variables (i.e., solar radiation, topographic wetness index, wind velocity, seasonal air temperature, basal area (BA), tree density, basal area in largest trees (BAL)) had an effect on productivity. In our study, productivity was defined as the mean annual increment of the stem volume of a forest stand in m3ha-1yr-1. Plot estimates of tree volume growth are based on averaged plot measurements of volume increment over a 9-year growing period. We investigated relationships between productivity and tree species diversity using a parametric model, i.e., multiple linear regression, and two artificial neural network models, i.e., multilayer perceptron (MLP) and radial basis function (RBF) networks. According to a sensitivity analysis, diversity had significant and positive effects on productivity in species-rich broadleaved forests (approximately 31%), but the effects of biotic and abiotic variables were also important (29% and 40% respectively). The artificial neural network based on the MLP was found to be superior for modeling productivity–diversity relationships.

Real-time detection of trees and obstacles in complex forest environments using 3D depth cameras and machine learning

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Accurate monitoring and efficient forest resource management are essential for sustainable forestry practices. Recent technological progress has significantly transformed numerous facets of forest management, offering opportunities to enhance inventory management and optimize planning processes. By leveraging these advancements, it becomes feasible to streamline operations, ensure resource efficiency, and promote environmentally conscious practices within the forestry sector.

This study focuses on developing a fundamental methodology that utilizes a 3D depth camera, real-time object detection, and deep learning techniques to detect trees and machine obstacles in complex forest environments, enabling more efficient forest management practices. Implementing a tree and obstacle detection and localization system holds the potential for significant benefits, including improved planning, enhanced situational awareness for forest machine operators, and valuable positional data crucial in facilitating informed decision-making processes by precisely pinpointing the positions of trees and primary machine obstacles. Therefore, this study intends to implement a system prototype that automatically locates trees and main machine obstacles based on accessible hardware and standard software infrastructure.

This work describes and evaluates an automatic tree and object detection and localization system based on ZED 2i stereo camera sensing, capable of capturing high-resolution color and depth maps. We employ the NVIDIA Jetson Orin AGX computer as the computational platform for camera control and data analysis to facilitate seamless integration and processing. As a key component of our system, we utilize the YOLO (You Only Look Once) object detection algorithm, a deep-learning approach that enables efficient and accurate detection and localization of objects of interest. By leveraging YOLO object detection, we can derive precise object positions in 3D space, further enhancing the capabilities of our object detection and localization system.

To validate the effectiveness and performance of our methodology, comprehensive field trials will be conducted, involving manual labeling and precise positioning of trees and machine obstacles.

Regeneration in a Complex Forest: What Can We Learn From, and About, Machine Learning?

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Forests in the northeastern United States are structurally complex and species diverse, and management relies on natural regeneration. However, concerns over adequate regeneration are chronic and widespread. We used data from the U.S. Forest Service, Forest Inventory and Analysis program, along with Random Forest (RF) and Mixed Effects Random Forest (MERF) machine learning, to examine the predictability of regeneration using a series of biotic and abiotic predictor variables. Regeneration was represented using a suite of community-level traits: abundance, average shade tolerance, proportion conifers, and proportion in primary economic species. We also evaluated multiple techniques for variable selection. RF and MERF showed very similar predictive ability, but MERF provided more accurate projections of prediction errors when compared against reserved validation data. Variable selection was far more sensitive to the choice of selection technique, than to the underlying model. Regeneration attributes remained difficult to predict, even with a large set of available predictors; however, expert selection informed by RF or MERF results led to a parsimonious model that retained substantial predictive ability along with interpretability.

Testing the accuracy of personal laser scanning data and different processing methods for individual tree attributes estimates in European beech forests

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Rapid progress in sensor miniaturization resulted in the development of lightweight and highly mobile personal laser scanning (PLS) systems that may be carried or held by person. The emergence and availability of new generation PLS systems with considerably improved features (e.g., scanning range and rate, measurement accuracy) of LiDAR sensor resulted recently in initial research on the possibility of its application in forest inventory, primarily for the estimation of the main tree attributes. The main goal of this research is to test the accuracy of three different methods of processing PLS point clouds for the individual tree attributes estimation. These methods are supervised automatic, unsupervised automatic, and semi-automatic. The research was conducted in twelve circular sample plots (500 m^2) distributed in two study areas of Central Croatia, i.e., in European beech (*Fagus sylvatica* L.) middle-aged and older forest stands. Considering their ecological, social and economic value, they are among the most important tree species in Europe. Sample plots were scanned using a GeoSLAM Horizon scanner, while three different processing methods were designed using the algorithms and procedures enabled by LiDAR360 software. The obtained results of tree detection, tree positions, diameter at breast height (dbh) and tree height for each PLS processing method were compared to ground reference data, i.e., estimates obtained from detailed field measurements and terrestrial laser scanning (TLS) data. TLS data were collected using a Faro FOCUS S70 scanner and multi-scan approach. As expected, the semi-automatic PLS processing method, which requires the most manual work, provides the results of the highest accuracies for all observed variables which are closely comparable to TLS estimates. The unsupervised automatic method provides the least accurate estimates, mostly due to a greater rate of non-segmented or incorrectly segmented smaller trees with dbh<20 cm. Supervised automatic method provides results of considerably higher accuracies than unsupervised method regarding the tree detection but compared to semi-automatic method the results of considerably lower accuracies for tree height estimates, especially in more dense sample plots with overlapped tree crowns.

The potential of artificial intelligence in forest growth and yield modelling

T5.1 Artificial Intelligence in Forest Biometry: from predictions to understanding

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Abstract: Artificial intelligence (AI) has transformational potential and promises to revolutionize almost every aspect of our life, but the revolution has not reached yet forest growth and yield modelling (FGYM). What are the niches within FGYM with the greatest potential to benefit from AI? What are the potential benefits? What is needed to fully benefit from the transformational potential of AI? In this talk I present an exploration of the potential applications of AI in the context of forest growth and yield. I will discuss the challenges and opportunities associated with implementing AI technologies in FGYM, including data availability, model interpretability, and the need for interdisciplinary collaboration.

T5.2 Artificial Intelligence in Forest Management – Opportunities, Challenges and Social Consequences

Causal understanding of the deep learning processes of convolutional neural networks by learning predefined features of digital terrain models

T5.2 Artificial Intelligence in Forest Management – Opportunities, Challenges and Social Consequences

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Abstract: Artificial intelligence could potentially augment decision making to the extent that autonomous machines and systems learn from observations and experience and reconfigure themselves when new components or information are introduced. However, deep learning applications in forestry are in the intermediate stages of achieving this overarching goal. One limitation to the adoption of these algorithms may be the excessive amount of specific terminology and concepts that an operator needs to understand in order to optimally implement these methods in practice.

For convolutional neural networks (CNNs), choices regarding the architecture and hyperparameters of the training process, as well as data augmentation (using synthetic data based on transformations) and transfer learning (using a limited local sample to calibrate a large pre-trained network) can effectively contribute to the predictive accuracy, efficiency and training time of the model, also depending on the available training data. CNNs may need to be contextually optimized for each application, where we identify challenges related to (1) obtaining sufficient amounts of representative and labeled training data, (2) difficulties in selecting an appropriate architecture and hyper-parameterization among many methodological choices, and (3) susceptibility to overlearning of the training data and consequent risks related to the generalizability of the predictions, which can, however, be reduced by appropriate choices on the above.

To provide guidance on appropriate method and parameter choices, we propose learning terrain micro- and macrotextural features from digital terrain models (DTMs) as a possible CNN training testbed. The simplest features, such as slope and aspect, are computed primarily by applying local filters to the DTM and should be learned by CNNs with a reasonable amount of iterations and data, depending on how well e.g. CNN filters match the initial choices. More complex features, such as terrain morphological features, flow accumulation, and wetness indices, depend on pixel neighborhoods and flow direction and distribution from the watershed, and thus require more complex CNN training. Since all these features can be uniquely defined from the DTM, their learning provides an excellent demonstration of the required training data, associated learning processes, and transfer learning. We discuss these implications more generally with respect to forestry.

Digital literacy among individual forest owners in Sweden – Is it associated with sustainable management?

T5.2 Artificial Intelligence in Forest Management – Opportunities, Challenges and Social Consequences

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Abstract: Digital literacy is envisioned as a booster of sustainability. In the forest sector, digital literate owners are expected to become instrumental in spreading sustainable management. For instance, they can better incorporate up-to-date information readily available on-line into their management plans, or take advantage of ever evolving Artificial Intelligence tools. These type of owners would therefore be able to take informed actions to counteract climate conditions. To measure digital literacy for individual forest owners, we adapted a previous study, initially aimed to estimate Americans' digital awareness in utilising electronic devices to achieve online learning, to individual forest owners in Sweden. Using Horrigan's work as a baseline, we defined digital literacy through three components: a) *Digital skills*, one's ability to access online information; b) *Trust*, one's self-perception to separate trustworthy data from inaccurate news and c) *Use*, one's potential to take educated decisions about forest management using online information. In the survey, we dedicated two questions to *digital skills*, one question to *trus*t and another one to *use*. Logistic models' estimations were used to determine the association between digital literacy and sustainable forest management. Due to the fact that sustainable forest management as a concept presents its own "thorns", we asked forest owners a question about forest management practices engaged on their property and from their answers we elaborated our sustainability index. Through gathering and analysis of answers provided by a nationally-representative sample of individual forest owners in Sweden, this paper documents that i) only 10% of forest owners are digital literate; and ii) digital literacy is associated with a higher likelihood of observing sustainable management practices but only among individual owners of age 66 to 76 years old. These owners, in general, reside in rural areas, report higher education levels, and use their property for non-commercial purposes. A limitation of findings reported in this manuscript is that we relied on self-reported information from forest owners to develop our indexes. We discuss implications in terms of how we can increase digital literacy among forest owners and how its association with sustainable management can be strengthened.

Exploring the effects of abiotic drivers on the classification of leaf phenology groups in a tropical forest using machine learning

T5.2 Artificial Intelligence in Forest Management – Opportunities, Challenges and Social Consequences

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Abstract: The vegetation distribution is largely determined by the environmental drivers and stand age. Predicting future vegetation changes in response to abiotic drivers is crucial to identify and understand patterns and processes in tropical forests. Machine learning (ML) has been used by different ecological and environmental researchers to model forest types and ecosystem services classification. Thus, in this study we employed three main machine learning algorithms (Random Forest, Support Vector Machine and classification and regression tree) to predict the association of the abiotic factors and stand age for the classification of tree leaf phenology groups (evergreen, deciduous, and semideciduous) in an Atlantic tropical forest, in southeast of Brazil. Especially, we used ML models with the climate data (climatological water deficit, CWD), soil data (sum of basic exchangeable cations (SB) and exchangeable acidity potential (HAl)) and topographic data (elevation, slope and convexity) during tropical late-secondary forest succession to predict the classification of functional leaf phenology groups. The data were obtained through a long-term forest inventory (1980-2020) in a Atlantic forest. The prediction of leaf functional groups classification based on multiple abiotic predictors using the three different machine learning-based classification algorithms showed higher accuracy and suitable Kappa using the Random Forest (A = 0.753, K = 0.629) compared to the classification and regression tree (A= 0.470, K= 0.648) and Support Vector Machines (A= 0.460, K= 0.640) algorithms. Using random forest, it was observed that the most influential predictor in the classification of functional groups was topography and soil properties. Specifically, elevation shows a high explanatory contribution in the three functional groups followed by soil properties such as SB and HAL. Our results showed that topography, mainly elevation, is a important driver for leaf phenology group classification in a tropical forests. The prediction of functional group classification can be the basis for the identification of key species to be used during ecological restoration and for defining environmental policies and forest management strategies under different topography and soil-dependent conditions in the Atlantic forest. Furthermore, the use of ML expands traditional data analysis and offering fast processing and allowing significant advances in data description and predictive modeling.

Forest Owners' Perspective on Machine Learning in Forestry: Uncovering the "Tree-mendous" Influence of Context with Q-Methodology

T5.2 Artificial Intelligence in Forest Management – Opportunities, Challenges and Social Consequences

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Abstract: The application of machine learning in forestry has gained considerable attention in recent years due to its potential to enhance decision-making processes and promote sustainable forest management. However, understanding the perceptions of individual forest owners towards the use of machine learning in this domain is crucial for successful adoption and integration of such technologies. Previous research has suggested that perceptions of machine learning applications are conflated with opinions about the context – implying that perceptions of what are appropriate applications is largely shaped by one's relation to the social context. Social context refers to the set of social circumstances that shape an individual's experience, actions, and interaction within a particular social setting.

Based on Q-methodology and naturalistically derived Q-statements the aim of this study is to explore the diverse viewpoints held by individual forest owners regarding the use of machine learning and forest management in Sweden.

The study involved a purposive sample of forest owners from various geographic locations within Sweden, reflecting a range of demographic characteristics and forest management practices. Q-methodology, a systematic approach for exploring subjective opinions and perspectives, was employed to identify the underlying factors influencing forest owners' perceptions. Participants were asked to rank a set of statements representing different attitudes towards machine learning in forestry administration and forestry administration in general, according to their level of agreement/disagreement. The statements were derived from several purposefully sampled semi-structured interviews across Sweden.

The findings confirm previous findings that social context is important in shaping perceptions, but that the concept has been underspecified in previous research. Context has been used analogously to "area of application" rather than as a collection of potential factors which shape the perceived appropriateness of application. Through employing Q-methodology with statements regarding both context and technology use – the paper suggests a more granular way to understand how context and perceptions of technology-use go hand-in-hand.

This study highlights the importance of considering individual forest owners' perceptions and attitudes when implementing machine learning solutions in forestry administration. These insights can assist policymakers and technology developers in tailoring interventions that address the concerns and expectations of forest owners.

Intelligent management of forest ecosystem based on multi-source information

T5.2 Artificial Intelligence in Forest Management – Opportunities, Challenges and Social Consequences

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Abstract: Ecosystem Management reflects human behavior of utilizing and protecting natural resources scientifically and sensibly. Sustainable development relies on renewable resources, especially the rational use of biological resources. Hence, ecosystem management is an important approach to the sustainable development. The paper aims to study wisdom management of forest ecosystems comprehensively. The ecological data in the study area been obtained by remote sensing and other wireless sensors. Through analyzing the multi-source data, the paper discussed the adaptive management model of forest ecosystem based on multi-agent system theory. The paper also constructed the aggregation and segmentation algorithm of forest ecosystem in flexible scales and calculated the dynamics of uneven-aged forests providing ecological services for developing a strategy model of optimizing algorithms taking multi-agent into account. On this basis, the paper tried to draw up a multi-sector social accounting matrix. After examining parameter and analyzing variance of the data on the social matrix, a multi-sector model of ecological economic system would been developed to illustrate various impacts of ecosystem management on the economy in the same area.

Key words: Intelligent management; forest ecosystem; multi-source information

T5.3 Assessing forest sustainability through operations research

A behavior-based robust decision making approach for managing forest under risk and uncertainty

T5.3 Assessing forest sustainability through operations research

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Abstract: Forest management in times of climate change asks not only for integration of adaptation and mitigation strategies but also taking into account multiple risks affecting forest processes and functions. Moreover, climate change is challenging forest decision processes due to larger fluctuations in the severity and frequency of biotic and abiotic disturbances. Thereby, forest processes are subject to uncertainty because of the dynamics of natural systems and inherent deep uncertainty of future climate change represented by IPCC as a set of plausible scenarios. As the expectations about forest management outcomes in the future are built based on the dynamics of forest ecosystems and the timing of management interventions over planning horizon, novel decision-making approaches are essential to deal with these challenges. Robust decision-making (RDM) provides a unique opportunity to optimize the forest outcomes under deep uncertainty. RDM trades nominal optimality for robustness under worst conditions subject to a set of climate change scenarios, management options, and forest conditions. However, it is essential as well to integrate the risk and uncertainty attitudes of decision-makers in the robust decision-making process. Therefore, a set of robust decision-making approaches are investigated to assess the effects of risk and uncertainty aversion on final decisions. The outcomes confrms the sensitivity of RDM to risk and uncertainty behaviors and concludes that it is essential to communicate the effects with forest owners and decision-makers.

Automatic detection of forest management units as a basis to optimally coordinate planning, operations, controlling and assessing sustainability

T5.3 Assessing forest sustainability through operations research

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Abstract: Forest management in Central Europe provides numerous ecosystem services in addition to the provision of wood as a raw material. Managing these forests sustainably thus requires an efficient planning for management objectives (ecosystem services) and execution of harvesting operations. To consider planning and forest operations jointly and having an efficient controlling, it is essential to subdivide the forest area into smaller forest management units (FMU). The aim of FMUs is to have forest entities that can be managed and planned independently of each other; meaning each FMU should have a self-contained fine access into the forest and should be homogenous in terms of operational harvest methods and management objectives.

For an efficient and sustainable forest management and its assessment, it is particularly important to have well-chosen and meaningful boundaries between neighbouring FMUs. However, the demarcation of the FMUs is challenging, especially in steep terrain harvested by cable yarders. The planning of the layout and installation of the cable roads is usually very time consuming and associated with high costs.

We will present a spatial optimization model (Mixed Integer Linear Programming) that automatically identifies FMUs. The optimization pursues three goals: BWEs should be as compact, spatially contiguous areas as possible (objective 1), within each FMU forest management should be technically and operationally coordinated (objective 2), and the area should have as homogeneous properties as possible, such as the harvesting method used, the ecosystem service provided, or the administrative affiliation (objective 3).

The model was developed and successfully tested in close cooperation with the Forest Service of Grisons in the Swiss Alps. The model allows to generate different FMU layout variants in a short time that can easily be compared. The generated solutions can afterwards be reviewed by local experts and adopted, or slightly modified if necessary. The use of this method enables a transparent and efficient demarcation of FMUs considering multiple forest management planning goals and operational criteria at the same time.

Balancing biodiversity and ecosystem services in forestry under changing climate - Insights from a Swedish case study

T5.3 Assessing forest sustainability through operations research

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Abstract: Forests play a crucial role in providing both biodiversity conservation and essential ecosystem services to society. However, the management of forests to address multiple objectives is a complex task, particularly in light of climate change, which places additional uncertainties in the way of informed decision making. In Sweden, intensive forest management has traditionally prioritized wood production as the primary ecosystem service. This has resulted in large areas of relatively homogeneous production forests with limited quantities of key features typically found in more natural forests, such as dead wood and old trees, vital for maintaining biodiversity. Furthermore, features associated with other ecosystem services such as recreation and carbon sequestration is often overlooked, leading to suboptimal management practices with regard to these services.

Here we assessed the implications for biodiversity and various ecosystem services resulting from the adoption of different forest management strategies within the framework of the Swedish SPARC project. The consequences were identified by quantifying conflicts and synergies between biodiversity conservation and ecosystem services in different future scenarios, considering various climatic projections.

Utilizing data from the Swedish National Forest Inventory, simulations of forest development were performed using the forest decision support system Heureka. A multi-objective optimization approach was applied to identify conflicts and synergies, between different indicators within each management strategy and climate scenario.

The results of this study revealed complex relationships between biodiversity conservation, ecosystem services, climate change, and forest management strategies. While some management alternatives show conflicts between biodiversity and ecosystem services, others demonstrate potential synergies. Thus, trade-offs are needed when deciding future forest management.

Our study contributes to the advancement of understanding regarding how multiple goals in forestry can be achieved by balancing biodiversity conservation and ecosystem services in the face of climate change. By quantifying conflicts and synergies through trade-off analyses, this study provides valuable insights for identifying effective combinations of management strategies that promote sustainable forest management in the face of ongoing environmental changes.

Bridging the gap between models of forest dynamics and decision support systems in forestry

T5.3 Assessing forest sustainability through operations research

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Abstract: Forests provide multiple ecosystem services crucial for humankind. Changes in environmental conditions caused by climate change, natural disturbances, and shifting societal needs jeopardize the provision of forest ecosystem services. Thus - more than ever – tools are needed to (1) reduce the uncertainty of forest growth projections considering climate change and risks, and (2) efficiently assess sustainable management alternatives.

Models of forest dynamics (MFDs) are essential tools to project future forest trajectories but have not often been integrated into Decisions Support Systems (DSSs) for forest management. DSSs and MFDs represent tree demography to some extent, but their necessary inputs, risks, and management considerations differ considerably. In general, MFDs include rather complex formulations of ecological processes. Some MFDs have management modules, but obtaining results with optimal management strategies for more complicated models remains challenging. DDSs commonly use much simpler models of forest demography that predict yield considering a more varied set of management strategies and often include the possibility of finding optimal solutions by applying mathematical optimization approaches. DDSs in forest management are gradually moving towards a more general, causal-oriented approach in which other relevant aspects, such as climate change, are being considered.

We review how MFDs and DSSs assess forest dynamics by considering management, risk, and climate change. More specifically, we evaluate 1) how climate change, risk, forest management, and optimization techniques are considered, 2) how flexible management is represented concerning the formulations of forest dynamics, risk, and environmental change, and 3) current gaps and research recommendations for these tools.

We base our assessment on 40 MFDs and DSSs that represent tree demography and have been used in the last 20 years to assess the implications of climate change, risk from natural disturbances, and/or forest management. MFDs and DSSs are classified according to variables representing their approach to modeling forest dynamics and how they consider risk, climate change, and management. We analyze each of these aspects and variables concerning their flexibility and complexity. Ultimately, we provide recommendations for a way forward related to flexible forest management under risk considering changing environmental conditions for implementation in the context of forest operations research.

Developing a Forest Ecosystem Management Decision Support System (FEMDSS) for Enhanced Adaptability and Generality

T5.3 Assessing forest sustainability through operations research

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Abstract: Developing a comprehensive Forest Ecosystem Management Decision Support System (FEMDSS) is time-consuming and expensive, often spanning several years or even decades. Even though efforts have been made to generalize and share knowledge and resources, given the complexity, researchers have focused on developing FEMDSS tailored to specific forest contexts, models, and methods. However, to address the evolving climate change challenges through nature-based solutions, modern FEMDSS must transcend conventional applications. A modern decision support system should be embedded within a Multicriteria Decision Analysis framework and designed to be inclusive, allowing researchers, forest managers, and practitioners from diverse regions, countries, and forest contexts to utilize it effectively. Therefore, FEMDSS's resulting plans could encompass all aspects of a multifunctional forest while considering financial viability.

In this study, we introduce the initial two modules of the Romero® FEMDSS, namely *iGen*, and *iMath*, which were conceptualized in a cutting-edge technological environment. Both modules are Python packages designed to function as components of local solutions, utilizing SQL databases for the Rule-base, initial forest state, and scenario results. The iGen module contains an engine that generates management alternatives, allowing forest managers to describe their forests using variables, rules, formulas, functions, and procedures. They can define possible interventions, their temporal progression, and how they change in the initial forest state. Outputs can be related to yields, income, costs, or other ecosystem services.

The iMath module allows users to specify the accounting variables and their calculation methods using variables from the preceding module. These accounting variables can subsequently be employed as constraints or objectives within a linear programming model (LP or MIP). Notably, the FEMDSS is not limited to, adapted to, or focused on any particular region, landscape, forest condition, projection method, or yield function. Instead, it aims to maximize generality, enabling it to address various Forest Ecosystem Management Problems.

This presentation demonstrates the flexibility, adaptability, and generality of the developed FEMDSS, highlighting the *iGen* and *iMath* modules. By showcasing these components, we contribute to the discourse on forest ecosystem management, providing a powerful decision-support tool for researchers and practitioners across diverse contexts and locations.

Joint analysis of forestry and factories using linear and nonlinear programming methods

T5.3 Assessing forest sustainability through operations research

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Abstract: The open source software Jlp22 available at github.com/juhalappi/Jlp22 provides many methods for analyzing forestry data. The most interesting may be the linear programming functions which provide a flexible interface and an efficient algorithm for forest management planning problems. Jlp22 is a completely rewritten successor of the J software which was the successor of JLP software used in the Finnish Mela planning system. J provided possibilities to include factories in the analysis. Jlp22 will provide more advanced methods for analyzing transportation of logs to sawmills, chips from sawmills to pulp mills, pulp wood from forest to pulp mills and import and export of timber. The data structures and functions have been developed for nonlinear programming and piecewise linear functions. Ecological constraints and objectives can be included in different spatial scales. The utilization of parallel computation in supercomputers is under development. A book will describe the mathematics of the applied optimization methods and show how the interaction between forestry and industry can be analyzed from the view point of forest owners, independent saw mills, companies having both saw and pulp mills and government. The carbon and climate change can be included in the analyses when proper data and models will be available. Uncertainties in growth and price trends will also be considered.

Spatial configuration at landscape level for reducing spruce bark beetle susceptibility: a mathematical modelling approach

T5.3 Assessing forest sustainability through operations research

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Abstract: Spruce bark beetle (Ips typographus L.) is considered a significant threat to European forests often resulting in extensive tree mortality and economic losses. Forest management planning, using operations research, can be a valuable tool to address this problem by understanding which are the factors that contribute the most to susceptibility and finding ways to address them in the long term. In this study we adopted a landscape approach to generate new spatial configurations promoting less prone conditions to spruce bark beetle susceptibility. We simulated forest development alternatives and implemented the heuristic method simulated annealing to optimize the spatial configuration of harvest activities at landscape level. The objective is to optimize harvest activities to achieve forest conditions for lower overall susceptibility to spruce bark beetle at landscape level while achieving the largest possible financial value. Our mathematical model consists of three parts describing the development of spruce bark beetle susceptibility of the forest, and a fourth part accounting for financial value, 1) total spruce bark beetle susceptibility at landscape level, 2) distance between areas with high susceptibility, 3) size of areas with high susceptibility, and 4) net present value estimations for each management possibility. The proposed model is evaluated in a case study for Asa forest property located in southern Sweden and comprised by more than 700 forest stands and for a 50-year planning horizon. Preliminary results indicate that the model is functional and contribute to a forest with lower susceptibility against bark beetle damage. The evaluation of these results provides valuable insights into optimizing forest landscapes to reduce spruce bark beetle susceptibility.

Sustainable forest landscape planning under climate change: an interactive multi-scenario multiobjective robust approach

T5.3 Assessing forest sustainability through operations research

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Abstract: Forest landscape planning involves complex decision-making processes that encompass high dimensionality, conflicting objectives, and uncertainties from various sources. To effectively tackle these challenges, decision-makers require appropriate decision support tools. While some uncertainties, such as those arising from climate change, cannot be adequately addressed using probabilistic models, they can still be described as a set of plausible future outcomes known as scenarios. In situations where decision-makers lack information or consensus regarding the likelihood of these scenarios occurring, a condition referred to as deep uncertainty, support is needed to identify robust decisions that perform well across a broad spectrum of scenarios. Balancing tradeoffs among conflicting objectives and the uncertainties presented by various scenarios becomes crucial in this context.

We propose a novel interactive approach to address key challenges in real decision-making situations in forest management. These challenges include dealing with deep uncertainty from multiple sources and conflicts between sustainability objectives such as timber revenue, carbon storage, and biodiversity. Unlike previous approaches, the proposed approach enables decision-makers to explore various aspects of forest planning and assess objective conflicts in different future scenarios. This provides deeper insights and helps avoiding extreme losses by considering the unknown future. The interactive nature of the approach reduces complexity and cognitive load, providing a more conducive environment for decision-makers to learn about problem limitations and augment the data available with their domain expertise leading to better decisions. indeed, the tool supports finding the best balance among conflicting objectives and across scenarios. The benefit of analyzing multiple plausible future scenarios is to gain realistic insights into consequences, understand overall robustness, and ensure the robustness of the chosen management strategy to climate change and other uncertainties. We demonstrate the practicality of our proposed approach as a decision support tool through a case study of forest landscape planning with a 50-year planning horizon. It has four objectives and twelve scenarios (including climate change scenarios), showcasing the efficacy of our approach in aiding decision-makers in their complex decision-making processes.

The ease, or difficulty, of addressing forest sustainability through operations research

T5.3 Assessing forest sustainability through operations research

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Abstract: In a perfect world, the ability to consider socio-economic and environmental conditions through operations research methods employed to develop forest plans can help society assess the potential outcomes of the forests we manage. The language employed in forest plans today often suggests sustainability will be achieved by following certain courses of action. However, the metrics employed to measure sustainability, and the functional relationships that link management actions (as represented by formal decision variables in an operations research context) to sustainability metrics are often unclear. Further, concepts regarding what is, and is not, sustainable change as our knowledge of forest systems evolves. The objective of this presentation is to illustrate the outcomes from a survey where forest planners were asked how easy or difficult it would be to incorporate real-world statements of forest sustainability into an operations research framework. Results suggest that statements regarding the sustainability of provisioning ecosystem services may be easier to confirm through operations research processes, while statements regarding the sustainability of cultural, regulating, and supporting ecosystem services may be much more difficult to confirm. Insight is provided into challenges regarding the development of the data and the functional relationships necessary to sincerely assess forest sustainability through operations research. Commentary is provided on the potential disconnect between vague statements regarding forest sustainability and the ability to prove it through mathematical modeling, and whether certain aspects of forest sustainability have been generalized to such an extent that their meaning may no longer be of value.

Tradeoffs among Wildfire Protection & Other Ecosystem Services in a Forest Management Problem with Harvest Area Constraint: A Pareto Frontier Approach

T5.3 Assessing forest sustainability through operations research

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Abstract: Forest management has broadened its scope to consider various ecosystem services, including fire protection, beyond timber production. Given the need to balance multiple ecosystem services and understand their trade-offs amidst regulatory constraints such as harvest area and timber flow over a planning period, our research applied a Pareto frontier approach for a large mixed-integer forest management problem. With this method, we analyzed trade-offs between fire-related ecosystem services (using fire resistance indicators as a proxy) and other services such as biodiversity, erosion prevention, and carbon sequestration. The resulting interactive decision maps effectively depict these trade-offs while ensuring that harvest area and timber flow constraints are not violated. We applied this approach to a forest landscape in Northwestern Portugal, yielding promising initial results that enhance our understanding of ecosystem service trade-offs in spatially optimized forest management. This paper also highlights the challenges encountered during the study and discusses potential enhancements to our methodology for future applications.

Keywords: Wildfire protection, Ecosystem Services, Trade-offs, Pareto Frontier, Spatial Constraint, Optimization

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

A Decade of REDD+ in Nepal: Status and Way Forward

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

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Abstract: REDD+ is a climate change mitigation strategy aiming at reducing emissions from deforestation and forest degradation in the developing countries, and the role of conservation, sustainable management of forests, and enhancement of forest carbon stocks. This paper provides a general overview of the REDD+ readiness activities to get prepared for REDD+ implementation in Nepal. Readiness activities over the past decade have been focused on the development of National REDD+ strategy, capacity building and establishment of institutional arrangements. Although most of the readiness activities have been carried out, some additional activities, including strengthening national forest monitoring system and updating forest reference level are still ongoing. A participatory and inclusive approach involving and engaging stakeholders in the REDD+ process is adopted in Nepal. After more than a decade of REDD+ readiness, Nepal has already entered into REDD+ implementation phase. Emission reduction payment agreement with the forest carbon partnership facility (FCPF) of the World Bank in 2021 has paved the way for REDD+ implementation phase. During the implementation phase, Nepal is now implementing emission reduction program at the subnational level in 13 districts of the Tarai Arc Landscape. Seven emission reduction program interventions ranging from localized and improved community-based forest management, through private sector engagement in the forestry sector and alternative energy promotion, to integrated land-use planning is being carried out in the field. Furthermore, Nepal is also working with another emission reductions program in three Provinces including Gandaki, Bagmati and Lumbini provinces under the Lowering Emissions by Accelerating Forest Finance (LEAF) Coalition. With these programs in place, Nepal will be eligible to receive result-based payments for emission reductions that will ultimately contribute to forest based climate mitigation and adaptation at the grassroot level.

Decolonial environmental justice in forest landscape restoration

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

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Abstract: Chapter accepted and forthcoming in: Restoring forests and trees for sustainable development - Policies, practices, impacts and ways forward. Editors: Pia Katila, Carol J. Pierce Colfer, Wil de Jong, Glenn Galloway, Pablo Pacheco, Georg Winkel. Oxford University Press."

This presentation focuses on gender transformative approaches and environmental justice in international landscape restoration initiatives. We depart from the three-dimensional environmental justice framework to draw from decolonial, indigenous and gender justice perspectives, placing particular attention to human-nature binaries, epistemic justice, relational ontology, self-determination, and self-governance. We highlight the embeddedness of the current international landscape restoration efforts within the (neo)colonial and neoliberal natural protection efforts, risking similar injustices, violence and forms of oppression, including epistemic and political denial and oppression, ignorance and/or erasure of local people's histories, agency, their sense of belonging and ways of knowing, as well as weakening of their rights and access over their territories and livelihoods. Some of the major barriers to effective, just and equitable landscape restoration include: (i) prioritization of global over local knowledge systems, logics and politics in global landscape restoration; (ii) targeting of small-scale drivers of land degradation over large-scale and more profitable ones; (iii) offshoring burdens of global landscape restoration on the local people's shoulders; and (iv) reliance on state authority and institutional structures and bypassing of customary and indigenous authorities and legal systems. We conclude by proposing a set of questions and conditions for policy makers and scholars to contemplate and reflect upon when designing and analysing landscape Restoration projects and activities.

Implications and Policy Insights of the EU Supply Chain Due Diligence for the Korean Forestry Sector

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

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Abstract: This study conducts a comprehensive analysis of the implications and policy insights arising from the EU supply chain due diligence directive for South Korea's domestic forest policy sector. It focuses on examining market-related due diligence obligations and legislation pertaining to the forest sector, particularly in relation to supply chain due diligence. Additionally, the study investigates various guidelines and discussions that have influenced the formulation of OECD guidelines, with a specific emphasis on the Draft OECD-FAO Handbook on Deforestation, Forest Degradation, and Due Diligence in Agricultural Supply Chains. By comparing the findings of this analysis with the current forest policies and regulatory landscape in South Korea, the study aims to understand the response of the Korean forest sector and consider potential legislative implications. Notably, certain limitations within Korea's existing systems, including the Act on the Sustainable Use of Timbers' framework for promoting legal timber trade, are revealed through this research.

Preferences of private forest owners regarding membership in the forest owners association (FOA)

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

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Abstract: The purpose of this study is to determine the preferences of private forest owners regarding membership in the Forest Owners Association (FOA) - a case study for Poland. The intended goal was achieved by directly surveying a nationally representative sample of Polish farmers who own forests. The surveyed forest owners were offered to choose one of the four defined models of forest association organization in Poland, with the fifth option being to make their own proposal. The obtained distribution of preferences was analyzed using two log-linear models. They made it possible to explain the differences in the frequency of respondents' statements on the proposed models of forest association organization in relation to selected content variables (answers to three closed questions of the survey) and variables from respondents' statements (age, gender, and education). The survey was conducted on a representative large, nationwide random sample of forest landowners who are farmers (1003 questionnaires). The computer-assisted personal interview (CAPI) method was used, with a standardised interview questionnaire containing 16 factual questions and a survey metric. This publication provides the results that allow to indicate the preferred form of organization of associations in Poland, as well as the results of a random typology of a representative sample of forest owners (farmers) based on the preferred form of organization of associations, taking into account aspects of management of wood raw materials, as well as social variables of owners (gender, age and education). Owners of private forests in Poland agree to organize into FOAs. The preferred form of FOA depends, among other things, on the purpose of the harvested wood, the willingness to sell it, and the gender, age, and education of the forest owner. The financial situation of the owner, on the other hand, does not play a role. Based on the conducted analyzes, it can be concluded that the most beneficial solution would be to establish an association of owners in a community, working together at the district (poviat) level in Poland, which would allow forest owners to take various initiatives at the commune (local) level, including the joint sale of wood.

Reflections on forest policies in turbulent times: Hydra and Chloris worldviews

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

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Abstract: We live in turbulent times of multi-crises: climate change, biodiversity loss, deforestation, geopolitical conflict, increasing poverty. As a consequence, demands for and pressures on forest resources are tremendously increasing. At the same time, while many expect that forest policies might make some difference in addressing these crises, various scholars consider this position as very naive and even contra-productive, because these policies are part of the problem, not part of the solution. Although such worries and ciriticism are justified, we have to be careful not to become fully caught in a 'dystopic discourse' from which we cannot escape. Terms like crises, catastrophies, fragmentation, conflict, incoherence, marginalization, power asymmetries, etc. are all taking central stage, thus funeling our worldviews into ever darker tunnels with no light at the end. Many youngsters are even getting depressed of the world they are born in recently. So, maybe we have the obligation to show that another world is possible, and partly in the making, without becoming too naive and techno-optimistic. Maybe we also have the obligation to use or add alternative terms - like challenges, diversity, alternative practices, cooperation, success - in addressing the multi-crises, or show the dialectics between contradictory concepts. In this paper, the worldviews of Hydra (dystopic) and Chloris (utopic) will be presented, after which I will analyse how these relate in a dialectic way, are to be linked to forest policies, and how both are - at least in my view - legitimate positions. With the aim to bring at least some light at the end of the tunnel...

Synergies and conflicts in dynamic dialogues for shared forest governance between the Cree nation and the Quebec state in Eeyou Itschee, Canada.

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

François-Xavier Cyr[1]
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Abstract: Forest governance, long seen as either a state or private role, is increasingly recognised as a shared responsibility involving a variety of actors, from the local to the international. In *Eeyou Itschee*, traditional Cree territories in north-eastern Canada, new forest governance initiatives engage the Cree, the Quebec provincial government, private forestry companies, non-Cree communities, and the broader national society. We analysed the dialogue between the two key actors, the Cree and the Quebec state, since 2002 as they developed a new forest governance framework to accommodate multiple and often conflicting goals. In common with many modern states, Quebec has a strong centralized framework of policy and legislation for managing forests, that is not easily reconciled with the Cree's own values, knowledge, and aspirations, nor with their expectation for a redistribution of power in respect of their traditional rights.

In this poster we present key findings about the nature of this relationship, seeing it as a series of dynamic dialogues, themselves assemblages of practices and processes. We identify five clusters of practices that are used in differing ways in multiple processes, and with varying outcomes: distinct representations of the landscape; trickling-down of policy debates into "technical" issues; competing knowledge systems; a bureaucratic logic; and the role of gaps and bridges in collaboration. This can best be understood as a tapestry, where threads of varying colours represent different practices intersecting in different patterns or designs. The Quebec state, with greater resources and power, has more influence over these patterns and designs, although the Cree have made significant progress towards their own goals and Quebec has not obtained all it wants. This presentation shows that the distinction between synergy and conflict is not always clear and that the design and implementation of policies that respect the positions of parties is a challenging process.

Synergies or conflicts between international forest-related governance initiatives? Setting the scene

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

Lukas Giessen[1]
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Abstract:
This contribution to the round table will discuss international forest governance regimes based on my experience in political studies and tropical forestry
This contribution aims to take stock of recent and emerging forest governance initiatives at international scales, which have emerged as a response to various challenges and crises. In particular, it addresses forest-focused as well as forest-related public and private initiatives from climate change, biodiversity, indigenous rights, ecosystem restoration and bioeconomy policy realms. In a round table format, this contribution discusses the extent to which these initiatives and their policy instruments converge or contradict in their goals, theories of change, and expected effects on the ground. It will elaborate to what extent these initiatives might contribute to problem- and crises-solving, or on the contrary, will only remain symbolic entities. Their further potential impacts will be scrutinized, including on e.g. forest ecosystem service supply, trade and market organization as well as the relation between priced vs. non-priced services.

The forestry sector in turbulent times: towards a 're-concentration' of governance centers and capacities?

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

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Abstract: Policymakers have recently introduced strong normative frameworks and new policy tools to support a transition toward a climate-neutral and just society, and numerous private and market initiatives were and are being developed. However, new and forthcoming policies (e.g., EU Green Deal, Sustainable Development Goals, Bonn Challenge on Forest and Landscape Restoration, New York Declaration on Forests, REDD+, EU Deforestation Regulation, US Forest Act, and others) have contradictory goals with respect to the increase of forest coverage, use of forests for biomass production to support bioeconomy, biodiversity protection, and carbon sequestration. Contrasting demands are affecting the use of forest resources, increasing the risks of conflicts over ownership, management, access, and land use rights. The implementation of the new policy instruments will have large implications for individuals and organizations, markets (e.g., shifting trade patterns), and societies (e.g., raising inequalities), and beyond. If not designed and implemented carefully, this can lead to conflicting requirements of different policy instruments themselves, as well as among policy instruments and private sector and civil society initiatives. These new policy instruments should also carefully consider their potential impact on small producers, indigenous and traditional communities, thus avoiding replicating the power patterns that have put them in unfavourable and marginalized positions. Finally, the stakeholders living in and managing forests should be closely engaged in the process of the design and implementation of policy instruments, to avoid sentiments of new colonialism, and thus achieve 'true' participation and deliberation.

For all these reasons, a 're-concentration' of governance centres and capacities is much needed soon. But how are the new forest-policy discourses practicable considering our turbulent times and the need to balance environmental protection and decarbonisation with the associated increase in biomass production? How can power be redistributed to support a "just, sustainable, and green" society, considering the emergence of new needs and technologies? The paper will reflect on all these driving forces, suggesting principles and priorities for policy action.

The Impact of Environmental Regulations on the Power Dynamics of Third-Party Environmental Standards: The Case of the European Environment

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

Aynur Mammadova[1]
Luiz Henrique Cosimo[1], Mauro Masiero[1], Todora Rogelja[1], Davide Pettenella[1], Laura Secco[1], Jelle Behagel[2], Verina Ingram[2]
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Abstract: In recent years, regulatory actions have increased at the European Union (EU) level on different issues in response to public requests for an increased EU commitment to a greener and a just future. The growing number of environmental regulations shows the growing ambition of the EU as an environmental regulator and an important player in global quality standards of environmental performance. However, the governance implications of these new legislative acts individually and in relation with each other have not yet been studied.

An example is provided by the European Regulation on Deforestation-Free Products (EUDR) approved in 2023, whose requirements for due diligence and control for cattle, cocoa, coffee, palm oil, soya, natural rubber and wood products entering the EU market are becoming stricter than those of private standards in the relevant sectors. These changes influence the position and power of Voluntary Sustainability Standards (VSS) enacted since the 1990s, with the aim of primarily filling policy and regulatory gaps, that also influenced the landscapes and governance regimes in origin countries. It is not clear whether these VSS will adapt to the new policy and governance arrangements, remain relevant or simply disintegrate. Despite the generally welcoming attitude of private standards towards the new Regulation, the nested interests of various stakeholders in VSS suggest that the transition might be challenging and costly. This research seeks to explore the changes in power dynamics in Europe surrounding the topic of sustainable and deforestation-free forest management and agriculture. First, we take the EUDR as a case study and compare its criteria and requirements with those of prominent private standards in each of the commodity sectors. Second, to understand the narratives of adaptation, we present the discourse analysis of the public documents as well as of the interviews with the representatives of VSS. Our preliminary conclusions indicate that private standards and related enterprises will still play an important role in sustainable forest management and commodity markets, but their role is increasingly contested by origin states. Significant changes in their criteria and requirements are necessary to maintain the relevance in view of the newly adopted EU regulation.

The Wood Solution—Creating a high-value timber industry in the Global South

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

Rosa Goodman[1]
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Abstract: There is a serious disparity between high-value bio-economy solutions proposed in the global North (ie, CLT and mass timber buildings) and those proposed in the Global South (ie, beekeeping and other non-timber forest products). Given the dominant paradigm of tropical forestry, it is understandable that many environmentally and socially-conscientious people and organizations have shied away from engaging with timber production in tropical countries with developing economies. However, another model of management is possible for natural tropical forests—if we change the industry outside of the forests. Not only is it possible, it is necessary to transform the tropical timber industry or we will lose the immeasurably valuable natural tropical forests to more profitable land uses.

We theorize that the unsustainable nature of tropical forests begins with the market for large, standard dimensional timber, primarily for export. This model relies on harvesting the largest, best formed trees of a few well-known species from nearly pristine forests and degraded them with each harvest. Very little value is added in country; and it requires little transparency, so illegal logging is rampant. However, with an integrated and adapted industry, this trajectory can be transformed. If the final products are known in advance, it becomes possible to harvest timber from forests that would otherwise be deemed degraded and restore them through active management. This is made possible through adaptive small- and medium-scale timber processing systems—the often-ignored link between forests and forest products.

To be implemented at scale, this model needs to be genuinely enticing to rural and regional entrepreneurs and forest managers. Our analysis shows that over 3 times more value can be created with an integrated system across the value chain. Forests could gain 10 times their value, through increased productivity and timber quality. Operating margins in the local sawmills can increase nearly 28 times with an optimal mix of products and markets. Mass timber building is completely possible in tropical environments. Tapping into the $US10 trillion year^{-1} construction and engineering industry[87] could serve as a massive market driver for large-scale forest restoration and management and the creation of a new, regenerative industry.

Transnational timber legality and deforestation policy changes in the EU, UK, USA and China, and their implications on tropical countries

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

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Abstract: In my talk, I will present policy science results on the development and implementation of the transnational Forest Law Enforcement, Governance, and Trade (FLEGT) and new set of deforestation free regulations. I will show both stabilty and changes in the rules governing legality and sustainability, and point out both trade-offs and synergies between a range of regulations in the EU, UK, USA and China. I will conclude with offering a summary on the implications of the variety of transnational regulatory standards for market leackage and distortions on the global markets.

Voluntary carbon market in land use in the sector - development, demand and measures in Finland

T5.4 Between synergies and conflicts: public and private forest governance initiatives in the context of turbulent times

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Abstract: It is predicted that voluntary carbon markets will experience significant growth in the future due to companies' carbon neutrality goals and increased awareness of climate crisis. Voluntary carbon markets offer companies the opportunity to offset emissions of their operations that cannot be otherwise reduced in the short term.

This report examines potential mitigation activities in agriculture and forestry in Finland. The report also evaluates factors related to the demand and supply of carbon credits, the impact of legislation on voluntary carbon markets, and the implications of voluntary carbon market growth on the forest and agricultural value chains. The report also addresses consumers' and companies' perspectives on purchasing and using carbon credits, as well as landowners' and farmers' willingness to participate in voluntary carbon markets. The findings of the report are based on a literature analysis, expert and company interviews, and a consumer survey.

The results indicate that consumers may perceive carbon offsetting as greenwashing, and there is significant uncertainty surrounding voluntary carbon markets. Consumers' attitudes towards voluntary carbon markets and offsets influence the actions of companies and the demand for mitigation outcomes. There are challenges in demonstrating the additionality and permanence of mitigation outcomes for domestic projects, particularly concerning mitigation activities that increase raw material production. While companies value domestic mitigation activities, the lack of standardization and the issue of double counting of mitigation outcomes restrict their purchasing.

Creating a voluntary carbon market that simultaneously serves the goals of consumers, companies, producers, and society is challenging. The objectives of stakeholders in voluntary carbon markets are partially conflicting. Although reaching compromises is not mandatory as participation in the markets is voluntary, finding compromises is crucial for market development and climate change mitigation. Thus, the voluntary carbon markets can grow, and more carbon dioxide can be absorbed from the atmosphere.

T5.5 Climate Action in Forest Education

EduFire Toolkit: A new teaching resource for secondary schools in a world with a changing climate and growing risk of wildfire.

T5.5 Climate Action in Forest Education

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Abstract: In the context of a changing climate, wildfires are among the most critical social, economic, and environmental challenges that many societies are experiencing worldwide. Information and education are essential to increase community preparedness and to properly manage forest ecosystems and landscapes, increasing their wildfire-resilience.

Having identified this educational need, the Pau Costa Foundation (Spain) joined efforts with the Open University of Catalonia (Spain), Leitrim County Council (Ireland), and the School of Agronomy of the University of Lisbon (Portugal) to address this need through an Erasmus+ project. The EduFire Toolkit (Educational Toolkit for Secondary Schools in Wildfires and the Climate Change Context) is a set of multidisciplinary educational resources that address the socioeconomic and environmental complexities related to wildfires. This toolkit follows a Project-based Learning (PBL) approach and comprises activities that promote school community engagement. It targets secondary school teachers and students (ages 12-16) and provides educational material and activities dealing with real and local issues related to climate change and wildfire risk reduction or its mitigation.

The EduFire Toolkit content encompasses multiple disciplines and European educational competencies, addressing fire, wildfire, culture, and climate change concepts. Challenges with various activities demonstrate how these issues are interrelated and promote student participation and engagement. The PBL approach stimulates students to gain knowledge and skills by developing challenges that deal with real-life problems. All the materials and resources developed by this project will be open-access. These materials can be used to complement existing teaching materials, facilitating schools in addressing the issue of climate change with an emphasis on wildfire risks.

The final EduFire Toolkit content will result from a collaborative effort between the four project partners, teachers, students, and local communities. An extensive literature review on wildfire educational materials available online was conducted and was combined with every partner's technical expertise. Finally, an Advisory Board composed of education and wildfires specialists worldwide will review all the content created before pilot tests are conducted in each partner country, and final adjustments are made. The EduFire Toolkit will help our next generations to become more aware of climate change impacts and increase their wildfire preparedness.

Broadening forestry education to tackle the climate crisis

T5.5 Climate Action in Forest Education
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Anssi Pekkarinen[1]
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Abstract: Transparency helps build mutual trust and accountability and encourages countries to increase their climate ambition over time. Boosting the transparency of forest data for climate action will be vital to supporting the enhanced transparency framework (ETF) under the Paris Agreement. The Food and Agriculture Organization of the United Nations work towards enhancing and strengthening the capacity of developing countries to collect, analyze and disseminate forest-related data to meet the ETF.

To date, raising awareness of the evolving climate landscape – particularly, the transparency-related aspects of the Paris Agreement – has been supported by the Capacity-building Initiative for Transparency (CBIT) trust fund. The FAO and the Global Environment Facility (GEF) have collaborated on the project, Building global capacity to increase transparency in the forest sector (CBIT-Forest), to make forest data more transparent, accessible and available, in line with the ETF requirements.

Since 2020, the FAO Sub-Commission of the International Forestry Students' Association (IFSA) and the FAO Forestry Division (NFO) have collaborated to ensure students and young professionals can access educational transparency-related material. For example, the self-paced eLearning courses and the three editions of the massive open online courses, all in multiple languages. This has allowed more equitable access to forest and transparency-related knowledge with almost 40% participation of women in the online courses. More recently, a series of IFSA-FAO webinars organized on "Forests and Climate Transparency" has shared knowledge resulting from the forest and transparency case studies of Asia, Africa and Latin America regions.

It is crucial to make transparency-related efforts and knowledge visible and inform students and young professionals. This knowledge will empower them to help adapt local knowledge and practices to a changing world.

Emerging opportunities for forestry education through strengthening climate change curricula

T5.5 Climate Action in Forest Education

Regan Pairojmahakij[1]
David Ganz[1]
[1] RECOFTC

Abstract: Climate change is the global challenge of our era and is an existential threat. In a survey in the United Kingdom earlier this year, about a third of young people are scared, sad or pessimistic about climate change, with more than a quarter feeling overwhelmed. Given that the youth of today stand to suffer the worst effects of climate change in coming decades, this makes sense. This deep rooted and evidence backed source of concern can serve as a powerful trigger for action and for mobilizing a growing cohort of activists, scientists, advocates and voters. At the same time, there is a disconnect between the sense of urgency being experienced by global youth around climate change and the relevance and emphasis being placed on climate change in international educational curricula. While climate change and the science around it is moving rapidly, curricula and educational programs are updating materials to reflect climate realities at a much slower pace. For FAO in 2020, RECOFTC undertook a regional assessment of forest education in Asia Pacific. The findings based on extensive surveys concluded that 'forest jobs have an image problem' and that forestry education could be considered to be suffering from a growing gap with contemporary interests of students and youth, including direct exposure to forests, inclusion and gender sensitivity, and generally failing to incorporate critical issues of the time such as climate change. This panel presentation will outline some of these challenges and the role that embedding climate change more meaningfully within more adaptive curricula development processes could contribute to significantly revitalizing the forestry education sector.

Global Virtual Seminar in the MSc EF programme – A joint effort of six European universities to include SDGs and climate education in the curriculum

T5.5 Climate Action in Forest Education

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Lucian Curtu[2], Meriem Fournier[3], Heinrich Spiecker[4], Timo Tokola[1], Harald Vacik[5], Cristina Vega Garcia[6]
[1] University of Eastern Finland
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[4] University of Freiburg
[5] University of Natural Resources and Life Sciences, Vienna
[6] University of Lleida

Abstract: MSc in European Forestry (MSc EF) is an accredited double-degree Erasmus+: Erasmus Mundus MSc programme jointly organised by six universities: University of Eastern Finland, AgroParisTech, University of Freiburg, University of Lleida, University of Natural Resources and Life Sciences Vienna, and Transilvania University of Braşov. All partner universities collaborate intensively in the programme delivery by offering joint study modules in addition to their existing curricula. In addition, Associated Partner universities in Brazil, Canada and China and Associated Industrial and Scientific Partners contribute to the programme delivery. The aim of the programme is to provide academic education in the field of sustainable resource management with special emphasis on bioeconomy and climate change knowledge. Global Virtual Seminar (3 ECTS) is one of the jointly organised courses included in the curriculum to complement climate action education for students of the programme. It is introduced here as an example of good practise on how to involve several universities in organising a joint course, how to include SDGs and climate education in the curriculum and how to provide students coming from different cultural backgrounds with good skills in project management, time management and communication in a digital, online environment. After this course, students will have a global view about the SDGs with a special focus on the chosen topics and have improved their knowledge and resources to tackle climate change. In addition, Keynote Talks by experts from the Associated Partners in the final seminar provide feedback for each student project and bring additional value by highlighting the importance of evaluating SDG's in a global context. The project work within multicultural groups and lasting for the whole academic year improves students' project management, teamwork, critical thinking, leadership, data management, communication and time management skills and teaches them responsibility to carry out long-term projects which are the skills that are very much appreciated in the working life. In addition, they will be familiar with the SDGs and recognize the factors and strategies that can be used in tackling climate change and in working to preserve our environment.

IFSA TreE-Learning - Climate education for all!

T5.5 Climate Action in Forest Education

Jair Granados-Chacón[1, 2]
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[2] Instituto Tecnológico de Costa Rica, School of Forest Engineering, Costa Rica

Abstract: With the increasing threat and importance of climate change, many sectors, including forestry will need to undergo significant transitions to adapt. This will require a competent and well-trained workforce to face the climate-related challenges of the future. Currently, the topic is not well addressed in higher education curricula and the resources available are very limited. The TreE-Learning platform provides an innovative alternative to fill this gap and complement climate-related education in forestry studies.

During the period 2023/2024, we created three learning modules focusing on climate-related topics for the purposes of the TreE-Learning platform:

1. Wood Energy and forestry By-Products Potential. The module provides extensive information on renewable energy and forest by-products as a source of energy to combat climate change.
2. Soil Health and Land Recovery. This module focuses on the potential of agroforestry systems to restore soils and increase their productivity and carbon sequestration.
3. Forestry on Peatlands. Provides insights on practical forest management applications to achieve sustainable timber production in peatlands.

The results presented will include the number of students who have taken the modules, the regional and gender diversity of the students, and their feedback on how the modules contributed to their existing knowledge and formal education.

School forest Carolinum: where the next generation shapes the forest of the future

T5.5 Climate Action in Forest Education

Alexa Beaucamp[1, 2, 3]
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[3] Gemeinnützige Stiftung Wälder für Morgen (Foundation Forests for Tomorrow)

Abstract: While the young generation will be strongly confronted with the consequences of climate change, education curricula still do not sufficiently incorporate knowledge about mitigation and adaptation strategies. Besides the need for well-structured educational material within forestry degrees in the tertiary education, there is a strong lack of climate and forest related knowledge transfer within secondary education curricula as well. Education programmes are needed to counteract the resulting stigmatised images of the forestry sector, the increasing disconnection of young people with the natural environment (Aruguete et al., 2020) and to prepare young adults how to address future environmental challenges effectively (Bradley, et al., 1999).

The pilot project School Forest Carolinum aims to address the above-mentioned problem and actively integrates students into the sustainable management of existing forest stands, open sites and lakes (overall around 2500 hectares) in Northern Germany. The programme focuses on the interrelations between forests and climate change and uses an approach based on citizen science, stewardship and interdisciplinarity. This does not only encourage students to develop a strong feeling of responsibility for "their school forest", but it also promotes a project-based, scientifically-oriented educational approach to enhance students' knowledge and awareness about the various interconnections of forests and climate change. While more recent forest school projects also involve the planting of trees to combate climate change (Schröer and Sauerwein, 2014), our project extends this form of climate action to a *long-term climate change mitigation and adaptation project* with students. Informed by forests and climate science, students will support i.a. the transformation of pine monocultures into more climate-resilient mixed forests in cooperation with practitioners and scientists. This responds to the issue that environmental education programmes often do not adequately address the complexity and interrelation of specific environmental problems and do not offer concrete opportunities for participants to become active (Hudson, 2001; Davis, 2003). As an innovative and new interpretation of forest schools, the project also contributes to global aspirations of more sustainable forest management. This presents a prospect important for policy makers and other stakeholders, striving for collective climate action and coherent education programmes for students of all ages.

The European Regulation on Deforestation-free Products: The importance of Education and Training of experts in the Implementation of the Regulation

T5.5 Climate Action in Forest Education

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Abstract: Within the framework of the Green Deal the European Union is developing a broad range of regulatory and policy initiatives on environmental and sustainability issues. However, new regulations challenge present and future practitioners within targeted sectors putting them in need of specific guidance to cope with normative requirements. To facilitate a green transition, a fair access to green skills across vocational education and training systems is needed. In the EU, training uptake has been increasing, but is still considerably below the target for 60% of the adult population to participate in training each year by 2030, as set by the European Pillar of Social Right Action Plan.

The European Regulation on Deforestation-free Products approved in 2023 provides the latest example of a regulatory instrument for enforcing sustainable forest management. The new Regulation implies overcoming new challenges and investments into preparing professionals and practitioners who can properly understand the requirements and support the process of its enactment. The training of new experts will be crucial in supporting the public and private sectors in preparation, adaptation, and application of the best available tools for the compliance with this Regulation. This will need to involve education and training of students and professionals, as they will need knowledge, skills, and entrepreneurial mindsets on the adaptation of existing practices, as well as promotion, development, and implementation of emerging solutions from policy, research, and practice. With this in mind, the Erasmus+ project Innovation Alliance for Training Programmes for Deforestation-free Supply chains in Europe (EMMA4EU) responds to the emerging needs for new green, transversal, resilience and digital skills and qualifications in international education and training curricula to meet emerging professional needs for deforestation-free economies and sustainable development. We will present how the project aims to fill the identified gap by studying the training, awareness and knowledge needs, and developing a specialised training program for the relevant stakeholders, within its lifetime 2023-2026, and share preliminary results emerging from the early phases of project implementation.

Tranformative learning for climate action in forest education

T5.5 Climate Action in Forest Education

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Abstract: Climate action is transdisciplinary in nature. There is a growing need for transdisciplinarity learning in forest education in order to develop professionals that can integrate knowledge and skills from multiple disciplines to address problems around climate change that cannot be tackled effectively by a single discipline. The advantage is significant as students get to develop a diverse set of skills and perspectives, as well as the ability to work across disciplinary boundaries to address complex problems of climate change. The gradutaes are, therefore, well-positioned to pursue careers in a variety of fields that require an understanding of multiple disciplines, including climate action. How does a curriculum that produces such professionals look like? A case of Malawi.

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

A climate-sensitivity study of hybrid poplar plantations

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: Poplars (*Populus spp.*) are one of the most important fast-growing timber species in the temperate world, and their sensitivity to climate is of great interest to breeders. However, breeders often select by genotype and environment interaction, and rarely carry out large-scale 'climate-growth' modeling. Most of the current research on climate sensitivity is carried out in the field of ecology, and the modeling object is more of a tree species, which is difficult to accurately reach the species Section or clone level. Unlike natural forests, poplar plantations have little variation in age, planting density, tree genetics, etc., and can better focus on climate response.

The poplar plantations in this study are distributed in typical climatic zones of China and Europe, including 14 Köppen-climate types in temperate and subtropical zones. The experimental materials were poplars of the *Sect. Aigeiros, Sect. Populus* and *Sect. Tacamahaca* that were more than 10 years old. After drilling the wood core at each site, X-ray scanning is used with equipment from Woodlab and UGCT of Ghent University. The annual growth of tree rings is correlated with historical meteorological data. The sampling will be completed in China by October 2023 and in Europe by summer 2024. At the same time, soil data, survival rate and other plantation parameters are quantified and added to the model. Climate-sensitive analysis are used in linear mixed models or Bayesian models. It is the intention based on modelling to predict poplar timber production in 2050 can be predicted using future climate predictions.

Selected references

A New Approach for Modeling Stand Height Development

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: Climate Change leads to rapidly shifting environmental conditions, which influences the future suitability of currently established tree species. When determining the optimal composition of tree species for different management goals, stand height growth is one of the driving factors. Though it's is most prominent in economic analyses, it can also be used to assess carbon storage or, as auxiliary variable, for windfall risk.

Losing site consistency implies, that future stand growth potential changes, as well. This calls for management tools, which can estimate stand growth in a changing environment. We present a new approach for statistical, site-sensitive models, to estimate stand height at any age under a broad range of environmental conditions for several species, including European beech, Norway spruce and Scots pine.

Our models are based on a growth curve, i.e. a modified, linearized Korf function, such that all obtained predictions follow a biologically plausible pattern. The data we use for parameterization is a unique novelty, a combination of state-space and space-for-time data, i.e. research plots and inventories from several sources. From this data, we can derive both a longitudinally feasible pattern as well as plausible model effects over a broad range of environmental conditions.

As dynamic environmental variables, we consider temperature, precipitation and nitrogen deposition. These are calculated as a weighted mean of sums for the annually determined vegetation period. As weights, we use species specific growth functions. Moreover, we use soil characteristics and location as static variables.

To combine the longitudinal characteristics with a broad amplitude of covariates, a two step approach is necessary: First, we derive the basic shape of the Korf function from the state-space data with a mixed model. Then, we use this shape in a generalized additive model (GAM) with the full data to estimate effects for the continuous and categorical covariates. Thus, we are able to dynamically predict stand height for the whole stand life under changing conditions, without the need for initial height measurements.

In the presentation we will show characteristics and traits of the novel data set, the models themselves and applications.

A Novel Construction Principle for Yield Tables – combining recent observations and growth simulation data

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: Yield tables are still a useful tool for forest planning in many parts of the world, in many cases even without alternative planning instruments. But many of the presently used yield tables are outdated looking at the underlying growth dynamics or silvicultural management concepts. The empirical data foundation to construct yield tables traditionally relies on long-term experimental research plots.

However, observations from experimental plots measured in periods of the far past cannot be used to derive the common yield table attributes as changing site conditions due to climate change, depositions etc. result in shifts of growth dynamics. On the other hand, using only recent data as a consequence will result in a heavily reduced data set not being sufficient to derive a yield table in most cases. This issue is exacerbated looking at the prerequisite to have balanced data over site index and age.

Therefore, we developed a novel construction principle for yield tables combining recent empirical research plot data with growth simulations using a single-tree growth simulator. The empirical data ensures realistic starting values for the simulator. Applying growth simulation provides growth data at the current increment level and widens the data set as each simulation stand is projected for a 30-year time period. The new yield tables are derived for Sessile and Pedunculate oak, European beech, Norway spruce, Douglas-fir and Scots pine. They are valid for northwestern Germany. However, the new construction principle can be applied universally to other species and world regions.

Although the resulting yield tables are not sensitive to future climate change they can be applied for their primary use, i.e. giving decision support in forest planning for the next 10 to 20 years. Envisaged future updates of the yield tables ensures adaptation to changing climate.

Climate Sensitive Mortality and Growth Modelling in Québec

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: Evaluating and implementing forest management strategies relies on forest managers having accurate and reliable climate-sensitive forecasts of where particular tree species are likely to survive and grow. However, current operational growth models are not fully climate-sensitive or only consider a limited number of species. My research focusses on modelling mortality rates for 29 individual species and 4 species groups in Québec, Canada, using 190,475 non-overlapping intervals measured over the period 1970-2018 in about 12,000 permanent sample plots.

Individual tree mortality was predicted with a generalized linear model (GLM) based on a complementary log-log (CLL) link function. Tree and plot-level variables along with disturbance variables were tested as potential variables in reference models. Enhanced models were built to include climate variables and were compared to the reference models in order to quantify the improvement in the model fit. These models of mortality will be used as a component to build a climate-sensitive individual-tree growth simulator for Québec.

Effects of functional traits on tree growth rates - now we know

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract:
Ensuring the sustainability of goods and services provided by forest ecosystems in the face of global change implies understanding the mechanisms underlying tree growth and being able to predict their relative influence across taxa and biogeographic environments. Functional ecology suggests that mechanisms affecting resource acquisition operate through differences between individuals that can be estimated from their functional traits. However, previous attempts to link traits to the individual growth rates of trees have shown that the most commonly accessible traits only explain a small portion of their growth. Furthermore, these small effects are inconsistent across studies and environments. In our study, we tested the relationship between the height growth rate of 35 tree species and 6 functional traits (specific leaf area, wood density, seed mass, leaf dry matter content, leaf nitrogen content, and photosynthetic capacity). Trees were planted in monoculture plots in common garden experiments, minimizing the influence of biotic and abiotic factors across seven sites of the IDENT network of experimental plots in North America and Europe. The individual height growth of each tree species was calculated considering several time intervals following planting over an 8-year period. Species-specific functional traits were identified by generating averages of individual values from the TRY database and the literature. Bayesian generalized mixed models were parameterized to predict growth as a function of the traits. Our results showed that functional traits have a slightly greater effect in the early years of growth, and those occupying a distinctly more important role in the first years of growth are subsequently replaced over time. Moreover, the magnitude of the effects exerted by these traits varies markedly between deciduous and evergreen species. We argue that the wide variation in the values of certain traits between deciduous and evergreen trees can mitigate the effects of traits on growth and highlight the importance of assessing trait effects for these two groups separately. Our results provide forest managers with reliable trait effects that will be useful for better predicting and managing the performance of planted and managed forests in tackling global change.

Empirical growth modelling in the Swiss National Forest Inventory: developments, achievements and challenges

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: Understanding tree growth dynamics is crucial in economic, ecological, and socio-political contexts and has implications for forest development scenario analyses and management strategies. Traditional empirical models for basal area increment (BAI) typically rely on basic tree, stand, and site information, assuming constant environmental conditions. Recognizing the urgency to incorporate (a) effects of environmental change and (b) more complex stand dynamics, the BAI modelling based on forty years of Swiss National Forest Inventory (NFI) data has undergone a variety of advancements over the recent years.

Regarding environmental change, initial efforts focused on incorporating temperature, drought, and N-deposition effects into empirical BAI models using a space-for-time substitution approach. We specifically optimized the definition of climatic variables by complementing NFI with tree-ring data. Findings indicated that using mean values of temperature and precipitation rather than extremes and considering whole-year or spring information, rather than vegetation periods, is advisable for capturing climatic effects on decennial BAI measured in the NFI. Further model developments specifically involved interactions, particularly between drought and N-deposition. Additionally, while studying the effects of the severe 2018 drought on a sub-selection of NFI plots, we found that compared to decennial intervals between inventories, annual remeasurements improved the quantification of drought effects on growth.

Regarding more complex stand dynamics, we found that mixed forests can promote BAI compared to monospecific stands, depending upon stand, topographic, climatic, and soil conditions. Furthermore, by combining NFI data collected on plots smaller than typical forest stands with growth and yield data, growth partitioning was investigated, i.e., the relative contribution of differently sized trees to total stand growth. Currently, our research makes use of the long-term nature of NFI data, which provides a unique opportunity to study temporal growth trends at regional and national scales, providing crucial insights into global change effects.

Our research revealed the great potential of NFI data for empirically modelling growth dynamics, as well as pathways to complement NFI with other data sources for further improvement of targeted growth-related research.

Environmental filtering of forest inventory data to incorporate climate response in site-based carbon capture models

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: Reforestation projects are increasingly funded by parties aiming to compensate for their CO2 emissions. These projects are paid for *ex-ante* based on the projected CO2 capture over a 40-year period. Accurate projection of the carbon capture of the potential reforestation of a site is thus of key importance for decision making on the financial viability of the project.

We developed a multi-species carbon capture model which is data-driven and globally applicable for site-level decision making on reforestation. The structure of our model is based on IPPC higher-tier approaches, expanded with competition for space between the tree species. The accuracy of this model is determined by calibrating the model to growth and yield data considered to be representative for the future growth conditions of the site. This is attained in a 3-stage process:

1) filtering national forest inventory data (NFI-data). We compiled both NFI-data (currently: US, Canada, Australia, Iberia, Iceland), and environmental data (among others: current and projected climate, soil type, elevation, elevation). NFI plots, containing the same species as planted, are selected if they fall within preselected ranges in the environmental data and distance to the planting site,

2) calibrating site-specific model parameters to the filtered NFI-data. We developed a user-interface allowing the user to select state-variables and several goodness-of-fit statistics to find the best model fit to the filtered data. The outcome of this step are optimal parameters and a covariance matrix on the variability and correlation structure between the model parameters,

3) applying the model and reporting its outcome. The optimal model parameters and the covariance matrix is used to arrive at a distribution of projections, representing the mean and uncertainty ranges of the output.

Climate response is thus implicitly accounted for based on selection of NFI plots that have grown in the expected future climate of the planting site. This approach thus avoids the explicit modeling of climate-growth relationships which requires the estimation of many parameters. The constraint of the method is thus that it relies on the availability of growth data that can be considered as representative for the future growing conditions of the planting site.

Integration of climate drivers into tree mortality modelling in Nova Scotia, Canada.

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: Empirical individual tree growth and yield models for the Acadian forest region are an important tool used in strategic, tactical, and operational forest management planning. Climate normals are a component of two Acadian forest site productivity models, used as inputs to two commonly used growth and yield models in the region (Forest Vegetation Simulator - Acadian Variant and Open Stand Model). The use of climate normals in a single sub-model (site productivity) within a model composed of many sub-models (diameter increment, height increment, mortality, and recruitment) presents several limitations. Under a changing climate, these climate normals used as inputs become invalid for future growth projections. The site productivity sub-models can be re-developed using projected climate normals from various representative concentration pathway scenarios, however this methods lacks the ability to deal with temporal changes in climate during model simulations. An evaluation of Forest Vegetation Simulator - Acadian Variant and Open Stand Model predictive accuracy was completed with permanent sample plot data from 1965 to 2022 in Nova Scotia, Canada. This evaluation assessed the predictive accuracy of the sub-models used within these two growth and yield models, and overall (net growth) model predictive accuracy. The permanent sample plot dataset and historical climate data were used to develop a mortality model that directly includes climate variables, providing the ability to incorporate temporal changes in climate into mortality predictions during simulations with these two growth and yield models commonly used to make forest management decisions.

Machine Learning Forest Simulator (MLFS): R package for data-driven assessment of the future state of forests

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: The Machine Learning Forest Simulator (MLFS) is the first fully data-driven model of forest dynamics. It is an easy-to-use and freely available tool applicable to all forest ecosystems, from even-aged monocultures to mixed forests with diverse vertical structures. The MLFS (v0.4.2) is available as an R package and can be downloaded from the Comprehensive R Archive Network (CRAN). It is a model system consisting of five sub-models for 1) calculation of tree and crown heights, 2) prediction of radial increments, 3) mortality of individual trees, 4) recruitment and 5) simulation of timber harvest. Thus, the newly developed model system requires forest inventory field plots data from at least two inventory periods and does not need to be manually parameterized. The main task for the users is to prepare the inventory data correctly and define the simulation assumptions, including climate, disturbances, mortality and harvesting rates. In the first step of a simulation, MLFS checks the input data for possible inconsistencies, calculates tree and crown heights, tree volumes, and competition and stand variables, and divides the data into independent training data sets needed to calibrate specific sub-models that are then applied sequentially during the simulation. At the end of each simulation step, dead and harvested trees are removed, and all other trees are made the subject of the next simulation step. We tested the MLFS with the latest national forest inventory data from Slovenia and simulated different mortality, harvesting, and climate scenarios. We show a wide range of possible applications and input settings that result in different growing stocks, yields, and forest structures. MLFS produces reasonable long-term simulations that can be used as forest management or decision support tools, for understanding the future national greenhouse gas emission trends, and for scientific purposes related to understanding forest dynamics from multiple perspectives.

Mixed-effects height prediction model for Juniperus procera Hochst. ex Endl. tree from Dry Afromontane Forest in Ethiopia

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: The height of a tree is an essential variable to determine the aboveground biomass, volume, site productivity, and vertical structure in a forest stand. However, measuring the total height of trees is challenging. This study aimed to develop an accurate height prediction model for *Juniperus procera* Hochst. ex Endl. trees using a nonlinear mixed-effects modeling approach. We recorded 1215 pairs of height-diameter measurements from 101 randomly established plots in Chilimo Afromontane Forest in Ethiopia. The most appropriate base model was chosen after comparing fifteen nonlinear models. We included the sample plot as a random effect in nonlinear mixed-effect models. The effect of adding various stand variables on the model's ability to predict height was then assessed. The best sampling alternative and methods for calibration were determined by comparing various sampling alternatives using an independent data set. The bias, root mean square error (RMSE), and Akaike information criterion (AIC) was computed and used as the model evaluation criteria. Our findings revealed that the Michaelis-Menten model best represented the height-diameter allometry of *J. procera* trees and was selected as a base model. The best mixed-effects model improved the height prediction performance with the RMSE and bias values of 2.692 and 0.043, respectively. The addition of the quadratic mean diameter and stem density slightly improved the prediction performance of the model. However, the best-mixed effects model captures the largest proportion of between-plot variability in height-diameter allometry and provides the best plot-level prediction. The best-mixed effects model's fixed effect can be used to predict the mean height of *J. procera* trees for a given diameter. The calibration response revealed that the systematic selection of the three largest diameter trees in a plot was the best sampling alternative to estimate the random effects and predict the height of *J. procera* trees from new plots. Generally, the height-diameter model developed in this study will help forestry practitioners and researchers reduce data collection efforts and improve decision-making regarding stand volume and biomass estimation in Afromontane forests in Ethiopia and elsewhere.

Keywords: forest inventory, native tree, allometry, calibration, stand volume

Transferable Climate Sensitive Growth and Yield Models: Improving Projections for Interior Spruce in British Columbia

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: The goal of many climate sensitive growth and yield models in practice is to estimate future conditions under climate change, often requiring predictions in settings outside the available training data. Using the example of interior spruce (Picea engelmannii x glauca) in British Columbia, Canada, we examined the potential of several techniques to improve the ability of climate sensitive models to extrapolate to future climatic settings. These methods include novel combinations of data sources, such as data drawn from multiple ranges, and novel model selection techniques. Existing provenance trials have been previously proposed as a source of climate response data in commercial tree species, but typically lack wide climatic coverage. In this project, we combined provenance trials from multiple native and exotic planted ranges of interior spruce with permanent sample plot data, to cover a wider range of climatic and stand conditions. We additionally utilized model selection techniques inspired by research in causal statistics to identify the climatic and edaphic variables best suited to prediction in uncertain future conditions.

Tree height, crown and slenderness ratio mixed-effects seemingly unrelated models for the Transylvanian region

T5.6 Continuing Challenges and Novel Solutions: Adapting Growth and Yield Modelling to the Global Change Paradigm

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Abstract: Tree height estimation plays a pivotal role in individual tree growth and yield models. It serves as a fundamental step that enables the computation of other essential variables, such as crown ratio and tree slenderness, which are important for predicting individual tree growth. The conventional approach involves developing separate models for each of these variables and using height as a predictor in the crown ratio and tree slenderness ratio models. However, an alternative approach is to establish a connection between these three models, and one way to achieve this is through simultaneous fitting. By employing simultaneous fitting, the interrelationships among height, crown ratio, and tree slenderness can be effectively captured, enhancing the accuracy and coherence of the growth and yield modelling process.

The aim of this study is to develop height-diameter, crown ratio, and slenderness ratio models specifically applicable to the Transylvania region. Spanning from 2020 to 2022, the study involved the measurement of over 24,000 trees on a systematic grid of plots covering the southern part of Transylvania in Romania. Height-diameter relationships, crown ratio models, and slenderness models were established for the most prominent tree species. The selection of functions was based on the cross-correlation power of their coefficients while in order to account for the hierarchical structure of the data, the models were fitted simultaneously using mixed-effects seemingly unrelated regression.

These developed models incorporate both stand-level and tree-level variables, taking into consideration the competition effect and they can be readily employed by forestry practitioners and growth modellers. A notable advantage of these models is their ability to cross-calibrate the random effect when new observations are available. This feature reduces fieldwork time and simplifies the calibration process of an entire growth model, as only a few tree heights are needed. The study highlights the benefits of employing a mixed-effects seemingly unrelated framework and demonstrates the cross-model calibration of one of the functions when new observations arise.

T5.7 Deadwood mapping based on remote sensing – Methods and applications, progress and perspectives.

Airborne and Mobile Laser Scanning for Instream Wood Detection: A Case Study Across Nine Headwater Streams in British Columbia, Canada

T5.7 Deadwood mapping based on remote sensing – Methods and applications, progress and perspectives.

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Abstract: The presence of instream wood, including trees, logs, and branches, is a critical component of healthy riparian ecosystems. Instream wood provides habitat for fish, promotes nutrient cycling, and helps to stabilize the stream channel. Mapping instream wood features is essential for managing and restoring riparian ecosystems. Airborne laser scanning (ALS) and more recently mobile laser scanning (MLS) have emerged as valuable tools for mapping instream wood features due to their ability to provide high-resolution data—both from above and below the tree canopy. ALS and MLS use laser pulses to capture the 3D structure of the forest canopy and the ground surface. ALS is typically acquired from a fixed-wing or helicopter platform, while MLS is acquired from the ground, often using a handheld or backpack-based platform.

We present a framework for the integration of ALS and MLS for mapping instream wood features in two forested watersheds across nine different stream reaches in British Columbia, Canada. Both watersheds have extensive harvesting histories beginning in the 1920s, with areas of both second growth and old growth currently present. Primary inputs of large wood to stream channels result from windthrow and mass wasting events. Historically, riparian harvesting and cross-stream yarding also contributed wood to stream systems.

Our mapping framework consists of three key steps to detect instream wood features from laser scanning point clouds 1) point cloud filtering, 2) skeletonization, and 3) validation protocols. Using ALS data, we found that our methodology was able to detect instream wood features with moderate overall accuracy ranging from 37–87%. Further, logjams were delineated with 87% accuracy and individual instream wood features with 49%. We then examined which laser scanning metrics, environmental characteristics, and instream wood properties (i.e. length, width, submerged depth) influence the detection accuracy. Our results indicate that the number of returns classified as ground, absolute scan angle, wood orientation, and submerged depth of wood have significant effect on detection accuracy.

Overall, the use of ALS and MLS for mapping instream wood features represents a significant advancement in providing information for improved forest management and planning in forested watersheds.

Dead tree dynamic monitoring with the use of multitemporal ALS and CIR data

T5.7 Deadwood mapping based on remote sensing – Methods and applications, progress and perspectives.

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Abstract: Climate change often causes extreme weather conditions that have a huge impact on forest vitality. Floods, extreme winds, fires, and hailstorms of insects, for example, cause trees to die. Monitoring the dynamics of dead wood occurring in the forest with a highly dynamic process and an extensive area requires access to a dense time series of remote sensing data to add value and actually support the Forest Service's operations.

In the Polish part of Białowieża Forest, monitoring of dead trees was conducted for eight years from 2015 to 2022. In the activities, we used multi-temporal airborne laser scanning data and mainly aerial CIR data. These data were acquired at different points in the growing season and allowed us to map the condition and detection of individual trees.

The monitoring results indicated that during this period several million trees died, and the share of spruce in the stands of the Bialowieza Forest decreased by more than half. The highest spruce mortality was recorded in the Białowieża Forest District, whereas the lowest was in the Białowieża National Park. The analyses carried out showed that the more open, older (over approx. 90 years old) spruce stands were the most susceptible to dieback in the initial phase of the outbreak. As a result of the thermal conditions in 2015, which were highly favourable to the spread of the European spruce bark beetle, more spruce stands died in the forest in subsequent years. Areas with young trees less than 90 years old proved to be the most resistant to the pest.

The fusion of ALS and CIR data enabled precise monitoring tree mortality process. It also supported practical management decisions in the Bialowieża Forest area, and increased the safety of people visiting it.

Detecting tree mortality and vitality in temperate forests using aerial RGB and RGBI imagery and deep learning

T5.7 Deadwood mapping based on remote sensing – Methods and applications, progress and perspectives.

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Abstract: In the last years, concerns about climate change risks to global forest health are rising due to increasing tree mortality as a result of anthropogenic climate extremes such as drought and windthrows and consequently pathogens and insects' infestations. To better understand mortality processes and quantify trends sufficient data for long-term monitoring is required. Tree mortality monitoring is a challenging task that typically requires extensive and costly field surveys. However, new perspectives are given by the advent of computer vision methods and the availability of high-resolution remote sensing data.

Here, we developed a highly automated, straight-forward approach to detect tree vitality and mortality covering the heterogeneous forest ecosystems in Switzerland using the object detection algorithm YOLOv7 and countrywide freely available RGB and RGBI aerial imagery. As reference data over 10,000 individual trees were labeled dead, heavily damaged, and slightly damaged using aerial image interpretation.

Validation with an independent test data set revealed that higher accuracies were obtained for dead trees than the other vitality classes, i.e., around 20% of the heavily and slightly damaged trees were misclassified as dead trees. In some cases, roads or open forest ground were misclassified as dead trees. A comparison of the model's performance based on RGB and RGBI imagery revealed a slightly higher dead tree detection for RGB images (F1-score = 0.76) than for RGBI (F1-score = 0.73). Together with the CNN models, we present a dataset of more than 10,000 individually labeled trees that can be used for further studies on tree vitality.

This work advances our current tree vitality and mortality inventory by providing a highly automated and reliable approach for identifying and geolocating individual tree health in heterogeneous forests over large areas using the available CNN framework. It also shows the potential of the single usage of RGB imagery and that the near-infrared is not a must-have. Thus, the presented CNNs models and approach are compatible with low-cost UAV systems that are applicable to a wide range of users. This can serve as a basis for planning, and targeted management actions for more resilient forests.

Evaluating the effectiveness of retention forestry for bats using remote-sensing-based forest structure variables

T5.7 Deadwood mapping based on remote sensing – Methods and applications, progress and perspectives.

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Abstract: Retention forestry, i.e. retaining groups of trees or small stands from harvesting, is an important conservation instrument for enhancing structural complexity and biodiversity in multifunctional forests. However, in contrast to local scale effects, its large-scale effectiveness is largely unknown, as this requires area-wide and sufficiently precise information on the target structures such as old trees and standing deadwood, as well as on associated species' habitats. Bats are particularly sensitive to forest structural characteristics and are therefore target organisms of most retention programs. To assess their response to retention efforts, we here compared key habitat structures and overall habitat suitability for bats across forest areas with and without retention, using forest structure variables derived from remote sensing along with topographic, climatic and land-cover variables and a multi-scale modelling approach. Based on acoustic data from 135 1-hectare plots across the Black Forest, Germany, we calibrated area-wide species distribution models for 9 bat species or bat species groups thereby identifying the best-performing scale (50 – 1000m radius) for each predictor and species(-group). Forest structure variables explained 38.3% of bat habitat selection, with forest height heterogeneity and the percentage area with standing dead trees performing best, mostly at small spatial scales (50 - 100m). Especially standing deadwood was identified as a limited resource for most of the investigated species. Their habitat suitability increased steeply at low deadwood levels and showed optima that by far exceeded the average amounts of deadwood in the study area. To assess the benefit of retention forestry for bats, we finally compared forests with and without retention measures. Forests with retention showed higher values of all bat-relevant structural variables, resulting in higher predicted habitat suitability for all dependent bat species(-groups). The results highlight the positive effects of retention programmes, and the value of remote sensing for evaluating the effectiveness of conservation instruments that aim at enhancing key forest structures for biodiversity.

Satellite Time Series Analysis for Near Real-Time Mapping of Deadwood and an Estimation of its Causes

T5.7 Deadwood mapping based on remote sensing – Methods and applications, progress and perspectives.

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Abstract: Deadwood mapping from remote sensing data is currently done at various scales: from terrestrial laserscanning on a local scale to airborne applications on a regional scale to large area mapping based on satellite data on a national scale. Our project focuses on the latter and builds on time series data from Sentinel-2. We have developed an automated system, which is able to map forest disturbances in near real-time, i.e. with an observed time lag of 15 – 30 days depending on location. This is possible through the smart integration of a Kalman filter in modeling of the spectral reflectance over time. Our approach produces useful results even in areas with a distinct phenology (deciduous tree shares) and in mountainous environments, where other methods fail or return very erroneous results. However, the availability of cloud-free observations is still a pre-condition for mapping any disturbances and longer time lags occur regionally if cloud or snow conditions are unfavorable.

The accuracy of our disturbance detection varies per year (due to weather conditions and thus image availability) and region. For Germany, the annual change maps derived from the NRT workflow show an overall accuracy of 99.1 ± 0.1 % over multiple study areas and years. The overall user's accuracy for the disturbance class was 83.8 ± 2 % and the overall producer's accuracy was 83.6 ± 3.3 %.

The time series behavior not only indicates the disturbance itself, but also gives important information on the underlying disturbance cause. Storm damage occurs very fast, while drought-induced dieback, often associated with bark beetle attacks, shows a longer deteriorating trend, which the time series data depicts. In combination with the specific spectral signatures of areas affected by different disturbance agents, it is also possible to distinguish red and grey attack stages for bark beetle infested forest stands.

The system runs both on DIASes and on desktop computers and has been developed in the frame of various research projects (AlpMon, BEAT IT!, FNEWs). It is currently running on test sites in Germany and in a wall-to-wall application in Austria (ESA FCM, ESA GTIF). A wall-to-wall roll-out for Germany is currently in preparation.

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

dataDriven: A Google Earth Engine and R tool for design-based data-driven mapping and per-pixel error estimation

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Accurate information about forest ecosystems is critical for conservation, resource management, land use planning, understanding ecosystem services, advancing research and education, making informed decisions and supporting sustainable practices.
The value of remote sensing in providing such information has been a topic of historical discussion. Although remote sensing has made enormous progress in recent decades, several limitations persist, leading many researchers and authorities to favor ground data acquisition. This is because although map products derived from remotely sensed data are increasingly available, reliable quality indicators and uncertainty estimates may be lacking. Consequently, clearer and more transparent validation and uncertainty estimation of maps remain a major challenge in forest remote sensing. Here we present dataDriven (https://github.com/saveriofrancini/dataDriven), an open access tool that exploits cloud computing features (google earth engine) and high-level programming language (R) to make users able to easily produce maps of environmental attributes and maps of the associated per-pixel error within a specific area of interest. This tool uses a data-driven design-based approach and relies on Sentinel-2 remote sensing data as auxiliary information, avoiding the need for extensive modeling associated with model-based approaches. Also, reference data are needed and must be available for a sample selected by simple random sampling, one per stratum stratified sampling, or systematic sampling. A unique aspect of our tool is the generation of both the attribute map and the corresponding map of estimated precision. This allows users to make informed assessments of the attributes being investigated.

A design-based critical look at k-NN spatial interpolation

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Mapping the spatial pattern of natural and environmental resources is essential for monitoring and management. Many spatial prediction methods have been developed that allow maps of the survey variable to be constructed based on a selected sample of units. Among them, the k-nearest neighbour (k-NN) technique has been widely adopted for a long time. Many applications of the k-NN method are related to the coupling of field data and satellite data for the mapping of forest and environmental attributes, also due to the increasing availability of freely accessible remote sensed data. Despite its popularity, most papers are of an applicative nature while only few are of a methodological nature.

Only recently, the asymptotic properties of k-NN predictors have been investigated by the authors in a design-based framework such that the statistical properties derive only from the probabilistic sampling schemes adopted to perform the surveys. More precisely, consistency of k-NN predictor has been proven when neighbours are determined in the geographic space, while consistency could be precluded when neighbours are defined only in the space of auxiliary variables, i.e. neglecting the geographical location.

A simulation study based on a real population of pixels partitioning a forest area is implemented to investigate the finite sample performance of k-NN predictors and, in particular, whether the exploitation of auxiliary information provides relevant increases in the precision of the predictors versus that achieved considering only the geographic space.

Furthermore, the simulation study aims to compare the performance of k-NN exploiting auxiliary information with that of alternative model-assisted predictors, which are obtained by considering auxiliary variables as covariates in a prediction model and the prediction errors are interpolated defining neighbours in geographic space.

Finally, some applications of k-NN and model-assisted predictions are presented.

A partnership to operationalize small area estimation within a national forest inventory

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: The Forest Inventory and Analysis (FIA) program of the United States Department of Agriculture Forest Service (USFS) is responsible for the national forest inventory in the United States. The program uses a combination of remotely sensed data and over 140,000 field plots to gather data on tree and forest attributes. Portions (panels) of the field plots are measured annually, with complete remeasurement taking from 5 years in the east to 10 years in the west. Approximately one field plot is measured per 2,400 hectares, resulting in a sample that provides reliable estimates with specified precision at the regional and national levels. However, the broad array of forest sector users who depend on FIA data have repeatedly called for efforts to enhance the precision of smaller domain estimates using FIA data to assist in carboning reporting, wood supply analysis, and assessing resource sustainability. Thus, the US Congress has directed additional funding to USFS Research and Development to address these needs. Challenged by disjoint research efforts producing sometimes conflicting results, the FIA program responded by initiating a Partnership for Small Area Estimation to unify its research and development efforts. Coordinated funding now supports small area estimation approaches that combine field inventory data with remotely sensed and other auxiliary data to enhance the precision of key parameters such as forest area, biomass, and carbon stock changes. This Partnership brings together a diverse range of stakeholders across industry, academia, government, and non-profit organizations, and their collective expertise is directed towards developing innovative approaches and computer applications that deliver valuable information products to the public. This presentation will describe the Partnership's origins, structure, and the process by which it is mobilizing research and technology to develop credible and accessible small area estimates through the national forest inventory of the US.

A separable bootstrap variance estimation algorithm for hierarchical model-based inference of forest aboveground biomass using data from NASA's GEDI and Landsat mission

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Hierarchical model-based (HMB) statistical method have been developed in response to demands for efficiently utilising multiple data sources, such as field and earth observation data, for assessing forest conditions. The method is currently employed in connection with NASA's Global Ecosystem Dynamics Investigation (GEDI) mission for global assessment of aboveground biomass and the associated uncertainty at a resolution of 1-km grid cells. This study focuses on uncertainty assessment using a bootstrapping procedure that separates the problem into parts, thus substantially reducing the time required for computations, which may otherwise make bootstrapping less attractive in this context.

The bootstrap procedure we propose is based on a theoretical decomposition of the variances into two parts based on a conditioning approach known as the law of total variance. Through this decomposition, each variance component can be estimated separately and simultaneously through bootstrapping. The variance components are (i) the variance conditional on the predictions obtained from the second model, i.e., the variance due to the first prediction step propagated through the second step, and (ii) the variance conditional on the first prediction model, i.e., the variance due to the second prediction step. The separable algorithm not only leads to less time-consuming bootstrap variance estimation but also allows a combination of bootstrap methods with analytical methods.

Reference:

Saarela, S., Healey, S.P., Yang, Z., Roald, B.-E., Patterson, P.L., Gobakken, T., Næsset, E., Hou, Z., McRoberts, R.E. & Ståhl, G. (in review). A separable bootstrap variance estimation algorithm for hierarchical model-based inference of forest aboveground biomass using data from NASA's GEDI and Landsat mission. *Environmetrics.*

Airborne LiDAR Reveals the Wood Density of Central African Forests

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Wood density is a key parameter for understanding the forest functioning and to quantify the amount of carbon stored in trees and forests. This fundamental functional trait is associated to physiological, structural, and defensive trade-offs of trees, and reflects the ecological processes that shape forest communities and their responses to environmental and historical drivers. As of today, there is a lack of adapted remote sensing approaches to depict this key determinant of carbon stocks, remaining the missing link for accurate mapping of AGB. Here we show that structural patterns of forest canopy, which can be readily captured by airborne LiDAR remote sensing, serve as reliable predictors of forest wood density. Our study reveals a strong relation between LiDAR-based canopy metrics, such as the sizes frequency-distribution and the proportion of gaps, and the successional stage of tropical forests, which determine the average wood density of the ecosystem. This result demonstrates that complex ecological processes are reflected in the canopy of the forest, and that LiDAR remote sensing is well suited to intercept this structure. We anticipate that our assay will be a breakthrough in achieving accurate largescale estimates of aboveground biomass (AGB) through remote sensing. Furthermore, as wood density is a key functional trait of trees, this methodology paves the way for future studies on the macroecological functioning of tropical forests.

AN APPROACH TO SILVOPASTORAL LANDSCAPE PLANNING IN THE BRAZILIAN CERRADO USING THE POTENTIAL FOR CONSERVATION USE INDICATOR

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Environmental Zoning (EZ) is considered a useful process for planning socioeconomic and conservation activities from a landscape perspective. Among the scalable and objective methods for integrating EZ, the Potential for Conservation Use (PCU) stands out. In this study, the PCU is calculated as an indicator based on relevant components expected to affect silvopastoral potential. The thorough evaluation of extensive regions is crucial for developing cohesive action plans, mitigating conflicts, and promoting effective public policies, especially in the Brazilian Cerrado. The intersection of ecological significance and agricultural activities in the region necessitates tailored approaches to ensure sustainable land management and biodiversity conservation. This study assesses the land suitability for silvopastoral purposes in the Brazilian Cerrado considering soil, vegetation, and ecosystem services supply. The PCU was computed using a script in Google Earth Engine, incorporating three sets of layer information: [I] soil class and terrain slope, [II] natural conservation areas, carbon storage, annual water yield, and habitat quality, and [III] a combination of [I] and [II]. Soil classes with favorable drainage, clayey texture and fertile values received higher scores, as did the flatter reliefs that were deemed more suitable for economic activities. The second set considered a higher percentage of natural conservation zones as conducive to biodiversity and successful reforestation, indicated by lower scores. Carbon storage, annual water yield and habitat quality were factors influencing agricultural or grazing aptitude. The variables were weighted using the Analytic Hierarchy Process to assess their individual effects on the PCU score. The PCU classification distinguishes the land potential for conventional agricultural activities (PCU ≥ 3) and underscores its importance for biodiversity conservation in the context of the Cerrado and its silvopastoral systems. Silvopastoral systems, known for their capacity to maintain biodiversity, can be key areas for biodiversity conservation, as reflected by a PCU score below the threshold of 3. We hypothesize that the PCU approach, integrated with environmental zoning, can improve sustainable landscape planning by offering insights into land suitability for tailored purposes. We expect that the results can contribute to a broader understanding of sustainable land management and support evidence-based decision-making processes in biodiverse landscapes.

An improved method for mapping understory bamboo from Gaofen-1 imagery

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Obtaining the distribution of understory bamboo is an important task for monitoring giant pandas and their habitats. Mapping understory bamboo distribution is significant to understand the spatial distribution pattern of giant pandas' habitats, and to assess habitat suitability, habitat fragmentation and ecological carrying capacity. In this study, we extracted the spectral features, texture features, vegetation indices and topographic features of coniferous forests, mixed coniferous and broad-leaved forests, and deciduous broad-leaved forests in Baishuijiang National Nature Reserve, China. A regression decision tree was used to calculate the importance values of the classification features, and the features with the top 15 importance values were selected to participate in the modeling. After reorganizing the classification features with the help of Gradient Boosting Decision Tree, a deep neural network model was applied to predict the spatial distribution of understory bamboo. The results show that the method has an accuracy of 89.56%, a recall of 93.37% and an F1 value of 0.90 for predicting the distribution of understory bamboo. The regression decision tree can effectively screen out the characteristic variables affecting the distribution of understory bamboo and weaken the influence of factors unrelated to the distribution of understory bamboo. The deep neural network framework combined with the gradient boosting decision tree can extract the spatial distribution of understory bamboo and promote the application of remote sensing images in monitoring the distribution of giant panda staple food bamboo.

Analyzing Forest Fragmentation Patterns through Vegetation Indices: A Study in the Tuchola Forest, Poland

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: This study aims to determine the optimal vegetation index (VI) for analyzing forest landscape fragmentation in northern Poland, with a specific focus on the Tuchola Forest. Utilizing Sentinel-2 images over the comprehensive summer period of 2019, our analysis leverages an extended suite of vegetation indices – NDVI, DVI, RVI, PVI, IPVI, WDVI, TNDVI, GNDVI, GEMI, ARVI, NDI45, MTCI, MCARI, REIP, S2REP, IRECI, PSSRa, SAVI, MSAVI, EVI, LAI – selected for their sensitivity to various plant parameters such as structure, growth condition, canopy closure, and understorey contribution.

To assess forest fragmentation, this research employs the Foreground Area Density (FAD), which measures the degree of fragmentation from Guidos Toolbox, analyzing forest cover across five observational scales and categorizing it into six fragmentation classes: Intact, Interior, Dominant, Transitional, Patchy, and Rare. This methodology facilitates a detailed examination of fragmentation patterns and their variability with observation scale.

Correlation analyses, employing Pearson's r for linear relationships and Spearman's rho for non-linear ones, were conducted to identify which vegetation indices most closely reflect changes in forest fragmentation. This dual analytical approach ensures a comprehensive understanding of how specific VIs correlate with the extent and nature of forest fragmentation.

By leveraging a broad array of vegetation indices and a sophisticated fragmentation analysis framework, the research offers profound insights into the intricate relationship between vegetation dynamics and landscape fragmentation. These insights are instrumental for developing more refined strategies for vegetation monitoring and forest management, ultimately contributing to the enhancement of forest ecosystem resilience and sustainability in the face of climatic challenges. This study underscores the importance of tailored, multi-scale analyses in informing effective forest conservation and management practices.

Application of Videogrammetry in Volumetric Measurement of Forest Structure Characteristics and Silviculture

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: The scientific community in recent decades was endowed with an advanced form of forest assessment and monitoring availed by high-tech remote sensing tools and techniques. However, the choices on which apparatus or technique to opt for would be narrowed down to a handful as it is dictated mainly by the study goal, extent, required detail and precision, budget, and time. Meanwhile, measurement of what appears to exist underneath the dense forest canopy is one of the main challenges that most radar and optical satellites fail to resolve. Instead, alternative techniques such as mobile laser scanning (MLS) have recently been investigated and proved promising for a broad spectrum of forest assessment endeavors. As helpful as they look, the MLS applications can also be problematic once the budget excels in importance, among other rivaling criteria. Hence, we tested videogrammetry, a subgroup of close-range photogrammetry, in different parts of the Caspian Hyrcanian forests, in pursuit of attaining high-resolution topography of the forest surface (e.g., terrain, 1st order stream tributaries, and artificial designs such as dams, walls, and excavation pits) and volumetric measurement of forest structural complexity and silviculture (type mapping, disease and pest detection such as gummosis, burls, galls, and tumors). By doing so, different photogrammetry products such as dense point cloud, high-quality mesh, texture, and 3D models were generated and rescaled. The results revealed that videogrammetry (extracting frames from videos) could compensate for the small areal coverage and occlusion of standard photogrammetry shoots (photography) due to the agile movement of the camera and the high frame rate obtained from high-definition videos. On the other hand, the surveyor is strictly advised to adhere to the basic photogrammetry rules such as camera settings (ISO, shutter speed, focus, lenses, diaphragm, depth of field) and following nested spiral/circular patterns rather than camera panning and 360 movements. Moreover, the mixture of photography (single shots) and video-oriented frame as an integrated photogrammetry technique would recompense the blurred photos due to motion blur and camera shake during the exposure time.

Assessing the transferability of nationwide forest attribute models to different spatial resolutions using airborne laser scanning data in Norway

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Fine-scale, spatially explicit forest resource maps are essential for monitoring sustainable forest management practices. Such maps, based on the combination of National Forest Inventory (NFI) and remote sensing datasets, have a long tradition to characterize timber volume, biomass, basal area, and Lorey's height and other forest attributes in the Nordic countries. For instance, the Norwegian Forest Resource Map (SR16) is currently produced using mixed effect regression models at 16 m resolution with predictor variables based on Airborne Laser Scanning (ALS). The spatial resolution of these maps was set according to the NFI plot size. This, however, limits their applicability in various local-scale forest management applications.We therefore investigated whether the spatial resolution (i.e. pixe size) of forest attribute maps can be reduced while utilizing models fit on original scale. We processed ALS datasets at various spatial resolutions (1, 5, 10, and 16 m) to assess the transferability of nationwide models using independent field validation data from two geographically separated regions in Norway. Our initial results show that the prediction accuracy of the main forest attributes is not substantially affected by the spatial resolution of the ALS-based predictor variables. This suggests that the nationwide models are robust and transferable to a finer spatial scale. The result of this study is an important step towards harmonizing forest attribute maps across countries to match their spatial resolutions for European-scale forest monitoring.

Can GEDI accurately model vertical structure and Above-Ground biomass along rainfall and fire disturbance gradients?

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Miombo woodland covers large parts of eastern and southern African. Miombo woodland faces deforestation, which affected 17.0% of the wooded area from 2007 to 2010 and resulted in an almost 55% loss of woody biomass. Despite this human pressure, Miombo woodland still plays an important role for the human population and provides several products and services such as timber and non-timber forest products, fuelwood, construction timber, and tangible services (regulation of climate, carbon storage and maintenance of biodiversity). Stand structure is fundamental to maintaining the capacity of the forest to provide these products and services.

Traditionally, monitoring of forest structure and above-ground biomass (AGB) has been achieved through in situ field methods. These methods however, are costly, laborious, and difficult to apply at larger spatial scales. In this research we investigate the vertical structure of Miombo woodland along a rainfall and fire disturbance gradients, integrating *in-situ* and remote sensing data, to develop models that will enable scaling from local to regional scales. We focus on the use of Light Detection and Ranging (LiDAR) data, specifically the Global Ecosystem Dynamics Investigation (GEDI) full-waveform LiDAR due to its coverage (+/- 51.6 degrees latitude) and its capability to penetrate the canopy layer. This gives LiDAR the ability to measure vertical structure parameters and to produce detailed 3D point clouds illustrating the vertical structure of woodland vegetation.

This research used data collected in 12 sample plots in Namibia and the Democratic Republic of Congo: (a) to evaluate the potential of GEDI to estimate the vertical structure of forest Miombo woodland stands; (b) to describe the vertical structure of Miombo woodland and to understand if these characteristics differ along the rainfall and fire disturbance gradients.

Comparison of different methods to estimate canopy openness using close-range sensing and field surveys in temperate rainforests

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: To estimate and monitor canopy gaps and fragmentation, which could be triggered by natural or anthropogenic disturbances, there are several alternatives, such as direct field measurement or through remote sensing applications related to canopy openness or vegetational indices. In this study, we compared two field survey techniques and four remote sensing methods, using a close-range approach to estimate canopy openness over four categories of forest disturbance: none, low, medium, and high. The method was applied to 12 forest stands, with three repetitions in each category. The remote sensing methods consisted of using an unmanned aerial vehicle (UAV) based on photogrammetry principles that produced 3D point clouds. These point clouds were further processed to estimate canopy openness and detect forest disturbances in *Araucaria*-*Nothofagus* forests. The two field instruments used were the Canopy-Scope (CS) and Hemispherical Photography (HP). Although the four remote sensing analysed spatially the 3D point clouds from the canopy to map estimated canopy openness values over the area. The results show a correlation between the two field methods of R^2 0.58 when all the observations were included, which means they were not separated by category. However, when the observations were divided by the category of forest disturbance levels, the R^2 between CS and HP was not significant for the category "none" but increased in value and significance at higher disturbance categories. The best remote sensing method consisted of a direct estimation of canopy openness from the point clouds using a software developed ad-hoc for this work. This method has a R^2 of 0.68 without grouping by forest disturbance categories and increased to 0.90 over the "high" category, but with a lower and non-significant correlation in the lower category. Our finding suggests that results using a 180° field of view (FOV) to simulate HP from point clouds can distinguish the four forest disturbance categories and, therefore, can be a useful tool to determine canopy openness in remote areas, which is linked directly to forest fragmentation.

Data assimilation – a tool for making use of big data to improve forest stand information

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Data assimilation (DA) has been used for a long time in fields such as meteorology. It is currently considered an interesting option in forestry due to the large amounts of remotely sensed (RS) data available for predicting forest characteristics. With DA, new information can be merged with existing information, such as predictions from a previous time point updated with a growth model. Thus, old information is not discarded when new information becomes available but is used to the extent motivated by its accuracy. With ever-increasing amounts of RS data, it is important to evaluate not only how to make assessments and growth updates through DA but also how to best utilize large amounts of RS data within single years.

Within the Norwegian SmartForest program, the first large-scale application of DA in Norway has been initiated. DA is being applied between 1998 and 2022 in an approximately 900-ha forest area in Våler municipality in southeastern Norway. By utilizing data from previous time periods, we will be able to improve the estimates for 2022 compared to using information from this year only. However, applying DA in practice is far from trivial. During the presentation, we will report results on evaluating whether building separate models for each RS dataset and applying composite estimation or merging all data into a single model through principles of partial least squares regression and random forest non-parametric regression yields the best results in terms of prediction accuracy. The RS data were acquired in 2022 and included ALS point clouds, digital aerial photogrammetric point clouds, and Sentinel-2 spectral data. Alongside comparing prediction accuracies, we conducted a qualitative assessment to discern the practical advantages and disadvantage of each method in integrating them into a multi-temporal data DA system.

Reference:

Saarela, S., Gobakken, T., Ørka, H.O., Bollandsås, O.M., Næsset, E. & Ståhl, G. (in review). Handling single-year big data in forest inventory system based on remote sensing and multi-temporal data assimilation. *Remote Sensing of Environment.*

DETECTING FLORISTIC DIVERSITY OF FORESTS IN RESTORATION USING REMOTE SENSING AND MACHINE LEARNING

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Forest restoration is considered one of the best options to mitigate the effects of climate change and reduce biodiversity loss. Several forest restoration techniques were developed in the State of São Paulo, playing a crucial role in the protection of the Atlantic Forest. However, the methods for monitoring the success of restoration mostly depend on field trips to analyze different factors, such as diversity and floristic composition, a time-consuming and costly process. With the use of remote sensing techniques, we can reduce the cost of monitoring by increasing the spatial and temporal scale and combining different sensors to detect various vegetation characteristics. The Sentinel 1, Sentinel 2 and the Planet satellite constellations image in different bands of the electromagnetic spectrum, ranging from visible to microwave , detecting different aspects of the water content and vegetation composition and structure. In addition, images derived from LiDAR sensor data, which is capable of providing a 3D view of forests, are useful for estimating different structural variables, which can be related to floristic variables. This project used remote sensing images (Sentinel 1, Sentinel 2, Planet and LiDAR), combined with forest inventory data obtained in the field (Newfor project - #FAPESP 2018/18416-2) and Machine Learning techniques to analyze the diversity and floristic composition of semideciduous seasonal forests under restoration in São Paulo state. By doing so, it was possible to identify wich Remote Sensing variables have the highest correlation to floristic parameters, allowing for a more precise monitoring of forest in restoration remotely. The highest correlation found was between the LiDAR data (Canopy Height Model) and the Menhinick diversity index (0.5). As for the Satellites, the Sentinel 2 Red, RedEdge and SWIR bands had some correlation with the Simpson index, specially in the rainy season, however, the values were still low (0.3 - 0.4), indicating the need to combine different variables and use higher spatial and spectral resolution satellites to obtain higher correlation values.

Determining the optimum mesh size for evaluating site productivity for Cryptomeria japonica using airborne laser scanning data

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Airborne laser scanning (ALS) data at a fine mesh size are being widely used to analyze site conditions to evaluate site productivity. However, the optimum mesh size for evaluating site productivity remains unknown. In this study, the optimum mesh size was determined by analyzing the relationship between site conditions derived from ALS data and height growth data obtained from the long-term monitoring of an experimental *Cryptomeria japonica* site. We assumed that (1) based on the optimum mesh size, the site conditions should demonstrate the lowest mean standard deviation of height at a given age, which is an indicator of site productivity, and (2) site productivity class derived from site conditions of an appropriate mesh size has the smallest numbers of trees whose actual height growth curve differed from the growth curve of the site productivity class. Four digital elevation models with different mesh sizes (1.0, 2.5, 5.0, and 10 m) were calculated using the ALS data and used for developing maps of slope type, topographical type, soil deposition type, and slope location. Trees with the same site conditions were combined to calculate the average and standard deviation of tree height at the ages of 30 and 45 years based on the long-term monitoring data. The mean standard deviation for the 5.0-m mesh size was the lowest (1.97 m), followed by that for 1.0 m (1.99 m), 2.5 m (2.00 m), and 10 m (2.14 m) at 45 years. Site conditions were also classified into site productivity classes based on the average height data. Subsequently, the height growth curves of productivity classes and the actual height growth curve were compared for each tree and the number of contradicted trees were measured. The contradicted tree number for the 5.0 m mesh size was the lowest (19), while it was 28, 22, and 37 for 1.0, 2.5, and 10 m, respectively. Thus, the appropriate mesh size for evaluating site productivity of *C. japonica* was concluded as 5.0 m, which might provide accurate evaluation of site productivity that influences the profitability of forestry and the future forest management regime.

Development of a single-tree extraction method for broadleaf trees using Air Borne Laser Scan data

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: In general, tree analysis using Airborne Laser Scan (ALS) data is suitable for extracting coniferous trees with relatively well-defined topped edges, while broadleaf trees with flat topped edges are less likely to be used for tree analysis.

In this study, we verified whether it is possible to extract broadleaf trees using tree height information obtained from ALS data, relative laser reflection intensity, and aerial photographs taken at the same time as the survey.

Method：

1. Generate Digital Canopy Height Model (DCHM) from tree height information to reproduce the tree canopy shape by the slope angle and contour lines around the tree canopy
2. Extract the canopy surface by using relative ALS reflection intensity and contour lines of the reflection intensity map
3. Extraction of tree tops from DCHM
4. Assuming that the ALS reflections are from near-infrared radiation, calculate pseudo-NDVI

These were overlaid on the GIS and the degree of agreement between the data was verified.

Main result:

Visually, the data were found to be consistent with each of the tree canopy shapes, and the data were found to be visually usable without any consistency problems.

Conclusions:

Although the shape of the trees could be visually confirmed, it would be necessary to confirm the trees by field survey and verify data consistency by merging data in the GIS.

Extraction of dendrometric parameters from UAV LiDAR data with a focus on the treeline ecotone

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Rare and endangered species thrive significantly in treeless ecosystems at higher altitudes. However, they are affected by the movement of the treeline to higher elevations. The trend has been documented in numerous alpine regions, especially those with a very limited extent; for example, in Krkonoše (50.75N, 15.58E), a mountain range located in the north-western part of Czechia and covered by protected arctic-alpine tundra.

In 2018 and 2021, dendrometric data was collected using traditional inventory methods on permanent monitoring plots. The areas cover the entire gradient of the treeline ecotone and consist of Picea abies, Sorbus aucuparia, and Betula pendula stands. New and dead wood and seedling survival were recorded. Based on the analysis of the changes in vegetation structure, the dynamics of the upper treeline were assessed. A different rate of biomass growth and canopy cover in parts of the treeline ecotone was detected. The lower parts of the ecotone are characterized by a more intensive height, radial, and crown area increase. Higher areas have the smallest height increase and most symptoms of non-temperature stress.

Traditional forest inventory is rather time-consuming and expensive, limited to selected locations. Remote sensing provides a suitable alternative or support for ground measurements. UAV LiDAR data with high point density represents a versatile tool, particularly suitable for smaller to medium-sized areas, less accessible locations, or when data must be acquired repeatedly at shorter time intervals. According to the results of the literature search, its use in heterogeneous forest environments and for understory vegetation remains a challenging topic.

Throughout the summer months of 2023, new dendrometric measurements will be collected along with high-density LiDAR point clouds from a Riegl miniVUX-1 UAV laser scanner equipped with the APX-15 UAV GNSS/IMU and mounted on a hexacopter DJI M600. Data will be acquired throughout two gradients in the treeline ecotone. Results of individual tree detection and subsequent dendrometric parameter extraction from UAV LiDAR data will be presented, with the aim of effective continuing of the monitoring on permanent plots and assessing the dynamics of the treeline ecotone.

Forest condition assessment – A benchmarking study in Germany

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: With a continuous assessment of forest condition since the 1980s, Europe takes a keen interest in its forests. It is therefore no surprise that the increasing hot drought frequency and the unprecedented post-2018 forest decline in Central Europe spiked a range of new remotely sensed products to assess its health. They could not be further away from the ground-based assessment of the previous 30 years which aim to directly quantify canopy condition (e.g. percentage of leaf loss), while remotely sensed products provide information on the spectral reflectance which can be considered an indirect measure of canopy condition. However, the information on crown condition is based on the ground assessments of ICP Forests. Therefore, the term might not be ticking the box when presenting remote sensing derived indices. It is thus our aim to define the wording being aware of the differences caused by the change from ground assessment to airborne or spaceborne analysis.

However, the opportunities for high temporal resolution and a gapless spatial cover are fulfilled with a variety of remote sensing products. Here we present a selection of German forest monitoring products derived from satellite-borne remote sensing products, i.e. Sentinel, Landsat and MODIS. The products are compared among each other based on ground-truthed, and thus well-documented changes in forest condition (e.g. defoliation, forest fire, wind-throw). The comparison aims at documentation of the various products, the definition of the methods and terms, as well as the start of a discussion to improve the respective algorithms within a benchmarking process. This process covers two parts: firstly, the presentation and discussion of the currently available products with a focus on the influence of resolution, forest mask, reference year or period, time of detection, and indices used. Secondly, the provision of more detailed information on the specific potentials to map forest disturbance (e.g. storm, forest fires) and the underlying algorithms, discussing aspects of phenological phases, thresholds, and variance.

Besides identifying potentials for product-specific improvements, the study aims at improving their applicability for various users, especially those with little working knowledge in remote sensing.

Global forest management intensity data set

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Spatially explicit information on forest (and trees) management intensity is critical for understanding the status of forests, planning sustainable forest management, restoration and conservation activities, assessing wood and biomass supply potential, among others. Here, we present a reference data set and a globally consistent forest management map with high spatial detail on the most prevalent forest management classes such as intact forests, managed forests with natural regeneration, planted forests, plantation forest (rotation up to 15 years), oil palm plantations, and agroforestry. We developed the reference dataset of 226 K unique locations through a series of expert and crowdsourcing campaigns using Geo-Wiki (https://www.geowiki.org/) tool for visual interpretation of very high resolution imagery and vegetation indices. We then combined the reference samples with time series from PROBA-V satellite imagery to create a global wall-to-wall map of forest management at a 100 m resolution for the year 2015, with forest management class accuracies ranging from 58% to 80%. The data set is peer-revied and published (Lesiv, Schepaschenko et al., 2022) in Scientific Data journal and Zenodo. A revised and further developed data set for the year 2020 is expected by the time of IUFRO congress 2024.

Hierarchical hybrid estimation of boreal forest biomass using ICESat-2 data

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: The ICESat-2, launched in 2018, carries a photon-counting spaceborne lidar that provides strip samples of points over the terrain. While primarily designed for snow and ice monitoring, ICESat-2 has been shown to also provide relatively accurate canopy height measurements. There has also been a high interest in using ICESat-2 to predict forest above-ground biomass (AGB). Due to ICESat-2 using a polar orbit, it provides good spatial and temporal coverage of boreal forests. The aim of this study is to test ICESat-2 data in hierarchical hybrid estimation of boreal forest AGB.

The data consist of two adjacent study areas of circa 50 x 50 km in eastern Finland, near Valtimo and Nurmes, respectively. The areas are mostly forested, with Scots pine (*Pinus sylvestris*) as the dominant species, followed by Norway spruce (*Picea abies*) and birches (*Betula* spp.). The study areas have field plots, wall-to-wall airborne laser scanning (ALS) data and Sentinel-2 images captured in the summer of 2019 and 2020, respectively. On Valtimo area, we have ICESat-2 data from years 2018 and 2019, and on Nurmes, from the year 2020.

The modeling chain is as follows: 1) predict allometric AGB on Valtimo field plots, 2) build a model for predicting proxy AGB using ALS and Sentinel-2 data, 3) predict proxy AGB on the ICESat-2 tracks in Valtimo, 4) build a model for predicting AGB using the ICESat-2 data and proxy AGB, 5) use the Valtimo ICESat-2 model to predict AGB on Nurmes ICESat-2 tracks. Finally, the ICESat-2 AGB predictions in Nurmes area are used in a hybrid inference setting to estimate the average AGB. Uncertainty is propagated through the whole model hierarchy. For validation, we have a separate ALS and Sentinel-2 based AGB model trained in Nurmes area, which is used in hierarchical model-based estimation.

The preliminary result for the ICESat-2 hybrid inference for the average AGB in the Nurmes area was 63.2 ± 1.9 Mg/ha (2.9%). The reference estimate using local ALS and Sentinel-2 data in Nurmes was 63.9 ± 0.6 Mg/ha (1.0%). The preliminary validation results support the use of ICESat-2 data for estimation of boreal forest biomass.

High-resolution tree height mapping from GEDI data: the case study of Mediterranean forests

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Structural information related to forests, such as tree heights, diameter, and density, is crucial in quantifying biomass and carbon stock and managing forest ecosystems in light of climate and land use changes. NASA's Global Ecosystem Dynamics Investigation mission (GEDI mission) has provided valuable data on canopy heights worldwide since late 2018. However, the GEDI mission's satellite footprints do not offer detailed spatial data on tree heights. In this study, we present an approach for mapping canopy heights at a resolution of 10 meters by combining GEDI data with Sentinel-1, Sentinel-2, and topographic variables (elevation, slope, and aspect). Three machine learning techniques—Random Forest (RF), Gradient Boosting (GB), and Classification and Regression Trees (CART)—were tested. The study focused on two Mediterranean forests in Italy, one characterized by a conifer stand and the other by a multilayer mixed-species stand. The complete GEDI data collected over the study area was used, with the dataset divided into training (70%) and testing (30%) subsets to evaluate prediction accuracy. We compared the GEDI canopy height map with Airborne Laser Scanning (ALS) data to assess the performance using a pixel-by-pixel analysis. The RF algorithm exhibited the highest accuracy (adjusted R-squared: adj. $R2 = 0.90$; root mean squared error: $RMSE = 3.09$) compared to GB (adj. $R2 = 0.83$; $RMSE = 3.93$) and CART (adj. $R2 = 0.84$; $RMSE = 3.16$). Across all algorithms, the comparison between GEDI canopy heights and ALS data showed moderate agreement, with adj. R2 values ranging from 0.27 ($RMSE = 5.23$) to 0.48 ($RMSE = 4.58$) for pure stands and weak agreement, with adj. R2 values ranging from 0.06 ($RMSE = 6.87$) to 0.14 ($RMSE = 5.59$), for the multilayer mixed-species stand. The proposed approach will contribute to forest monitoring initiatives, especially in inaccessible or remote forests worldwide.

Improving Aboveground Biomass Estimation methods through Multi-Sensor Data and Prediction Modeling Correlated with Ground-Based Information

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: The European Union's current climate policies aim to position Europe as the first continent to achieve climate neutrality by 2050. This ambitious objective places significant responsibility on the forest sector to contribute to the overall reduction of greenhouse gas (GHG) emissions. Accurate aboveground biomass (AGB) estimation is particularly crucial for carbon stock assessment and sustainable land management practices. In recent years, integrating multi-sensor data synergy and prediction modeling techniques has shown promise in improving AGB estimation. This study accentuates the potential of utilizing synergistic data from multiple sensors and developing prediction models correlated with ground-based data to improve AGB estimation.

Diverse remote sensing data types, both airborne and satellite, such as optical, radar, and LiDAR, were used to assess vegetation structure and composition across a heterogeneous topographic region spanning 15,000 ha^{-1}. Ground-based data, such as field measurements of forest inventory, were collected concurrently with remote sensing data to establish a robust correlation between AGB and the sensor data. Ground measurement data involved over 24 000 trees on a systematic grid network of 450 plots of 1000 m^2, each located in the Southern Carpathian temperate mixed broadleaves-coniferous forest ranging from 500m to 1650m above sea level (ASL). Several random forests (RF) regression models were trained using a subset of the data, and their performances were evaluated using cross-validation techniques. The prediction models were then applied to the entire dataset to estimate AGB at the landscape scale. The study aims to analyze the most valid combination of sensors for a comprehensive characterization of vegetation structure and, finally, to predict AGB accurately.

The prediction models developed using the integrated data achieved high accuracy in estimating AGB, as indicated by low root mean square error (RMSE) and a high coefficient of determination values (R^2). The study also highlighted the importance of ground-based data in the modeling process. The correlation analysis between the remote sensing data and ground-based measurements provided insights into the relationships between sensor-derived variables and AGB. This information facilitated the development of more robust and reliable prediction models, resulting in improved AGB estimation accuracy.

Integrating Radar and Multispectral Data with Machine Learning for Accurate Fuel Models in Forest Fire Management

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: The increasing frequency of megafires in Mediterranean areas underscores the critical need for updated fuel models to mitigate the impacts of these wildfires. Climate change has heightened the risk of forest fires. This was evident in the summer of 2017 when a single fire engulfed approximately 180,000 hectares of agricultural and forest systems in the Maule Region (Chile) within a matter of days. The recurrent occurrence of such destructive wildfires necessitates the development of tools and strategies to effectively prevent and manage their consequences. This study aims to develop accurate and precise fuel models for effective forest fire management. The integration of radar and multispectral imagery plays a vital role in obtaining reliable fuel models. Strategic project sites, ranging from 500 to 1,000 hectares, were carefully selected to capture maximum variability in fuel models. A combination of synthetic aperture radar (SAR) and high-resolution satellite imagery was analyzed to derive both structural and spectral information. Post-processing of the sensor data resulted in various outputs, including forest metrics (40 in total), high-precision topographic models, and spectral resolutions depicting the forest reality. Machine learning techniques, including several algorithms, were employed to analyze the metrics and predict fuel models. Among them, the Random Forests algorithm consistently produced the best results in terms of accuracy and performance. The study yielded compelling results, with 12 fuel models achieving area under the curve (AUC) values ranging from 0.4412 to 1. Accuracy scores varied from 0.774 to 0.7763, with kappa coefficients ranging between 0.717 and 0.7402. These metrics provide quantitative evidence of the robustness and reliability of the developed fuel models. This study demonstrates the effectiveness of integrating radar and multispectral data, coupled with machine learning techniques such as Random Forests, in obtaining updated and precise fuel models. These enhanced models will enable more efficient management of forest fires, facilitating strategic decision-making and the implementation of preventive measures to protect ecosystems and ensure the safety of affected communities. The findings have significant implications for forest fire management, where the threat of megafires necessitates accurate and reliable fuel models for effective response and mitigation strategies.

Integration of remote sensing techniques in national environmental monitoring

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: This presentation will focus on the constant development that is taking place within a national environmental monitoring programme to make several different technology applications more efficient, be it for the sampling of aerial photo inventories, for modelling of potential habitats or for using neural networks to model parts of the inventories or develop image recognition.

The sampling strategy developed within the programme for targeted environmental monitoring allows for large-area searches without adding large costs for field inventory, due to the employment of several phases in the scheme. The data collected utilises the whole chain of geographical scales, from satellite images through aerial photos, drone images and to quality variables collected in the field. Collection of detailed field data makes up the decision basis for recording the actual nature type but also has great value as input data for models and algorithms, as well as constituting next year´s ground truth and in-house education on mid-level data collection from aerial photos and drones.

The National Inventories of Landscapes in Sweden, (the NILS programme) is a monitoring programme functioning as an umbrella for several target inventories on the national level. Commissioned by the Swedish Environmental Protection Agency, the monitoring is target-based for habitats with insufficient data from other monitoring programmes to provide sufficient data for national reporting according the EU Habitat Directive, or Annex-1 habitats, completing the overall national knowledge of the targets. Current targets are deciduous forest, hardwood deciduous forest, grasslands, raised bogs, several seashore habitats and the entire mountainous area of the Scandes Mountain range.

Mapping of deforestation and forest degradation in Vietnam using Sentinel-1/2 images

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: About 85%of the natural forest in Vietnam is regenerated and secondary forest. These forests are under very high pressure due to land conversion to agriculture and other land types. Furthermore, substantial illegal cutting and burning occurs in remote forest areas that are not easily detected by the forest rangers. As result, the forest can be cut for a long time without being detected. Hence, remote sensing constitutes an attractive alternative to monitor large areas timely, especially solutions based on free satellite images.

In this study, we investigate approaches to use satellite images to identify and monitor deforestation and forest degradation in the Central Highlands of Vietnam. The active forest management and short rotation periods in Vietnam can make it challenging to distinguish between permitted and illegal forest cuttings. The fast regrowth is furthermore quickly eliminating traces of illegal cuttings. Therefore, it is of high importance to develop methods that allow continuous monitoring and rapid identification of forest-degraded areas. The region is frequently covered by clouds, which makes dense acquisitions of optical data difficult. Therefore, SAR imagery constitute a good complement, which however has lower spatial resolution and is sensitive to the hilly terrain in Vietnam. We have developed a workflow in Google Earth Engine (GEE) to pre-process and extract time series of Sentinel-1 synthetic aperture radar (SAR) images and Sentinel-2 optical multispectral images. The optical images were used to compute the normalized difference vegetation index (NDVI) and distance-red-swir (DRS). The Sentinel-1 backscatter and the vegetation index data were analyzed and compared with more than 200 reference areas spread across southern Vietnam, located in different forest types. The references consisted of field reference data and high-resolution Planet imagery, which were visually interpreted and used for delineation. The forest degradations are mostly clearly visible, while the analyses will continue during 2023 to clarify and quantify the effects in different forest types and regions.

The main result of this study is a procedure to apply GEE for mapping the deforestation and forest degradation in the Central Highlands of Vietnam, which can be applied for many other inland forests in the country.

Mapping surface fuels in three-dimensional space using terrestrial laser scanning and RGB image mosaics

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Changing weather patterns due to climate change can result in increasingly dry summers in formerly not fire prone forest systems in central and northern Europe. A prerequisite for fire occurrence is the presence of burnable materials, that is fuels. Fuels can be classified according to their vertical position: ground fuels (humus, tuff), surface fuels (shrubs, woody debris, logs) and canopy fuels (tree canopies). Much research using remote sensing technology has focused on canopy fuels. In contrast, remote sensing research on surface fuels has been scarce as established optical remote sensing approaches from satellite or UAV platforms are hardly able to collect information from below the canopy.

In a new research project, we aim on increasing our understanding of small-area spatial patterns of surface fuels and develop alternatives for traditional field sampling methods for forest fuels. For this, fuels are mapped using 3D and RGB data and results are compared to traditional field sampling methods.

We use a) a terrestrial laser scanner for the acquisition of 3D point clouds and b) under canopy RGB image mosaics for a continuous representation of the forest floor and the understory. For reference, traditional field sampling is carried out in subplots. Sampling will take place in pine forests in Brandenburg, Germany, during summer 2023.

The research objectives are a) to create a detailed continuous map of different surface fuels using deep learning and the RGB image mosaics to b) explore the capacities of remote sensing methods compared to traditional, time-consuming, and potentially subjective field sampling and c) relate patterns detected by remote sensing to fire behavior models and ecological processes.

At the IUFRO conference we will present the developed methodical workflow and first results from the field campaign.

Methods to reduce the design-bias of model-based predictors based on remotely sensed data

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: The choice of framework for statistical inference is important when utilizing remotely sensed data for mapping and estimating forest characteristics. This choice is sometimes delibe-rate, but often it follows indirectly from the methods applied to make predictions. For example, large-area mapping and estimation of biomass has emerged as a very important field of applying remotely sensed data, where parametric or non-parametric regres-sion models are typically applied. Such approaches provide approximately model-unbiased biomass predictions for individual population units (often grid-cells in maps), conditional on the input data. Thus, implicitly a model-base inference approach is adopted. However, if we instead adopt a design-based perspective, it can be shown that model-based predictors are design-biased, and that typically there is a trend in the design-bias implying that small true values are overestimated and large true values are under-estimated. This has important negative implications in many fields of application where wall-to-wall information from remotely sensed data are used for the decision-making. In this presentation, different approaches to reduce the design-bias of model-based predictors will be proposed and compared. The presentation will focus on estimation and prediction at the level of individual population units, but also demon-strate the effects when such estimates are aggregated to domains and population totals.

Modeling forest attributes using public LiDAR of Aleppo pine (Pinus halepensis Mill.) forests in a Mediterranean island context.

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Mediterranean forests, especially naturally regenerated Aleppo pine (*Pinus halepensis* Mill.) ones, have a crucial role in climate change. Despite being threatened due to temperature increase and precipitation decrease, intensifying the desertification risk and wildfire potential, these forests are key in climate change mitigation, as they are extremely adaptative and can provide valuable information like carbon or timber stocks. However, quantifying these forests' attributes and productivity should be done first. Although National Forest Inventories are an acceptable approach, continuous cover maps of Mediterranean forest stand attributes are still lacking, as these efforts are normally done for more productive species. In this work, we use the low-density public Spanish PNOA LiDAR flights to model forest attributes (i.e., dominant height, above-ground biomass, volume, tree density, and basal area) in the context of naturally regenerated Mediterranean forests of Aleppo pine, abandoned and unmanaged since mid-XXth century. We compared two different methodologies: area-based and individual tree detection, with the ultimate goal of generating continuous maps for these variables. We trained and validated the models with ground forest inventory data and found that the two approaches yielded similar results in terms of goodness of fit and error. For the latest version of the methodology, area-based approach models yielded $R^2 \sim 0.7$, RRMSE ~ 1.5 m, and RRMSE ~ 12% for dominant height and $R^2 \sim 0.7$, RMSE ~ 25.6 Mg ha^{-1}, and RRMSE ~ 30% for above ground biomass; whereas the individual tree detection models yielded $R^2 \sim 0.7$, RRMSE ~ 1.5 m, and RRMSE ~ 12% for dominant height and $R^2 \sim 0.5$, RMSE ~ 30.3 Mg ha^{-1}, and RRMSE ~ 38% for above ground biomass. Due to the higher computational power of the latter and no significant increase in quality relative to the former, we encourage the use of area-based approach for large-scale mapping. We believe these models, and their corresponding maps, will be a great asset for policymakers and different stakeholders not only for the region they have been created for but also for similar environments of unmanaged Aleppo pine forests throughout the Mediterranean basin.

Reconstruction of the evolution of afforestation and abandoned agricultural lands using retrospective geosimulation

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Natural forest regeneration on non-forest land in Lithuania is only recognized as a forest after it reaches the age of twenty years. If these areas are not properly inventoried and registered, they may be treated as abandoned agricultural land. Consequently, this can lead to legal sanctions or a decision of landowners to clear large areas leading to the removal of young trees. This study aims to investigate the potential of timely inventory of afforestation on agricultural land by employing a combination of advanced spatial analysis, artificial intelligence, and remote sensing techniques. We hypothesized that the improvement of abandoned land identification in Lithuania depends on mapping and specifying trees outside currently registered forest lands. Primarily, we mapped and specified areas covered by woody vegetation using remotely sensed data based on airborne laser scanning (ALS) and aerial imaging. A combination of individual tree detection and area-based approaches in processing the ALS data resulted in most promising solution for mapping the objects of interest. Spectral information from optical images increased the accuracy of estimations. Then, we improved the characterization of mapped objects by reconstructing their historical development using simulation models based on machine learning and deep learning approaches. All available auxiliary historical geographic information was used to facilitate the identification of afforestation on non-forest lands and the abandonment of agricultural lands. Alongside mapping areas grown with woody vegetation, we managed to achieve better understanding of factors behind abandonment of agricultural lands and clearing out potential new forests. We suggest our approaches to be used also for wall-to-wall land-use change mapping in the past or future in accordance with forthcoming EU legal acts for the LULUCF sector within the frames of greenhouse gas management efforts.

Remote sensing of functional complex networks for the forests of the northern hemisphere

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Forest ecosystems play major roles e.g. in climate change mitigation by storing and capturing vast amounts of atmospheric carbon, in the water cycle and in the sheltering of biodiversity. Yet, they are increasingly threatened by climate change and the related increases in temperature, severe droughts, pest invasions and wildfires. Innovative theories in forest ecology suggest that, in order to be resilient to external forcings, forest ecosystems should present a wide range of functional traits coupled with an organization at the landscape level under the form of a functional complex network. However, this theory has yet to be confirmed in practice and validated at different spatial scales and for different regions of the world.

In this context, the case of northern forest ecosystems is particularly concerning, notably due to the long history of silvicultural practices that focused mostly on timber production which led to current poorly resilient ecosystems. Consequently, I develop here a research project that tests the functional complex network theory for these northern forest ecosystems, building innovative approaches from innovative remote sensing technologies, i.e. airborne and spaceborne LiDAR. Using a multiscale framework, I (i) identify key airborne LiDAR metrics characterizing key functional traits in similar yet contrasted forest plots from Wallonia and Quebec at the stand level; then (ii) identify key landscape properties enabling functional connectivity between forest patches from the combination of LiDAR and spectral data at the landscape level; and finally I map (iii) the current and (iv) potential state of the functional networks at the biome level to localize and qualify key functional gaps where we should act upon to make our forest ecosystems resilient, either through an adaptation of silvicultural practices or through ecosystem restoration.

Remote sensing-based assessment of relationships between native Oak tree structure and wind damage in the UK following Storm Arwen

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Oak trees are an essential component of the UK's treescape, yet, in recent years, their population has declined due to several threats. Extreme storm events have been identified as a significant abiotic threat to the health of native Oak, causing severe damage and mortality. Due to climate change, storm events are increasing in intensity and occurring in regions that were once unaffected. The UK Winter 2021/22 storm season was particularly damaging regarding event occurrence and intensity. Storm Arwen caused extensive damage to Oak in the North of England and Scotland. Extreme windspeeds came from an unusual North-Easterly direction. As the predominant UK wind direction is from the South-West, the root plates of many Oak may not have been adapted, contributing to windthrow.

The research aims to profile the consequences of Winter 2021/2022 extreme storm events upon the health of the UK's native Oak population, studying Oak in different settings such as woodland, parkland and field margins. The unique wind direction of Storm Arwen presented an opportunity to study the interrelationships between Oak health and strong wind in the North-East of England.

Novel remote sensing techniques are incorporated into the project. A GeoSLAM ZEB Horizon laser scanner, and DJI Matrice RTK quadcopter drone, mounted with a LiDAR sensor, were used to create high-resolution 3D models of the structure and canopy of the damaged Oak. Analysis of the structure, using the ITSMe R package (extracted parameters include DBH, tree height, crown area and tree volume), will help determine the extent to which local wind strength and direction were responsible for storm damage. At each site, a GeoSLAM ZEB Horizon scanner has also been used to derive the amount of carbon lost from the canopy and stored in deadwood. This is significant, as Oak has the potential to store more carbon than any other native UK tree species.

An understanding of which factors contribute to damage during extreme storms will provide national stakeholders with suggestions to alleviate stresses and aid Oak management practices. The research has the potential to be applied to other species of storm damaged trees, both nationally and internationally.

Satellite data reveal differential tree species recovery to unprecedented 2018 drought

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Rising global temperatures together with the increase in drought frequency, intensity, and duration are affecting the productivity, phenology, regeneration, and mortality of forest ecosystems. Species-specific responses to drier conditions are likely to be influenced by their functional traits and local site conditions. Yet knowing which species are affected by drought and where is often a difficult monitoring task.

Here, we analyzed forest recovery from drought using an extensive network of field-based inventories and remote sensing data. We compiled forest health indicators based on field-based canopy condition and vegetation indices derived from Sentinel-2 satellite data (Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI)). We quantify the drought response of more than 10,000 individual trees of 11 tree species in Switzerland, across ten biogeographical regions. We calculated NDVI and NDWI changes between 2017 and 2021 to capture tree species' health before, during, and after the 2018 drought.

Preliminary results show that all species had high vitality prior to the 2018 summer drought and were significantly affected by the drought, except for *Pinus cembra*. While most species recovered significantly within one year of the drought, *Quercus petrea* only recovered two years later. Pre-drought vitality was not regained in most cases within the next three years after the 2018 drought, except for *Betula pendula, Populus nigra,* and *Pinus sylvestris*. Factors influencing tree recovery were the prevailing climatic conditions in the ten biogeographical regions and species-specific drought coping strategies.

Our results demonstrate the suitability of satellite-based quantification and monitoring of drought-induced tree species damage and recovery at high spatial resolution across large areas. Knowing which species are most affected and how they recover from extreme droughts will help us develop adaptive management strategies and understand processes that improve the adaptive capacity of forests to new climatic conditions. Coupled with tree species recognition models, this approach can serve as a basis for more automatic monitoring of forest health.

Seeing sick trees from the air or space: Opportunities and challenges in forest health assessments from remote sensing

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Forest mortality rates are increasing globally. Tree mortality is the fastest way to lose carbon and biodiversity from intact forests. Increasing our capacity to detect forest health issues when they are limited in spatial extent, while there may still be time to mitigate them remains one of our best hopes for limiting tree mortality. Early detection of tree mortality events and tree decline through remotely sensed products provides an avenue for biodiversity conservation and carbon sequestration. Mortality events most often occur at the scale of the individual or a small group of trees in a forest. Our ability to detect shifts in tree mortality and determine the causal factors responsible is defined by the intensity, scale, and frequency of our observations. Currently, most observations are too coarse in spatial scale and too infrequent in time to determine causal factors of mortality or how they vary across space and time and lack detail of why a tree died. We aim to fill this knowledge gap. Our objective is to address this challenge and build scalable models of tree mortality with underlying factors associated with tree death.

To evaluate causal factors and detectability of mortality from remote sensing, we collected three years of annual tree health data across five spatially mapped ForestGEO plots for over 60,000 trees. We also accessed repeated airborne remote sensing data (lidar, RGB, and hyperspectral) collected by the National Ecological Observatory Network (NEON) at all plots and their surrounding landscape. We also acquired very high-resolution data from UAV collections to leverage both spectral and spatial information about different tree health status conditions. Our field surveys have found a wide range of species-specific mortality rates and an even wider assortment of factors associated with tree death often with species-specific syndromes. We have found that the species that are experiencing the highest mortality have compound causal agents corresponding to an accumulation of problems that ultimately kill the tree. We will present our results on connecting remote sensing data to tree health censuses with advanced algorithms to provide insights into how we might detect forest health threats in the future.

Spectral behavior variables are key indicators for mapping and discriminating restoration methods in secondary forest areas in the Atlantic Forest

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Forest ecosystem restoration is crucial for biodiversity preservation and mitigating the impacts of climate change. However, accurately mapping and differentiating restoration methods in secondary forest areas pose challenges for researchers. In this study, we utilized comprehensive datasets to investigate actively restored and naturally regenerated secondary forest areas in the Atlantic Forest of São Paulo State, Brazil. Our first dataset examined landscape context, including variables such as slope, proximity to watercourses, and statistical analysis of primary vegetation within a 300-meter buffer around each restoration area. We also evaluated the current spectral behavior using four vegetation indices during rainy and dry periods. Furthermore, we analyzed the historical spectral behavior of vegetation using various indicators, including trend, magnitude, anomalies, seasonality, mean NDVI, and interannual variation, derived from time series data of each study area. Principal Component Analysis revealed that the combination of current and historical spectral behavior variables explained 65% of the restoration and regeneration areas across the first three principal components. Context variables, on the other hand, contributed only 6% and were limited to the fourth principal component. These findings emphasize the crucial role of vegetation spectral behavior characteristics in distinguishing restoration methods. To validate our method, we trained four classifiers using machine learning algorithms: XGBoost, Gradient Boosting, Bagging Classifier, and Linear Discriminant Analysis. The XGBoost classifier achieved an impressive accuracy of 88%, while the other algorithms also yielded promising results with an accuracy of 84%. Our results demonstrate the feasibility of using current and historical spectral behavior variables to differentiate actively restored and naturally regenerated secondary forest areas. This method's accuracy is essential for guiding effective restoration strategies and ensuring proper monitoring of these areas, thus guaranteeing the persistence and sustainability of young forests. The study represents a significant advancement in forest restoration monitoring, offering a comprehensive and accurate approach to distinguish restoration methods in the Atlantic Forest's secondary forest areas. The acquired results are of paramount significance in improving the management of degraded landscapes, promoting biodiversity conservation, and advancing environmental sustainability. Furthermore, it provides an opportunity to model the potential for natural regeneration by removing active restoration plots.

Synergistic Forest Carbon Estimation using Spaceborne Active and Passive Remote Sensing Data

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: The enhancement of forest carbon sink is an effective approach to achieve carbon neutrality goals. The forest carbon sink contributes over 80% sink amount over terrestrial ecosystem. Accurate measurement of forest carbon stock can provide scientific support for achieving carbon neutrality goals. However, due to complex terrain and long-term human activities, the fragmentation and spatial heterogeneity of forest patches bring significant challenges to accurately estimating carbon stocks. Through the complementary advantages of the active and passive optical remote sensing payloads, the first Terrestrial Ecosystem Carbon Inventory Satellite in China, called "Goumang" was lunched on Aug. 4, 2022. This satellite provides 5 beams full waveform LiDAR together with 5 angle multiple spectral cameras, which provides the forest carbon storage synergistic estimation based on active LiDAR and passive multi-angle optical. The forest carbon stock measurement system at the footprint level of spaceborne LiDAR will be developed using a big dataset and new LiDAR biomass indices. Then we built a forest bidirectional reflectance reconstruction method which couples kernel-driven models and multi-angle observation data. Then build forest structure characteristic parameter inversion models by the integration of angular and spectral information. The developed system of forest carbon stock synergistic estimation method using active and passive data based on deep learning framework was tested in the north and south of China.

The new generation of multi-layer fuel load modeling in tropical savannas from space

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Quantifying fuel load over large areas is crucial for effective integrated fire management in fire-prone regions, aiming to preserve carbon stock, biodiversity, and ecosystem functioning. It also plays a vital role in understanding global climate regulation as a potential carbon sink or source. The NASA's Global Ecosystem Dynamics Investigation (GEDI) full waveform lidar sensor holds great potential in addressing this need. However, its capability for estimating fuel load has not yet been evaluated. In this study, we developed a novel framework and tested machine learning models to predict multi-layer fuel load in the Brazilian tropical savanna (Cerrado), using GEDI simulated and on-orbit data. For GEDI data simulation, we conducted lidar flights using an unnamed aerial vehicle (UAV) over selected sample plots representing distinct Cerrado vegetation formations, including grassland, savanna, and forest. Field measurements were taken to determine the load of surface, herbaceous, shrubs and small trees, woody fuels, and the total fuel load. Subsequently, GEDI-like full-waveforms were simulated from the high-density UAV-lidar 3-D point clouds. We calculated vegetation structure metrics from these on-orbit and simulated waveforms and correlated them with field-derived fuel load components using Random Forest (RF) models. Overall, the RF models demonstrated better performance for woody fuels and total fuel loads ($R2 > 0.71$ and 0.79, respectively). Although performance for components in the lower stratum varied from moderate to low, the results remained reliable. This framework can be extended to other fire-prone regions where accurate measurements of fuel components are necessary. We anticipate that this study will contribute to the broader application of spaceborne lidar for integrated fire management and support carbon monitoring initiatives in tropical savannas worldwide.

Updating biomass maps at a European scale using remote sensing and machine learning ensembles

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: In this work, an ensemble of machine learning algorithms was trained using stratified sampling to extract values from an existing European-scale biomass map from 2018 to estimate an updated version for 2020. The strata are necessary to ensure that the full range of biomass values is represented. The sampled values from 2018 were distributed over areas that did not suffer forest loss according to the "Global Forest Change" forest cover/loss/gain map derived from Landsat time-series. We trained the algorithm using a total of 49 features obtained from bioclimate, land cover, tree cover, and tree height map, in addition to annual composites of maximum values of vegetation indices per pixel (EVI and NDVI) from Sentinel-2 imagery, and radar backscatter median annual values from Sentinel-1 products. Except for the bioclimate maps, all other features represent the 2020 conditions. The model divided Europe into 19 tiles to limit variability due to the differences in bioclimatic zones. The result is a raster with ~100 m cell resolution depicting estimated biomass (Mg ha^{-1}). The rationale of this method is that, in an ideal situation, training should be done with ground-

measured data. However, rarely a significant number of large forest plots (~1 ha) are available with biomass estimates for the year of interest, and be representative of the extremely varied biomass conditions of Europe. Therefore, we used existing biomass data for the training needs. These data have a larger error compared to ground measurements, but the very high number of samples that we can use allows the machine learning ensemble to minimize the error effect. Overall, results produced using validation data over Europe report a root mean square error (RMSE) of 37 Mg ha^{-1}, and a mean absolute error (MAE) of 24.7 Mg ha^{-1}. Regarding single tiles, the largest RMSE was 55.3 Mg ha^{-1} from the tile depicting the Alpine region and the western part of Eastern Europe, which can be explained by the very high actual variance of biomass values in the region.

USE OF EARTH OBSERVATION DATA TO ASSESS AND MAP LAND COVER CHANGES IN MT. ELGON FOREST BETWEEN THE YEAR 2010 AND 2016

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: Mt. Elgon is one of the major forests found in Lake Victoria catchment. The forest catchment serves the rift valley drainage system where rivers emanating from it are a source of water to downstream. The forest supports Kenya's economy by sustaining agriculture, manufacturing, horticulture, tourism and energy sectors. Despite the significance, the forest underwent degradation affecting its capability in providing both economic and ecological services. The study assessed and mapped land cover changes within the gazetted forest boundary and in 5 km buffer zone created around the forest; mapped the extent and distribution of the land cover types from 2010 to 2016; and established major threats facing the forest. Satellite images were used to generate land cover maps and the questionnaire survey conducted to collect socio-economic data. The approach of mapping was based on classification scheme proposed by the Intergovernmental Panel on Climate Change (IPCC), which was domesticated to seven classes namely; Forestland, Annual Cropland, Perennial Cropland, Open Grassland, Wooded Grassland, Open Water and Settlements. The generated maps were validated and compared to determine areas that experienced changes. Results indicated that forestland decreased by 6% within gazetted forest boundary. The rest of the land cover also decreased a part from annual cropland which increased significantly. In the 5 km buffer zone, forestland and wooded grassland increased by 1% and 24% respectively, while perennial cropland decreased significantly. The loss of 3,137ha of forest cover within the gazetted forest boundary over a 6-year study period was equivalent to a loss of 523ha of forest per year. Major threats facing the forest were established as: encroachment by farms and settlements; unsustainable harvesting of forest products; excisions and abuse of Plantation Establishment for Livelihood Improvement Scheme (PELIS). Based on these findings, there is need to reverse the negative trend in forest cover through the following measures: stop further excisions and survey the forest to update the boundary; stop forest encroachment and remove people who live or farm in the forest; strictly implement policies guiding PELIS; rehabilitate and restore the mapped degraded areas; and sensitize locals on tree planting in private farms adjacent to forest.

Using multi-level sampling and model-assisted estimation to support forest inventory in interior Alaska, USA

T5.8 Developments in complex remote sensing-assisted forest surveys to support monitoring and assessment of forest ecosystems

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Abstract: In 2016, the US Forest Service Forest Inventory and Analysis program (the national forest inventory of the USA) initiated the first systematic, comprehensive inventory of the boreal forests of interior Alaska in the modern era. This forests of this region, which represent approximately one-fifth of all US forestland (~46 million hectares), are extremely remote and costly to inventory using the conventional FIA sampling design. Through a partnership with NASA Goddard Space Flight Center, a cost-effective design was developed and implemented in interior Alaska which leverages high-resolution, multi-sensor G-LiHT (Goddard-Lidar- Hyperspectral-Thermal) airborne remote sensing data flown in a strip sampling mode and covering every FIA plot established on a relatively sparse grid (1 plot per 12,000 ha). G-LiHT provides detailed, high-resolution measurements of forest structure (e.g. biomass/carbon), vegetation composition (e.g. forest type), and condition (e.g. mortality). A model-assisted estimation framework was developed that integrates G-LiHT-derived measurements (obtained as a strip sample) with field measurements to provide precise, and unbiased, estimators of important inventory attributes, including totals (e.g. total live tree carbon), areas (e.g. total area of black spruce forests), and domain-level averages (e.g. average live tree carbon per hectare in black spruce forests). Here we present the model-assisted estimators used in this inventory, as well as an assessment of the statistical properties of these estimators (bias, coverage probability) obtained via simulation.

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

Combined terrestrial and digital mapping for area-wide maps, modelling soil properties and link re-mote sensing data with classical site surveys.

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: In many forest areas especially near the timberline there is a lack of spatial covering data about soil properties. To handle large areas in a reasonable time and with manageable manpower, soil development and soil properties are spatially covering modelled.

So-called substrate maps have established themselves as an important predictor for modelling physical properties such as permeability and pore volume and chemical soil properties such as the potential of cation release (K^+, Ca^{2+}, Mg^{2+}). These maps consist of polygons whose homogeneity is defined primarily by the sedimentological process essential in them, the gen-type, the genetical types of abrasion and accumulation which are responsible for the substrate, the matter in about 1 to 1,5 m beneath the surface.

Terrestrial mapping of corridors, mainly using forestry roads, provides important data about physical and mineral chemical properties of substrate. These hard data result directly from the field surveys or from results of analysed samples (x-ray diffraction, grain size distribution, mineral petrographical analyses).

Along the maped corridors, the location of polygon boundaries represent the change of gen-type or substrate properties. These boundaries can be defined to within a few metres. In this way, a full-surface pattern of directly adjacent polygons along the terrestric corridors is created.

This corridor-network is digitally supplemented to form an area-wide map. This work is also done manually according to the same rules as along the terrestrial corridors.

The result is an area-wide map of the quantitatively classified substrate. According to the different data basis for terrestrial corridors and referenced classified areas in between, the attribute information sharpness is applied. For the classified substrate, quantitative data for nutrient supply and water balance can be derived.

Through this combination of terrestrial mapping and modelling, the properties of large areas can be represented in relatively high resolution in a reasonable amount of time and with a manageable amount of manpower.

These maps are an essential predictor for spatial modelling of soil properties such as nutrients and water and also provide a useful link between remote sensing data and terrestrial point information.

Cost-efficient mapping of a site-based forest ecosystem classification using machine learning

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Ecosystem maps are an important tool for managing natural landscapes. Existing ecosystem mapping (EM) of the site-based biogeoclimatic ecosystem classification system use expert models or air photo interpretation, which are confounded by high cost, subjectivity, poor updateability and require expensive independent field verification to assess map accuracy. A data-driven, machine learning approach to EM has the potential to address these limitations, however, the high cost of training data acquisition has limited its application in practice. We outline a scalable, cost-efficient sample design that places line-intercept transects using cost-constrained conditioned Latin hypercube sampling of ecologically relevant landscape-level predictors. Ecosystem units, which reflect site conditions, are identified primarily by indicator species assisted by topographic and soils factors. Our hierarchical sample design provides spatially distinct units for 1) training data, in the construction of machine-learning ecosystem models, and 2) appropriately scaled experimental unit for statistical map accuracy evaluation. We produce accuracy statistics from a repeated leave-one-out model build and assessment. Mean accuracy with variance are reported for a suite of metrics that reflect proportional and spatially-explicit accuracy, a 'theta' metric to adjust for imbalanced map unit abundance, and fuzzy set scoring. The appropriate metric can be selected for different applications of EM.

We applied this methodology to sample, build and evaluate a stand-level ecosystem map in a 50 000 ha area of low boreal and subalpine forest using a Random Forests learner and a standard suite of predictor covariates derived from LiDAR. The sample design successfully sampled both important stand-level predictor distribution and a representative set of ecosystem map units, while reducing sample costs by an order of magnitude compared to single point sampling. Machine-learning models trained with optimally rebalanced training data from as few as 30 sample transects, representing 3-4 crew-days of effort, produced a stand-level forest ecosystem map with 85% +/- 10% agreement on map unit proportions and 75% +/- 10% spatial accuracy where fuzzy membership scores and 5m corrections for spatial misregistration are applied. This cost-effective method can be adapted to other inventories requiring intensive field sampling will allow implementation of comprehensive and reliable ecosystem mapping program.

Developing soil moisture maps at high spatiotemporal resolution for forest management and nature conservation: a study in a boreal forest landscape

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Digital soil moisture maps are valuable tools to practitioners, stakeholders and researchers for planning forest management and promoting nature conservation. However, mapping soil moisture at both high spatial and temporal resolutions is challenging, especially over spatially extensive geographic regions. By focusing on the Krycklan catchment in the boreal region of northern Sweden as a pilot study area, we propose a novel procedure that combines LIDAR-derived terrain and vegetation indices, reanalysis climatological data and in-situ field measurements within a machine-learning (ML) framework to develop daily soil moisture maps at 2-meter resolution. First, we explored the ability of numerous potential climatic, topographic and vegetation-related variables from different sources and with different spatial and temporal resolutions to predict soil moisture data recorded at about 90 sites across the study area over the snow-free seasons of 2022-2023. Second, these in-situ measurements of soil moisture served as a means to train and validate three ML models using (i) only field data, (ii) only remote sensing data, and (iii) a combination of both as predictors. The resulting maps reproduced well the spatiotemporal variability of soil moisture in the study area, with the second type of ML models performing only slightly worse than the other two. We argue that these dynamic soil moisture maps at high spatial resolution could provide valuable information for practical forest management and the methodological framework that relies exclusively on remote sensing data could be extended to the scale of Sweden.

Digital soil mapping and modelling of forest soils in Europe

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Forest soils are important providers of ecosystem services, underpinning economic sustainability. The health and sustainability of forest ecosystems depend on the health and functioning of forest soils. Their conservation and management are essential for the well-being of both natural ecosystems and human societies. It is fundamental to have up to date spatial information on forest soils for continental coverage in Europe for various stakeholders. In this work, carried out in the framework of the EU H2020 project on 'Holistic management practices, modelling and monitoring for European Forest soils' (HoliSoils), we will present two key aspects: 1) how forest soil datasets from different sources were integrated and harmonised, and 2) how these data were used to map soil properties of forest soils at continental scale. The soil data were processed following updated Extract Transform Load (ETL) procedures developed for WoSIS (ISRIC - World Soil Information Service). For the mapping, we used an approach featuring model tuning, covariates selection and regression random forest to map key soil properties at a resolution of 100 m and assess the spatial uncertainty for each pixel. The work shows the importance of quality-assessed, harmonised data when mapping and modelling across countries at continental scale to support decision making towards climate and sustainability goals.

Efficient sampling approach for digital soil mapping in mountainous forests of Japan

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Digital soil mapping (DSM) has developed rapidly in recent years in line with the development of machine learning, and there has been a growing focus on the approach for site selection to improve mapping accuracy (sampling for DSM). However, most studies have been conducted on less undulating areas, including farmland. Few studies have been conducted on mountainous forests with difficulty reaching target points due to bushes, steep slopes, and a lack of forestry roads. Thus, the more efficient sampling that enables accurate mapping at fewer points is necessary for reducing survey costs in Japan, where mountainous forests cover 75% of the national land area. This study focused on mapping soil thickness and compared the methods to determine the appropriate sampling for DSM in mountainous forests. The study area (ca. 120 ha) is in mountainous and hilly terrain, contains ca. 30 first-order drainage basins, and is mainly planted with *Cryptomeria japonica*. We measured soil thickness using a soil strength probe at 80 points each by covariate space coverage sampling (CSC) as the sampling for mapping and by traditional spatial coverage sampling (SC). CSC determines the sampling point using spatial covariates that are expected to be related to soil properties by k-means. Several topographic factors, such as slope, TWI, and TPI, were used for CSC. Finally, using random forest, DSM was conducted by both sampling sets and compared their accuracy. To test the sensitivity to the number of training points, DSM using 90%, 80%...10% of the total points are compared in both models. As a result, the accuracy of CSC was significantly higher than that of SC for all sampling points. The difference was more in smaller sample sizes. The predicted map by CSC was almost similar in spatial pattern to the map by all 160 points. Thus, CSC would be cost-efficient sampling for DSM in mountainous forests, where the topographic factor is strongly correlated with soil properties. Meanwhile, more efficient soil surveys would be possible if the distance from the roads or the location of bushes were considered in the CSC.

Fine-grained Soil Particles Prediction Based on GeoAI and LiDAR for Precision Harvesting Applications

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: In precision harvesting, it is important for foresters to understand the soil-bearing capacity in order to take appropriate measures to minimize soil compaction, preserve soil structure, and ensure that the soil is suitable for use by harvesters or forwarders. Fine-grained soils play a particularly crucial role in determining soil-bearing capacity, as they tend to be more sensitive to compaction and deformation than coarse-grained soils. Creating accurate and detailed maps of soil particles in forested areas is a complex and challenging task due to the significant variability in soil properties and the difficulty in accessing and sampling the soil. However, recent advances in technology, such as deep learning-based approaches and remote sensing data, offer promising solutions to this problem.

In this study, we developed a fully connected neural network (FCNN) approach that utilizes high-density LiDAR data derivatives to estimate the values of fine-grained soils. Our soil samples were collected from 47 forest stands located in southern Finland. We determined the distribution of grain sizes of the soil samples using the laser diffraction method. To create the target map of soil particles within each forest stand, we used geostatistical models. The predictors' layers, such as geomorphological and forest features, were derived from LiDAR metrics. These data were used to create training and testing datasets. After tuning the architectures and hyperparameters, we trained our FCNN using the training dataset and evaluated its performance using the testing dataset.

We anticipate that our model will produce promising results, with the potential to significantly improve the accuracy of the prediction of fine-grained soil particles in the forest environment. This could have important implications for the prediction of soil disturbances induced by harvesters, as well as the prediction of soil-bearing capacity. While our study is still ongoing and we have not yet obtained final results, we believe that our GeoAI-based approach has significant potential for advancing soil studies. We look forward to sharing our findings with the research community at the conference.

High-Resolution Map on Base Saturation: an Essential Tool for Forest Management in Austria

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Understanding soil nutrient status and its spatial distribution is crucial for effective forest management, especially in the face of climate change. This study focuses on the development and significance of a high-resolution base saturation map based on nutrient classes for a forest area of 1 million hectares in a complex topographic and geological environment in the federal state of Styria, Austria. This study emphasizes the importance of such a map in light of existing data limitations and future challenges posed by climate change.

In a first step, pedotransfer functions were developed using laboratory analysis of soil chemical parameters from 400 soil pits in 4 depth layers. In order to expand the dataset and enhance coverage, an additional 1400 assessment plots were characterized solely by field descriptive soil assessment. This dataset of 1800 assessment plots served as the basis for subsequent analyses. In a next step, a combination of base saturation, soil pH and mineralogical composition was identified as robust parameters for defining soil nutrient classes in form of base saturation types.

Different digital soil mapping techniques, including Random Forest and Artificial Neural Networks, were then utilized to generate projections based on the expanded dataset. These techniques enabled the development of a high-resolution base saturation map that captures the spatial variability of base saturation types and thus soil chemical parameters.

The validation of this modeling approach was conducted by comparing the model outputs with the presence of tree species at the forest sites, average tree species growth, and plant sociological communities. Results demonstrated a strong correlation between the base saturation map and tree species distribution, highlighting the model's accuracy in capturing important ecological relationships. Furthermore, the growth of tree species aligned closely with the predicted nutrient classes, validating the utility of the map for assessing growth potential.

The map serves as a valuable tool for forest planners, enabling them to identify areas of specific interest and subsequently develop targeted interventions and adaptive management strategies (e.g. tree species selection), addressing current and future challenges in respect to nutrient status.

Mapping carbon stocks in forest litter considering vegetation, topography, climate, and soil parent material factors

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: The forest litter is a carbon pool on forest floor and also a major source of soil organic carbon. Then, geographic information on litter layers is important for climate change research and understanding the global and regional carbon cycle via forested areas. Since litter layer observation using remote sensing approaches is unreasonable at a present and complex decomposition and accumulation process of litter layer are affected by vegetation, topography, climate, etc., factors, this information is limited. Therefore, to generate the reliable geographic data about litter layers in the forest area of Japan (*ca*. 250000 km^2), we try to predict carbon stocks in litter layer with a digital soil mapping approach at a 10m grid resolution. This study conducts a random forest modeling using 2462 sites litter carbon stock data investigated since 2006 until 2010 as training data. Initial trial of random forest modeling of this study is based on vegetation, topography, and climate factors, according to the computing flow of previous study for forest soil carbon prediction using same investigation data (Yamashita et al. 2022). The random forest modeling for carbon stocks in litter layers indicates that dominant tree species of forest might be effective vegetation factor as differed from previous study about prediction of soil carbon stocks in Japanese forest area. Although this study improved accuracy of prediction for carbon stocks in litter layers, we need more consideration of selection explanatory factors to improve accuracy reaching to same level as compared to previous soil carbon prediction. This study was supported by JSPS KAKENHI Grant Number JP22H02400.

Mapping Multiple Soil Properties Using Artificial Neural Networks: Creating Coherent Soil Datasets

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Mapping multiple soil properties is essential for soil-related ecological modeling, including the prediction of tree species suitability. In this study, we propose an approach that utilizes artificial neural networks (ANN) to simultaneously map soil properties, ensuring the generation of a coherent and plausible dataset. Our aim is to enhance the compatibility and plausibility of the predicted dataset by considering the interdependencies among different soil properties. To achieve this, we employed ANN to model individual soil properties while incorporating independent covariates such as climatic, morphometric, geological, and remote-sensing information. Our approach aimed to maintain the accuracy of the predictions by considering the relationships among soil properties and their interplay with the covariates. By leveraging the collective information from the dataset, we aimed to maintain a balanced representation of the soil properties. In addition, we implemented a topically clustered strategy, grouping target variables based on specific themes such as hydrological or nutrient-related properties. This enhances the quality and accuracy of the predicted values by capturing the interdependencies among certain soil properties within each cluster. To evaluate the effectiveness of our methodology, we compared the results obtained to both random forest and ANN predictions fitted for single soil properties. Through comparative qualitative analysis of predicted soil properties, we evaluated the agreement and consistency of the mapped properties, taking into account their interdependencies. The findings demonstrate the capability of our approach to produce accurate and reliable maps of multiple soil properties by employing ANN and considering interdependencies. These maps provide valuable insights into the spatial variability and distribution patterns of soil properties, actively supporting soil-related ecological modeling for mapping tree species suitability in the context of sustainable forest management.

Mapping the productivity of forest sites across the Canadian landscape to predict which species to plant where in a changing climate

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Long-term tree growth depends on the complex interaction between site, soil, climate, and biological factors. Forest inventories provide abundant plot-based information on tree growth, but often lack essential information on soil chemical and physical properties. To overcome this problem, we used digital maps of soil properties, terrain, and climate variables to predict groundplot site index, a measure of site productivity for four major Canadian tree species. The models predicted different optimal growing conditions for each species and revealed interactions between climate and edaphic variables. For example, species that performed well in a cold climate perform better with a warmer climate as long as they remain under the same edaphic conditions. However, above certain climatic thresholds they become less competitive with other species and their presence is limited to sites of lesser quality. Digital mapping of soil and site conditions is crucial to understand how the complex interplay between edaphic, climatic, and biological factors drive forest productivity. The results of this study will be useful to predict the suitability of the plantation of different tree species to edaphic conditions in a changing climate and to better know what to plant where.

Mapping understory vegetation density using airborne and mobile laser scanning

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Understory vegetation plays a vital role in characterizing forest sites, wildlife habitat, and fuel load, and it is a necessary metric for simulating fire behavior or understanding forest competition dynamics. Traditionally understory vegetation has been characterized through field vegetation surveys which are time-consuming and limited in spatial coverage. To address this challenge, we propose a digital mapping approach combining data from airborne laser scanning (ALS) and mobile laser scanning (MLS), which can provide understory vegetation information at a larger scale.

The aim of this study was to map the understory vegetation density employing ALS and MLS technologies. Ground reference data were acquired using MLS, with a voxel-based analysis to characterize the understory vegetation structure. After excluding the trunks of the trees using semantic segmentation, we calculate understory vegetation density at different heights (surface from 0 to 0.3 m, near-surface from 0.3 to 0.7 m, and elevated from 0.7 to 2 m) by dividing the 3D point cloud into 10 cm voxels and determining the proportion of voxels containing laser echoes.

We then construct predictive models that relate the understory vegetation density of each height layer to ALS metrics. New ALS metrics related to ground points were tested in addition to the standard height and density metrics from different parts of the point cloud. Linear regression prediction models were developed for each understory layer using the ALS metrics as input variables. The accuracy of the models was evaluated through leave-one-out cross-validation by calculating the relative root mean square error and mean deviation. Finally, a wall-to-wall map of understory vegetation density was generated for each layer.

Preliminary results show promising potential for predicting understory vegetation using ALS data, with R2 values of 0.20, 0.41, and 0.47 for modeling understory vegetation density in the surface, near-surface and elevated layers, respectively.

Mappingtheabove-groundbiomassofforestinGuangxibasedonthewall-to-wallairborne LiDARdataandaforesttypedistributionmapderivedfromanaerialorthophotoimage

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Accurately estimating forest biomass and carbon fluxes in extensive areas is critical for supporting sustainable forest management. In this study, the filed data and corresponding airborne laser scanning (ALS) data collected form 1086 sample plots distributed over the Guangxi between 2017 and 2019 were used to developed species-specific above-ground biomass(AGB) estimation models for other broadleaved forests, *Cunninghamia lanceolata* forests (*C. lanceolata* forests), *Eucalyptus grandis*×*Eucalyptus urophylla* forests (*E. grandis* forests), and *Pinus massoniana* forests(*P. massoniana* forests). There are three types of ALS instruments were employed to obtain the ALS data corresponding to our sample plots and the wall-to-wall ALS data. Therefore, Guangxi was partitioned into three distinct study areas, distinguished by the type of ALS instrument employed, wherein we subsequently developed species-specific AGB estimation models tailored to the forests within each respective study area. Then, a forest type distribution map with a resolution of 50m * 50m, derived from an aerial orthophoto image with a resolution of 0.2m * 0.2m, for validating and determining the forest type assigned to each grid cell within the rasterized wall-to-wall ALS dataset. Final, we generated a spatially-continuous map with a resolution of 20m * 20m of AGB by inputting the forest type and corresponding ALS metrics in each grid cell in the rasterized wall-to-wall ALS data to species-specific estimation models. The total AGB of other broadleaved forest, *C. lanceolata* forest, *E. grandis* ×*E.urophylla* forest, and *P. massoniana* forest in Guangxi in 2018 was $24433.07*10^4$t, $15291.22*10^4$t, $10993.97 *10^4$t and $18535.51*10^4$t, respectively. This article presents a method for acquiring a spatially continuous distribution map of AGB specific to different forests in the region of Guangxi, China. In subsequent research, a direct attempt could be made to determine the forest types of each grid cell in the rasterized ALS dataset , utilizing both the ALS and sample plot data.

Merging soil moisture forecasts and rolling resistance data by a forest harvester for predicting site trafficability and soil damages

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Mechanized forest harvesting operations with heavy machinery can lead to significant soil rutting. To avoid soil damages, reliable knowledge on site and time-specific trafficability and soil strength is needed. Factors influencing soil strength, such as soil texture, organic matter and clay content, bulk density, stoniness, and root system, have considerable spatial variability. These static or slowly varying site characteristics then determine how dynamic environmental conditions, e.g. weather patterns, drive the temporal variability of soil strength. While rather accurate spatial data on topography and above ground vegetation are available, the other landscape attributes influencing soil bearing capacity have much more coarse data resolution. More detailed understanding of the temporal variation in trafficability is crucial particularly due to climate change that might change the duration and timing of frost periods when trafficability is on sufficient level. Collection of detailed data on soil state and site trafficability is slow and expensive with traditional methods. We propose that utilizing the Arcnet-channel data from forest vehicles provides an useful data source and proxy for trafficability by informing about soil bearing capacity. In our project TRAM, funded by the Research Council of Finland, we have collected Arcnet data from a forest harvester and forwarder under normal forest operations. The data allows computing the rolling resistance based on engine power used, machine characteristics and local slope. We characterize and interpret the rolling resistance variability in typical forest landscapes in Southern Finland using the extensive machine data and open geospatial datasets. We explore how accurately rolling resistance can be predicted with machine-learning models using spatial data and high-resolution soil moisture predictions using a distributed hydrological model. We consider how the rolling resistance variability correlates with observed soil rutting derived from drone-based photogrammetry. We focus on 11 sites in Southern Finland harvested during spring and summer of 2021 under varying hydrometeorological conditions.

Potential for Using Machine Learning to Improve the Swedish National Soil Surface Deposit Map

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: In the age of precision forestry, accurate and detailed soil information is crucial for optimizing forest management practices and forestry logistics. Soil classification provides a foundation for understanding key soil characteristics such as texture, nutrient content, water-holding capacity, pH, and other essential physical and chemical properties important for forest management. However, soil maps such as Sweden's current quaternary deposit maps suffer from limited high-quality coverage areas, rendering them impractical for hands-on use in some cases. This limitation arises partly due to the dense forest canopy prevalent in boreal regions, which poses challenges for traditional mapping techniques that rely on visual interpretation or direct field observations.

To address this issue, this study focuses on leveraging insights from field sampling data from the Swedish forest soil inventory and quantitatively assessing the effectiveness of incorporating indices calculated from the LiDAR-derived digital elevation model (DEM) and satellite imagery as input for machine learning models. Furthermore, the study aims to determine the optimal model for spatial prediction of soil classes, which will be deployed to generate a map of soil surface deposits at 2-m resolution for the entire country. Additionally, we will estimate the uncertainties associated with each soil class and discuss the advantages and limitations of this approach. The quality of the conventional maps at various scales and the machine learning-based surface deposits map are evaluated against a subset of the field observations. Preliminary results indicate that integrating field data with machine learning improves the identification of most soil types. We are confident that the machine learning-generated map can effectively complement the existing conventional soil maps in Sweden, but expert geological and pedological knowledge is still required when identifying certain sorted sediment types. The improved soil surface deposits map will serve as a decision support tool for future precision forest management, facilitating key tasks such as site-index determination, tree selection, and soil trafficability assessment, among others.

Predicting forest water status under climate change scenarios: A case study in Central Europe

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Soils play a major role in the hydrological response of ecosystems. Spatially explicit forest soil attributes are however largely missing in Austria. Therefore, we developed a framework to map soil hydraulic properties and drought stress indices for a forest area of 1 million hectares at a spatial resolution of 10 m x 10 m. We aim to assess water budgets of forest site units for the past 40 years and for two climate scenarios until the end of this century.

Our approach combines various data sources: high-resolution digital terrain information, properties of the parent material for soil formation (sub-solum geological substrate) at polygon level, vegetation properties derived from remote sensing, downscaled high resolution climate data and point information (site and soil description of 1800 plots, analyses of physical soil properties of forest floor of five geometric mineral soil horizons of 400 pits).

Soil properties were upscaled with digital soil mapping techniques like Artificial Neural Networks. The water balance for 1,800 surveyed forest plots in the study area was modelled with the lumped 1-D- hydrological model LWFBrook90R. Hydrological soil characteristics for the parameterization of the model were derived from pedotransfer-functions. We simulated changes in soil water content, matrix potential, and transpiration deficit as an indicator of stress for a ‘generic’ forest stand. Combining this output with soil and topoclimate information we assessed the site-specific water supply which was then upscaled for the whole study area.

To validate the models, we compared their outputs with dendrochronological records available for all plots as well as vegetation indices from the ground-vegetation and site indices derived from stand properties. Dendrochronology provides valuable information on past growth patterns and can help us assess the models' ability to describe physiologically relevant information.

Overall, the development of the water balance framework is a promising tool for assessing the impacts of climate change on forest ecosystems. We could show possible impacts on the water balance in a future climate for different scenarios and were also able to identify areas which might be susceptible to future droughts.

Site Mapping based on the Correlation of Site and Soil Properties to Eucalyptus Plantation Productivity

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: This study assessed the utility of an object-oriented approach to obtain accurate correlation of site characteristics and soil properties to *Eucalyptus* clonal plantation productivity. The objectives were to characterize the soil physical and chemical properties and correlate them with two *Eucalyptus* clones productivity at age 42 months as well as to understand the most influential factors of site and soil on *Eucalyptus* productivity. We have built a model to predict productivity of *Eucalyptus* clonal plantations presented as digital maps. In the study, we characterized the site and soil spatially including clay content, soil CEC, organic carbon, pH, total nitrogen, extractable P, and exchangeable cations (Aluminum, Hydrogen, Potassium, Calcium and Magnesium). The most influential site characteristics and soil properties on *Eucalyptus* productivity were identified by using Global Boosting Model (GBM). Soil fertility status was divided into three clusters (high, adequate, and low) by K-Means cluster analysis. *Eucalyptus* clonal plantation productivity spatially has a high variation indicated by Universal Kriging Interpolation and Inverse Distance Weight (IDW) with high actual and predicted productivity correlations (R^2 of 0.9 for both method and clonal). The most relative influential factors of site and soil characteristics on *Eucalyptus* productivity variation at age 42 months old were clone variety (78% relative influence of R-square 0.73) where each clone showed different responses to site characteristics and soil physical and chemical properties. This study suggests that the current available soil data from soil survey can be used to predict site potential productivity for specific clones, however, data distribution (soil and growth) may affect the error; clone is main relative contributor in productivity variation and analysis; the genetic deployment plays an important role in productivity; Soil C-org, pH, P bray variation contributed to clonal productivity variation in most of the estates, so any operation must take care the soil for long term sustainable productivity.

Keyword: digital mapping, soil properties, plantation, Eucalyptus productivity

Spatiotemporal modeling for prediction of tree growth: integrating multiple data sources in forest management

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Spatiotemporal modeling is an efficient approach for predicting abiotic factors such as soil moisture and surface temperature – both affecting plant growth. This modeling technique holds great promise for supporting sustainable forest management, e.g. by the accurate prediction of forest yield.

In our study, we utilized time-series of ERA5-Land retrievals, and static information given by topographic indices, and soil maps to model the annual growth of mature stands in the Northern Calcareous Alps. To capture growth patterns over a span of 30 years, we conducted a forest inventory and analyzed annual growth with dendrochronological methods based on image analysis techniques. Multiple linear models and machine learning models were employed, followed by a feature selection process to identify the most influential predictor variables. These reduced models were then validated using 10-fold cross validation.

Our spatiotemporal modeling approach successfully predicted tree growth with a high level of accuracy. The final model incorporated static variables representing topography and soil information, as well as dynamic variables derived from ERA5-Land retrievals. These retrievals indicate significant temporal variations of forest growth over the observed time period.

Our findings demonstrate that by leveraging data from diverse sources, including ERA5-Land retrievals, topographic indices, and soil maps, we can effectively predict tree growth. This information can be utilized to enhance forest inventory and inform forest management practices. Particularly in the face of changing environmental conditions, a dynamic approach that incorporates mid-term weather anomalies to forecast forest growth holds increasing value.

The integration of levels of extent and scale in tree species distribution models of Abies alba (Mill.) and Fagus sylvatica (L.) in mountain forests

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Mountain forests in the European Alps cover the distribution margins of several tree species and therefore are particularly well-suited to reveal soil-climate effects on the shaping of these margins. Combining different scales and extents are essential in species distribution models when it comes to the investigation of the environmental niche of species. The study focuses on two levels of spatial extent, on the one hand the continental level of Europe, and on the other hand the regional level of the federal state of Tyrol in Austria. The potential occurrence of the two investigated tree species, *Abies alba* and *Fagus sylvatica,* was modelled with Deep Neural Networks. In the process, we observed a strong imbalance of absence and presence records at the continental level and evaluated different methods to address this issue. The potential predictor variables for species distribution modelling were grouped into climatological, soil, and topographical information. The combination of the different levels of scale and extent was implemented by using the outputs of the continental model as a predictor variable in the regional model. The binary classification of the 30% test dataset showed a True Skill Statistic of 0.73 to 0.76 for the regional level and 0.5 to 0.74 for the continental level, with slightly higher values for *F. sylvatica* than for *A. alba*. For both species and extent levels, the climatological predictor group showed the greatest contribution (81 to 96 %) to the models' predictive power. At the regional level, climate was followed by the soil and the topographical predictor groups. At the continental level however, topography showed stronger effects than soil information. In most cases, the consideration of soil information along climatological gradients led to an increase in the occurrence probability at the climatic distribution margins. There is evidence that edaphic conditions are more important in determining the inner Alpine distribution margins for *F. sylvatica* than for *A. alba*. To improve species distribution models at the regional level, e.g. in the Alpine area, a focus on soil information is proposed. In general, models which combine continental and regional data are preferable.

Topographically high-resolution mapping of catchment-scale soil carbon dioxide and methane fluxes

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Soil-to-atmospheric CO_2 and CH_4 fluxes in forest soils play crucial roles in the global greenhouse gas cycles. Soil CO_2 flux is a major carbon flux in forest ecosystems, while soil CH_4 uptake flux in upland forest soils represents the only significant biological sink of CH_4 in the global methane budget. To estimate catchment, country, and global-scale soil GHG fluxes, upscaling of observed GHG fluxes from field measurements is necessary. In this study, we upscaled observed soil CO_2 and CH_4 fluxes within a forest catchment using a digital elevation model (DEM) and machine learning techniques, and examined the spatio-temporal distribution of each gas flux within the catchment. The study was conducted in a 2.5 ha mountain watershed in Hitachi Ohta City, Ibaraki, Japan. Monthly measurements of soil CO_2 and CH_4 fluxes were taken at 10 different topographic positions in the catchment. The fluxes were upscaled using a Random Forest model with topographic and climatic covariates. The methane flux was predominantly influenced by the topographic index, while the CO_2 flux was primarily controlled by the climatic index. By employing machine learning analysis with the DEM-derived covariates and climatic covariates, we visualized the spatio-temporal distribution of CO_2 and CH_4 fluxes within the catchment. The generated map revealed lower CH_4 fluxes in the valleys and slightly lower fluxes in hilly areas. The valley consistently exhibited low CH_4 fluxes throughout the year, with predominantly uptake fluxes but occasional emission fluxes predicted. In contrast, CO_2 fluxes were slightly lower along the valleys and demonstrated clear seasonality, while CH_4 fluxes showed less pronounced seasonal patterns. The total catchment flux estimates based on the predicted maps often differed from those based on simple catchment means, indicating that the upscaling scheme considering topographic variability is useful for accurate estimation of catchment-scale fluxes.

Utilising spatially explicit site information for mapping tree species suitability: The role of digitally mapped soil data

T5.9 Digital (soil) mapping as a suitable approach to generate spatial forest site and biodiversity data at different scales

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Abstract: Tree species selection is an important strategic decision in forest management, especially in the context of adapting forests to climate change. However, uncertainty in future climatic conditions makes tree species selection a complex task. Therefore, tree species suitability models have been developed to support forest managers. These tools provide spatially explicit information on the suitability of tree species, considering the dynamic nature of site factors over time as well. In general, such models are based on the concept of the fundamental niche, i.e. tree species suitability is derived from the ecophysiological characteristics of tree species regarding nutrient and water supply as well as the thermal conditions. These site factors are represented by a set of climate and soil variables and need to be provided with a high spatial resolution in order to create spatially explicit tree species suitability maps.

In this contribution we introduce a static expert model that has been developed to map the suitability of 18 European tree species in Austrian forests. We demonstrate its use by mapping the suitability of tree species under current and projected future climatic conditions, and evaluate the sensitivity of the model towards input variables, with particular focus on the effects of uncertainty in soil-related variables. This focus is motivated by the wide-spread use of digitally mapped soil data.

The results highlight the general relevance of soil data for modelling tree species suitability and underline the importance of the quality of digital soil mapping techniques for creating spatially explicit data sets on tree species suitability.

T5.10 Digitalization for sustainable forest management

A New Approach for Feeding Multispectral Imagery into Deep Learning Improved Classification of Seedlings

T5.10 Digitalization for sustainable forest management

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Abstract: Accurate information about tree species is critical in management of forests, particularly in seedling (regenerating) forest stands. When remote sensing techniques are utilized to inventory the seedling stands where the tree crowns are often small and with lesser foliage cover, the spectral admixture of understory reflectance with seedling canopy occurs, which challenges the tree species classification process. To moderate the admixture issue, we proposed an image pre-processing step based on canopy threshold (C_{th}) to be applied on input tensors made of drone-based multispectral images, before training the convolutional neural network (CNN) and random forest (RF) classifiers. The aim of this research is to explore capabilities of CNN in classification of seedlings of Scots pines (*Pinus sylvestris* L.), Norway spruces (*Picea Abies* (L.) H. Karst.) and birches (Betula sp.) from other seedling species in south boreal seedling stands in Evo, Finland. Hence, this research focuses on 1) improving classification of seedlings utilizing the proposed strategy, 2) comparing the performance of the two classifiers (CNN and RF), and 3) improving classification of seedlings by adding vegetation indexes in the CNN classifier.

The classification of 5417 field-mapped seedlings from 75 forest plots revealed that applying the proposed method improved the overall accuracy (OA) of seedlings species classification from 75.7% to 78.5% on the C_{th}-affected subset of the test dataset using CNN method (2). CNN yielded more accurate OA (79.3%) compared to RF (68.3% pp; 2). Additionally, combining vegetation indexes with multispectral data improved the OA from 75.1% to 79.3% in CNN (3). Further investigation uncovered that shorter seedlings and tensors with higher number of C_{th}-affected pixels have negatively affected the classification of seedling. Based on the results obtained in this study, the proposed pre-processing step can be considered in the species classification of seedlings in operational forest inventorying using operational multispectral consumer-grade drones.

Airborne laser scanning application in operational forestry in Poland - good practices and challenges

T5.10 Digitalization for sustainable forest management

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Abstract: LiDAR technology makes it possible to accurately determine the biometric characteristics of trees as well as many stand variables. Airborne laser scanning has been used for more than 20 years to determine forest characteristics, whether based on the detection of individual trees or an area-based approach.

In Poland, work has been ongoing for almost 20 years to integrate airborne laser scanning data into practical forest management, which is carried out every 10 years. In recent years, it has been possible to develop and practically test a method for estimating growing stock volume (GSV) at the stand level using ALS data and permanent sample plots. This method is currently being implemented in forestry practice and is to be approved as an alternative in the preparation of forest management plans in state forests.

The presentation will demonstrate the process of implementing ALS solutions in forestry practice using a dedicated ALSgator application. The application consists of two modules - the control module and the stand variable prediction module. Within the control module, it is possible to check many parameters of the ordered point cloud and the aerial orthophoto and to check whether the data meet the requirements. The stand characteristics estimation module allows the determination of the following stand level characteristics: GSV, basal area of all trees, DBH of all trees, DBH of the 100 thickest trees per hectare, the number of trees per hectare, the top height of the 100 thickest trees per hectare, the average height of all trees, the average height of the first layer trees.

Furthermore, we will present the experiences and challenges in the practical application of ALS from the perspective of the Polish forestry sector.

Assessing Change Detection Algorithms for Monitoring PEFC forest certification: Towards Sustainable Management and Certification Compliance

T5.10 Digitalization for sustainable forest management

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Abstract: In this study we evaluate the effectiveness of change detection algorithms in identifying changes in forest cover within different provinces in Spain.

These algorithms leverage a data-driven approach to identify and quantify the occurring changes by analyzing multi-temporal satellite imagery datasets. In the second phase, we classify the changes to differentiate between changes caused by forest fires, clear-cutting, and thinning using machine learning methods. The results aim to highlight the accuracy and robustness of these algorithms for detecting forest changes with high spatial and temporal resolution.

The ability of these algorithms to provide consistent and objective assessments enables internal auditors and the certification body to focus audits on areas where changes have occurred and thus better assess compliance with PEFC's certification standards and regulations. Furthermore, the automated nature of the algorithms enhances efficiency, reducing the manual effort required for monitoring and auditing processes. The findings from this study will contribute to improve the transparency and accountability of PEFC forest certification.

Moreover, by employing a change detection tool for analysis, stakeholders can obtain valuable insights into the dynamics of certified forests, facilitating informed decision-making and policy development. This research underscores the importance of data-driven approaches in supporting effective forest management and the sustainable use of forest resources.

The study is part of the project "GO Bosques 3.0: Digitalization and remote sensing of sustainable use, biodiversity, and resilience of Spanish forests",

Automatic assignment of forest inventory plots to municipalities using Linked Open Data

T5.10 Digitalization for sustainable forest management

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Abstract: There is a growing demand in modern forestry to openly publish, share, and interconnect forestry information with other forestry and cross-domain data. National Forest Inventories (NFIs) serve as important databases supporting research, management, monitoring and conservation efforts for forest ecosystems. However, data interoperability between NFIs and other data sources often presents a significant challenge.

Semantic Web technologies offer promising solutions for addressing this problem through the publication of Linked Open Data (LOD). LOD encourages best practices for publishing open data on the Web, promoting interconnectivity between data sources. The W3C standardizes the formats and protocols for publishing LOD, including RDF, a standard model for data interchange on the Web, and SPARQL, a query language for RDF data. Besides, the OGC developed GeoSPARQL for representing and querying geospatial linked data.

In the EU project CrossForest (https://crossforest.eu/) we have published in LOD format an integrated repository of NFIs and land cover maps from Spain and Portugal, henceforth the CrossForest dataset.

We present here the work done to enhance the CrossForest dataset with official Spanish municipality data. By integrating administrative boundaries with plots location, CrossForest dataset increases their applicability in forest assessment and planning. Furthermore, this integration holds significant importance in Spain, since municipalities serve as the fundamental territorial division with jurisdiction over public forest management. Although the Spanish NFIs include municipality data, it is both incomplete and inaccurate.

To tackle this issue, we have converted the municipal entities and their geometries, provided by the Spanish National Geographic Institute, into LOD and matched them to the plots they contain comparing GeoSPARQL and a GIS. The enriched CrossForest dataset is publicly available through a SPARQL endpoint: https://crossforest.gsic.uva.es/sparql and on GitHub: https://github.com/Cross-Forest.

The integration of municipality data as LOD provides the foundation for extracting new information and conducting statistical analyses at geographical level as municipalities or counties (by aggregating municipalities). This offers valuable insights that contribute to effective forest management and informed decision-making. By leveraging this dataset, we were able to generate a series of maps that showcase the dominant species within each Spanish municipality, based on metrics such as basal area and tree density.

Characterizing structural changes in boreal forests by combining terrestrial and airborne laser scanning point clouds

T5.10 Digitalization for sustainable forest management

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Abstract: Point cloud-based observations of trees and tree communities enable non-destructive solutions to monitor their spatiotemporal structure and thus provide information of trees' physio-ecological functionalities and the dynamics of tree communities.

Terrestrial laser scanning (TLS) has been widely utilized for detailed 3D reconstruction and characterization of trees and tree communities. The resulting point clouds enable measurements with millimeter-level accuracy. However, when used alone, the TLS point clouds have a limited capacity to characterize the vertical forest structure and upper parts of trees crowns may remain occluded. Simultaneously, aerial point clouds have been widely used to characterize the vertical structure of trees with especially detailed view on the upper canopy structure.

Aerial point clouds have already been used for change detection of forests for decades, whereas tree growth and structural changes in forests have lately been investigated with multi-temporal TLS point clouds. Considering the certain limitations but also promising results of the earlier research, this study will be among the first to present a method, which uses fusion of terrestrial and airborne laser scanning (ALS) point clouds to improve the estimation accuracy of increment in tree height and tree crown volume.

Data from 2555 trees on 22 sample plots (32 m x 32 m) located in boreal forests of Evo in southern Finland was used. Both ALS and TLS point clouds were acquired in year 2014 and 2021 to create two date data that enabled characterization of spatiotemporal structure of trees and tree communities.

Benefits of using the multi-sensorial approach was assessed by comparing the respective tree characterization performance to that of methods utilizing TLS or ALS point clouds only. The results show that correlation between tree height estimates and reference measurements increased, whereas bias and RMSE decreased, when multi-sensorial approach was utilized instead of using only TLS point clouds for estimation. This indicates improvement in accuracy of characterizing changes in the structure of trees. The findings and experiences obtained in this study will be useful in justifying future data acquisition campaigns aiming at providing valuable information about trees and tree communities in space and time for purposes of sustainable forest management.

Combining laser data and aerial imagery in preparation for nationwide tree species classification

T5.10 Digitalization for sustainable forest management

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Abstract: The third phase of the Swedish national laser scanning is planned to start in 2024 and will have a higher point density than the previous phases. The denser point cloud can be used to map tree species at the level of individual tree crown segments. As part of the Mistra Digital Forest programme task 1.1, we use airborne laser scanning data combined with multispectral aerial imagery to classify tree species at the Asa test site in southern Sweden. The goal is to develop a methodology that can be applied nationwide and assess the classification accuracy for different point densities. The point density of the next national laser scanning is currently yet to be determined. Here, we evaluate how the classification accuracy changes with point densities varying between 5 and 20 points per square meter. This is accomplished by thinning out a denser point cloud. We also investigate the added benefit of combining the laser data with aerial imagery, and how the aerial imagery should be processed for optimal results. As expected, the results show that the overall accuracy decreases with decreasing point density. The aerial imagery was better for identifying deciduous trees than the laserdata, and was thereby an important complement. The positive contribution of the aerial imagery was consistent for both higher and lower point densities.

Deep learning-based tree species identification using high-density airborne laser scanning and forest harvester data

T5.10 Digitalization for sustainable forest management

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Abstract: Tree species composition is one of the most relevant features to consider in forest assessments at varying scales. Such information is essential for societies as there is increased pressure to use more wood-based materials instead of fossil fuels and plastic. According to Yu et al. (2017), species-specific size distribution of the trees is the optimum output from the mapping process requested by forest companies. Hence, in this study we evaluate methods for identifying tree species based on 3D branch structure and intensity values obtained from high-density dual-wavelength airborne laser scanning (ALS). The ALS data was collected in 19 stands in Hällefors, southern Sweden from a helicopter. The resulting point cloud had an average point density of > 500 points/m^2. After ALS data collection, the stands were harvested and the harvester production reports (HPR) were used as reference data for the identification of tree species. Such files contain detailed information on each harvested tree's tapering, location, and species, making them an excellent reference data source for forest modelling at individual tree-level. The preliminary workflow involves segmenting tree crowns using the three-dimensional segmentation method by Holmgren et al. (2022), generating images from the segmented tree crowns from different angles, and training artificial intelligence (AI) models with such images. By using the proposed workflow, we aim to demonstrate the effectiveness of using three-dimensional branch structure and intensity values obtained from ALS as an input for AI models of tree species identification. Finally, this study's results will contribute to development of precision forestry by enabling tree-level species-specific assessments of the forest state.

Developing multispectral and hyperspectral drone imagery to early identification of infestations of European spruce bark beetle

T5.10 Digitalization for sustainable forest management

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Abstract: With the aggravation of global warming, the outbreaks of forest pests happen more frequently and damage huge amounts of forests. Detecting and removing trunk-boring infestations from the forest at an early stage (green attack) is important to avoid spreading. By using remote sensing techniques, forest mortality can be efficiently detected and mapped; however, achieving early detection of the infestation is still challenging because the spectral changes are subtle.

This study assessed the detectability of the green attacks by the European spruce bark beetle (*Ips typographus*, L.) using multispectral and hyperspectral drone images. The scientific questions and objectives are (1) testing whether trees were under stress before the infestation (predisposition) and whether the stress can be sensed by multispectral and hyperspectral sensors mounted on drones, (2) quantifying the detectability of the attacked trees with different duration of infestations, and (3) developing methods of using multispectral and hyperspectral drone images for early detection, and comparing their performance.

The study area is Remningstorp in southern Sweden. We are monitoring spruce trees in 24 plots from 4 spruce-dominant stands by weekly health inventory from April to October. Pheromone bags are attached to the center tree in each plot to attract bark beetles and induce an attack. Sensors are mounted on 32 trees to monitor the sap flow throughout the season, indicating the potential water stress before and during the infestation. Bi-weekly multispectral and hyperspectral images are acquired, covering healthy and early to late stages of infestations. The images will be processed and the spectral signatures of trees will be analyzed. A methodology for early detection using drone imagery will be proposed, and the scientific question will be answered on how early the infestations can be detected by drone images.

Digitalization of the forest road maintenance by implementing sensor technologies and AI

T5.10 Digitalization for sustainable forest management

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Abstract: Forest roads are essential infrastructures in the forest management, since they provide access to the forest areas and are the basis for forest operations, fire protection and recreation. The ideal maintenance management of these infrastructures plays a key role to ensure the optimal use of those activities. Traditionally, the evaluation of the state of forest roads has been conducted visually by the forest owners on-site. Thus, this method is susceptible to misinterpretation due to its subjectivity. Consequently, the use of new technologies such as sensor technology-based devices and AI is currently being implemented in order to automate the assessment processes of the forest road maintenance and offer the stakeholders a digital visualization of the forest roads and their current maintenance state. The succesful implementation of these systems can provide the stakeholders a powerful tool for different objectives such as navigation or development of efficient maintenance plans.

Notably, several issues related to the implementation of such systems are currently unresolved, for instance, the diverse requirements concerning the forest road maintenance state according to each stakeholder, the parameters (for instance, trafficabiliy or construction material) to be included in the digital data, the used technologies or the capabilities of the stakeholders to participate in related subprocesses such as data collection. Therefore, a qualitative social study, which consisted of 30 semi-structured interviews and several workshops with a wide range of stakeholders, was conducted in Germany. In this framework, relevant information was collected to resolve the mentioned issues as well as determine possible implications of the implementation of such systems, especially, the development of data-driven business models that might provide further revenues to the involved stakeholders.

This presentation will firstly offer an overview of the diverse requirements concerning the forest roads maintenance state depending on each stakeholder. Secondly, different innovative possibilities to evaluate the state of forest roads using sensor technologies and machine learning will be shown, in particular, the output of using those technologies: the digital data as well as the possible applications. Finally, perspectives of using these technologies and their implications in the forestry will be demonstrated.

EDAPHOCLIMATIC BASED SPECIES DISTRIBUTION MODEL FOR PORTUGAL: PINUS PINEA & QUERCUS SUBER MIXED FORESTS

T5.10 Digitalization for sustainable forest management

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Abstract: The challenges that climate change imposes to forest production in the Mediterranean region require a new way of thinking forest planning. It becomes necessary to explore silviculture alternatives that guarantee species resilience to climate variability but, most importantly, that are able to maintain the productive sustainability function of many Mediterranean forests which many rural populations depend on. Mixtures are becoming an important topic for managers due to the potential to enhance ecosystem services in comparison to monospecific formations. Knowing were it is ecologically viable to install such formations was the objective of this study taking as examples the mixtures of *Quercus suber* (cork oak) and *Pinus pinea* (stone pine).
Probabilistic species distribution models (SDM) built on the current presence/absence were created with the aim of i) identifying the influence of a series of climatic and soil-related determining variables on the distribution of species; and ii) estimating the suitability of the Portuguese territories for the eventual presence of those two species together. The models, based on Generalized Linear Model (GLM) and Random Forests, were calibrated in the South of Portugal and, once validated, have been applied to the rest of the country.
In this regard, the models focus solely on the abiotic component of distribution and confirm the significant anthropogenic disturbance in the current occupation, upon which the modeling of potential distribution is based.
The results show that the most significant edaphoclimatic variable for both species is soil texture, specifically the percentage of sand. Meanwhile, maximum temperature and continentality are more relevant in the models for stone pine, while precipitation is more influential for cork oak. There is limited scientific consensus on the determinants of the distribution of these two species, highlighting the need for a better understanding of the impact of variables on both in order to increase the explanatory power of the models in the Mediterranean region.

eForestry - digitalisation of forestry in Slovenia

T5.10 Digitalization for sustainable forest management

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Abstract: Forestry in Slovenia has a long tradition of following close-to-nature, multi-objective and sustainable principles, which are embedded into forest management system on national level. Due to increasing social and climate change challenges in managing forest ecosystems and the need for harmonization of various interests, effective control over forest ecosystems as well as a modern digital tool to support decision-making about the future forest management is needed. Thus, Slovenia Forest Service, together with Ministry of Agriculture, Forestry and Food and Forestry Institute of Slovenia is working on a project to digitalise the key public forestry services including forest inventories and monitoring, forest management planning, supporting implementation of planned measures, and controlling use of forest resources, changes in the forest as well as forest health status. The focus of the project is to insure modern field and office equipment in combination with modern spatial information system that will support the most demanding spatial analysis and forest management processes with the main task to simplify, optimise and upgrade public forestry service in Slovenia. With the set-up of the new E-forest apps, the owners and managers of forests will have better insight into the history of forest development and new decision tools supporting participative decision-making. The innovative eForestry tools will be presented and further discussed.

Estimating Effects of Operator Assistant System Based on Mobile Laser Scanning in Cutting of Thinning Stands

T5.10 Digitalization for sustainable forest management

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Abstract: Thinning work is very challenging for harvester operators due to the need for several quick repetitive decisions regarding tree selection and bucking. Harvester operators must monitor thinning intensity, the width of strip roads and the distance between strip roads and issues related to biodiversity. Advanced Driver Assistance Systems (ADASs) in cars and traffic have been the subject of comprehensive research and development efforts for a long time. Similar technological inventions can also be utilized in the field of forestry. PONSSE Plc. has introduced Thinning Density Assistant concept based on Lidar technology. This system can automatically monitor the density of remaining trees and the distance between strip roads on site. In addition, the harvester operator can use the tree map on a separate screen in the cabin of the harvester. However, the effects of the system on thinning productivity or quality are unknown. As part of a dissertation, three studies investigated the effects of the harvester operator guiding in thinning work. The studies aimed to find and identify the impacts of such systems on cutting productivity, harvesting quality and workload of the operators. The productivity was determined using a comparative time study using video records and machine data. The assessment of harvesting quality was measured using the density of remaining trees, the number of defective trees, the width of strip roads, and the distance between strip roads. The first study clarified the effect of the prior tree marking on cutting productivity, thinning intensity and tree selection in a field study. The prior tree marking increased cutting productivity by 2.7–2.8%. The second study investigated the benefits and weaknesses of Ponsse's Thinning Density Assistant concept on real-world thinning sites. The third study specifically focused on evaluating the same system in a harvester simulator environment, which enabled the participation of novice operators in the study, as well as experienced ones. In conclusion: The specifically designed ADASs for forestry will become more common in forest machines during the next years. The research-based findings are essential to support the product development of these novel systems.

Estimating wood quality attributes from dense airborne lidar point clouds.

T5.10 Digitalization for sustainable forest management

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Abstract: Point clouds from laser scanning are a standard data source in forest research, but the lack of clear and robust workflows has limited the translation of experimental knowledge into operational tools. We present a novel machine learning-based workflow that uses individual-tree point clouds from drone laser scanning to predict wood quality parameters. Unlike object reconstruction methods, our approach is based on simple metrics computed on vertical slices that summarize information of point distances, angles, and geometric attributes of the empty space between and around the points. Our models use these slice metrics as predictors and achieve high accuracy for predicting diameter of the largest branch per whorl (DLBw) and stem diameter at different heights (DSi) from survey-grade drone laser scans. We show that our models are also robust and accurate when tested on suboptimal versions of the data generated by reductions in the number of points or emulations of suboptimal segmentation scenarios. Our approach provides a simple, clear, and scalable solution that can be adapted to different situations and has the potential to revolutionize forest management and monitoring

FLORESTA DB: A SOFTWARE PLATFORM FOR FOREST RESEARCH FROM IN FIELD COLLECTION TO INVENTORY AND ANALYSIS

T5.10 Digitalization for sustainable forest management

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Abstract: Forest research projects frequently involve collecting digital data and/or physical samples from forest trees, followed by laboratory analysis. Outdated methods such as pencil and paper or spreadsheets are prone to errors, can slow collection efforts, and do not manage data for the full research life cycle. We have developed FlorestaDB as a flexible and innovative system to manage forest tree research collections and provide a powerful set of software applications to support research from the field to the final data analysis. It includes a mobile app for in field collection for multiple collectors with barcode scanning and GPS location services. The mobile app is available for Apple and Android platforms, and works out of cellular range by saving data locally to the phone for later upload. It is currently available in Chinese, English, French, and Spanish, and contains infrastructure to support translation to additional languages. The FlorestaDB web application offers the ability to manage project participants, collaboratively plan expeditions, store permit documents, track samples during shipping, and maintain a record of physical sample inventories. As data analysis results are produced, they can be attached to the tree records and sample inventory. We are currently building support for wood anatomy, isotope, DNA and mass spectrometry analysis. FlorestaDB manages research projects separately and privately. Each project's data is accessible via an interactive website and map and through comprehensive reporting capabilities, generating summaries by location, species, expeditions, etc. With a focus on managing user permissions and digital security, all data is protected and private to the group that generated it. We have been operating for over 4 years with 2 member organizations, which manage over 300 users, 10,000 tree observations, and 37,000 physical samples from 47 different countries. While member organizations are focused on collecting physical tree samples to create a reference database to combat timber fraud, FlorestaDB has matured into a stable and well tested platform and is now open to partnering with additional organizations and use cases.

Four years of deep learning for forest monitoring and management in a nutshell

T5.10 Digitalization for sustainable forest management

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Abstract: Deep learning has emerged as a state-of-the-art technique for handling large and complex forest sensor data, accelerating innovation and digitalization in the field. This abstract summarizes four years of SmartForest's research and development in deep learning for forestry and highlights its deployment in real-world scenarios along the forest value chain. Our focus lies on the image, video, and point cloud-based models that have revolutionized forest monitoring and management.

Image-based deep learning models were developed to classify tree species, detect forest disturbances, measure tree growth, assess wood quality, and enable traceability. Utilizing LiDAR point cloud data, deep learning techniques were applied for semantic and instance segmentation of individual trees, thus enabing the creation of detailed 3D forest structure maps, facilitating improved forest inventory management and precise timber yield and wood quality predictions.

The deployment of these deep learning models in real-world scenarios has been integrated into SmartForest's ForestSens cloud platform. This platform empowers forestry professionals with data-driven decision-making capabilities, enabling remote monitoring, identification of critical areas, optimization of harvesting operations, and evaluation of management practices for sustainability.

Importantly, the scalability and generalizability of the deep learning models were achieved through transfer learning and domain adaptation techniques. This ensures their effectiveness across different geographical regions and forest types, expanding their applicability worldwide.

The research presented in this abstract demonstrates the transformative potential of deep learning in forestry. By leveraging image and point cloud data, our models offer valuable insights into forest resources and their dynamics, supporting sustainable management and preservation of this critical ecosystem. Integration of deep learning into the forest value chain represents a significant step towards digitization and intelligence in forestry, fostering innovation and resilience in the face of environmental challenges.

Overall, our work highlights the significant advancements made in deep learning for forest monitoring and management, underscoring its potential for revolutionizing the field and contributing to the sustainable management of forest resources.

GoForward moving forward: updated decision support tool for efficient forwarding in harvest operations

T5.10 Digitalization for sustainable forest management

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Abstract: Efficient forwarding is essential for achieving high productivity in harvest operations. GoForward is a decision support tool developed for optimizing forwarding in cut-to-length harvest operations by efficient co-loading of different wood assortments. The tool utilized the harvester production data and tracking to optimize the forwarding routes, loading, and unloading at the landing.

The first prototype of the decision support tool (published in 2022) indicated potential for efficient forwarding. However, when the suggested routes were compared with the actual forwarding routes, it was evident that the forwarder operators were using shortcuts compared to the harvester routes. Hence, the possibility to suggest shortcuts needed to be incorporated in the decision support tool. Another important improvement was to upgrade the two-dimensional model to three dimensions by including a digital elevation model for trafficability calculations and depth-to-water maps for identifying areas sensitive to driving where less wood should be transported.

In the present study, we have developed and tested a new version of GoForward on several clearcuts in northern Sweden. The new version includes a shortcut possibility and geospatial data such as slope and depth-to water maps. To facilitate field implementation, the adoption of machine data following StanForD 4.0 is proposed, which includes precise tracking of individual log positions. This facilitates real-time field tests of GoForward, as precision is improved compared to the previous version were the approximated log position was calculated from the harvester position when felling the tree.

A decision support tool for forwarding operations is high on the wish list of forwarder operators and with the suggested updates, the tool starts getting ready for trials in practical forestry. When implemented, the goal is to increase efficiency in forwarding operations, especially for new operators, and contributing to more sustainable forest management practices.

Hot Wheels: Assessing Soil Response to Fully Mechanized Timber Harvesting

T5.10 Digitalization for sustainable forest management

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Abstract: The increasing demand for wood, driven by the bio-economy, is leading to the increased use of fully mechanized timber harvesting systems. These ground-based harvesting systems typically have a large impact on the soil. This study investigates the impact of fully mechanized winch-assisted harvesting systems on sustainability criteria such as soil deformation and soil properties during late thinning in two beech stands on Stagnic Cambisol on Flysch. It is motivated by the need for more precise data to plan future harvesting operations on sensitive soils. A sample of 27 skid trails with an average slope of 35 % were scanned in April 2023. A mobile laser scanning system (GeoSLAM ZEB Horizon) with a simultaneous localization and mapping (SLAM) algorithm was used to generate a 3D point cloud and collect high-resolution data on soil deformation and soil properties in the study area. To our knowledge, this is the first study to use the SLAM algorithm to assess displaced soil volume on skid trails. The effects of harvesting with and without tracks, slope gradient, and number of forwarder passes on the soil will be compared and analyzed. We hypothesize that fully mechanized harvesting systems have a significant impact on soil deformation and soil properties of a Stagnic Cambisol on Flysch. We expect these effects to vary depending on the use of bogie tracks and soil conditions (e.g., moisture content) during logging operations. We anticipate that the results will highlight the need for careful selection of vehicle equipment, route planning, and timing to reduce the likelihood of rutting in fully mechanized harvesting operations. The study contributes to a better understanding of the impact of modern harvesting machinery on soil properties. It provides data to guide future sustainable harvesting operations on sensitive soils under expected future climate conditions.

How to make the most of digitalization in forest management - a global forest company perspective

T5.10 Digitalization for sustainable forest management

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Abstract: Most forest companies are eager to get on top of the opportunities offered by digitalization in the forestry sector. New digital data collection by handheld devices, remote sensing and forest machines, in combination with traditional field data, forms the foundation to feed artificicial intelligence to provide operational decision support and open for more automated data handling also taking the cloud processing capacities in consideration. Global forest companies also have the unique possibility to learn from digital evolution in different continents to try to capture values for the digital forestry. Stora Enso will share some of their efforts in digitalization of the operational forest management and keeping forest data up to date. We will also describe how we work in co-operation with the research community in order to shorten time from research to implementation.

Identifying cultural remains using airborne laser scanning

T5.10 Digitalization for sustainable forest management

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Abstract: Swedish forestry is highly mechanized with harvesters and forwarders doing the main parts of harvesting. The requirements are yet high to carry out forest operations without causing unnecessary damages to the surrounding forest and the environment. One challenge in Swedish operational forestry is the insufficient knowledge of the location of cultural remains in forested areas. They are often hidden under the vegetation and may not always be discovered before harvest. The legal consequences can yet be significant if the presence of such remains is ignored and they are damaged by forest machines. There is a national public database available with the currently known remains, which are inventoried by professionals (archeologists). However, the forest companies often have considerably more remains in their own maps because of new findings in the forest, which can however not be added to public databases without first being assessed by professionals. Another challenge includes remains not yet found. The work in this study aims to address both these aspects, by 1) proposing a complementary database structure containing more and other information about cultural remains in forests, and 2) by developing automatic methods for identification of remains using remote sensing. In the past five years, several projects have been completed that have started this process, by identifying, e.g., charcoal production sites, using convolutional neural networks (CNNs). One of the focuses of our study is to develop automatic classification methods for house foundations. The use of CNNs has proven efficient for classification tasks, although larger amounts of reference data are needed. Hence, our study investigates the possible use of various image classification methods, including several machine learning and deep learning methods. The study area is located in Dalarna, central Sweden, where airborne laser scanning (ALS) data as well as different field references are available. The work does also investigate the impact of laser point density, pre-processing to intermediate products, and the possibly added value with other existing open-source data.

Locating high-value broadleaf trees from the sky: unmanned aerial vehicle (UAV) aerial images analysis with deep learning

T5.10 Digitalization for sustainable forest management

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Abstract: High-value timber species are extremely demanded throughout the world, for their timber products with high commercial value. They are also important structural components in forest ecosystems. Such trees with economic and ecological importance are usually distributed at very low densities. Therefore, acquiring accurate location of these trees within a forest is critical for forest management practices. Traditional acquisition work for individually locating high-value trees is time consuming and labour-intensive. Here, recent technological developments integrating unmanned aerial vehicle (UAV) imagery and deep learning provides an efficient method for mapping forest attributes with the advantage of greater positional accuracy. In this study, we explored the applicability of high-resolution UAV imagery and a deep learning classification algorithm to locate high-value deciduous broadleaf trees of Japanese oak (*Quercus crispula*) in an uneven-aged mixed conifer-broadleaf forest in Hokkaido, northern Japan. UAV images were collected by using DJI Matrice 300 RTK UAV. The UAV flights were conducted in September and October 2022 before and after changing the colour of the leaves of Japanese oak to identify the suitable timing of UAV image collection. Our data analysis applied object segmentation scheme via semantic segmentation and watershed separation algorithm. We analysed the RGB information of UAV images through a ResU-Net model (U-Net model with backbone ResNet101), which has demonstrated state-of-the-art performance on multiple object segmentation tasks. Our results showed that the F1-score of the model trained using October UAV dataset was higher than that of the model trained using September UAV dataset. Our case study revealed that the integration of UAV imagery with the ResU-Net model was applicable to predict the location of Japanese oak with a reliable accuracy. It also suggested to use UAV images taken after changing the colour of the leaves for identifying Japanese oak trees through deep learning technology. Moreover, our findings highlight a potential methodology to offer transferable solutions to manage high-value timber species in other regions.

Looking backwards at countrywide forest cover using Unet and alpha shape

T5.10 Digitalization for sustainable forest management

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Abstract: Forest ecosystems play an essential role in climate regulation and carbon sequestration. Therefore, information on forest cover and its changes over time is a key input for assessing a variety forest services. Usually, forest changes are estimated by comparing forest cover maps of two different time periods. Modern remote sensing techniques provide a variety of methods to derive forest cover maps. But there is limited availability of high-resolution remote sensing data to obtain forest cover from the last century. Historical black&white (B&W) aerial imagery is a valuable but currently little exploited data source for deriving past forest maps. And it is challenging to derive past forest cover maps using historical B&W imagery due to the fact that only one band of information is available and the images had different geometric and radiometric qualities.

In this study, we assess forest cover maps of 1980s using available B&W historical images over the entire country of Switzerland. We first developed a BWForest-Unet model based on semantic segmentation to generate a tree/non-tree map. The model uses the 2019 orthoimages converted to B&W and trees are labelled based on the 2019 countrywide canopy height model (CHM). Since the historical B&W images have more severe distortions than the modern ones, image augmentations such as thickness, local elasticity, squeezing, scratching, and grid were performed to simulate the historical image quality on the 2019 training samples. After training the model, the 1980 tree cover map was obtained by prediction from the historical B&W images.

Subsequently, a forest cover map is derived from the tree cover map by applying an alpha shape algorithm that generates bounding polygons around a set of points. The forest/non-forest polygons of 1980s are generated from alpha shape follow the criteria defined by the national forest inventory based on tree height and canopy cover. The study shows that semantic segmentation using Unet combined with the alpha shape approach is an efficient method to map forest cover over the past century at a countrywide scale.

Mapping of structures for biodiversity in boreal forest in Sweden from airborne laser scanning data and Sentinel-2 satellite images

T5.10 Digitalization for sustainable forest management

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Abstract: Sustainable forest management is dependent on accurate geospatial information about the state of the forest. Size-related forest variables such as stem volume and tree height can be estimated with high accuracy from airborne laser scanning (ALS) data and surface models from matching of aerial images. However, there is a lack of methods for mapping information relevant for forest biodiversity. Planning and management of forest resources require such information both at a nationwide scale and in more detail for smaller areas.

New technologies offer opportunities to do this. Airborne laser scanning (ALS) data enables analysis of the structure of tree canopies and other vegetation. High-resolution ALS data offers the potential to identify individual trees and estimate their species and status (i.e., dead or living). The Sentinel-2 satellites provide multispectral images at short time intervals, making it possible to exploit phenological differences to map tree species. An important question is which type of information is most relevant for forest biodiversity because the habitats differ between different forest types and different forest-dwelling species have different habitat needs.

The aim of this study is to develop new methods to map and monitor forest biodiversity in boreal forest in mid-Sweden by deriving biodiversity indicators from RS data, in particular ALS data. The indicators include stand age, tree species, vertical and horizontal structure, and amount of dead wood. The analysis is done at landscape scale (i.e., approximately 300x300 km) from data with nationwide coverage. The indicators are validated with information on Natura 2000 habitats and with a dataset consisting of key substrates and structures for biodiversity. Finally, we present models to estimate the species richness in different species groups with statistics derived from the spatial distribution of the indicators in an area around the field plots as explanatory variables.

Mobile Application for Citizen Engagement in Forest Management

T5.10 Digitalization for sustainable forest management

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Abstract: Digitalization has surfaced as a propitious instrument for attaining sustainable forest management amidst the era of rapid technological progress. Within the SILVANUS H2020 Green Deal Project, our focus lies in investigating the roles of the citizens in forest management as well as examining how digital solutions can enhance their awareness, foster changes in their attitudes and behaviours concerning wildfires, and facilitate their participation in fire prevention and rehabilitation endeavours. The solution we propose introduces a novel application for citizen engagement that is aiming to provide citizens with up-to-date information, ensure their safety, and establish seamless communication with emergency responders. The Citizen Engagement App (CEA) aspires to become an important digital channel for forest fire management by pursuing the following goals:

1. Consolidate fragmented information and data from authorised sources for instance from firefighters, authorities and first responders as well as tools related to wildfire management into a unified, user-friendly application.
2. Establish a dependable communication channel between citizens and authorities/firefighters through diverse information-sharing functionalities.
3. Enhance situational awareness and actively involve citizens in fire prevention and rehabilitation initiatives.
4. Advocate for the innovative measures undertaken by the SILVANUS project.

The initial version of CEA is currently undergoing an internal testing phase for Android phones and contains a set of different educational and situational awareness modules for citizens. Within these modules, we have developed the modules for Guidelines and Safe Practices that were either integrated into a digital format from diverse authorised sources or crafted by SILVANUS' Citizen Engagement Program (CEP). The application also includes an interactive map showcasing reported fire locations accompanied by a Fire Reporting module enabling users to to relay their precise location, along with pertinent information about the forest fire (photos or videos), and textual description or voice recording. In addition, several pilot tests have been arranged for the SILVANUS Project, where the users will evaluate the functionality of CEA. Future improvements include real-time notifications of fires, analytics and warnings regarding high fire risk in the user's area, emergency indicators, additional educational content and news-sharing features, ensuring a bidirectional communication between wildfire management professionals and citizens.

Multi-Species Expert System for Supporting the Refloresta-SP Programme: An Essential Component of São Paulo's Climate Action Plan

T5.10 Digitalization for sustainable forest management

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Abstract: The Refloresta-SP Programme, an essential aspect of São Paulo's climate action plan, aims to restore 1,500,000 hectares of native forest vegetation by 2050. The program's objective is to ensure an equitable distribution of vegetation across the state, moving away from the current concentration in the coastal region. It targets primarily degraded areas and municipalities with limited native vegetation cover. It also aims to enhance vegetation recovery in areas with cover ranging from 10% to 30%, striving for a 30% native vegetation cover. This ecological target is crucial for sustainability, ecosystem services provision, and biodiversity conservation.
Over the past 12 years, the Secretariat of Infrastructure and Environment has developed an expert system to support these goals. This system integrates cutting-edge knowledge from over 40 scientists affiliated with universities and research institutions across the state. It encompasses a comprehensive knowledge base, including species adaptability, silviculture practices, region-specific costs, production tables, and growth and yield curves for wood and non-wood products. The expert system employs simulation techniques to generate species compositions that adhere to Brazilian forest regulations, ecological considerations, and economic parameters. Notably, the system incorporates nearly 200 species adapted to the state's unique ecological contexts, striking a balance between ecosystem services and economic feasibility. By considering the characteristics of the 62 microregions defined by Phyto physiognomies and ecological regions, the system generates approximately 5,000 cash flows and corresponding multi-species establishment and management plans. Policymakers utilize this knowledge base to tailor incentives based on the specific characteristics of regions.

Additionally, an internet-based application accessible through web browsers and mobile devices assists landowners in obtaining personalized recommendations, presenting the best 3 to 5 options aligned with their preferences and their land's conditions.

This presentation aims to provide a comprehensive overview of the expert system's structure, operational framework, and tangible outcomes achieved thus far. By shedding light on the inner workings of this expert system, we contribute to the broader discourse on sustainable forest management and climate action planning. Furthermore, we highlight the significance of the expert system in simplifying the realization of a multi-species structure, emphasizing its role in meeting climate and bioeconomy targets.

Open data, models, and software for machine automation

T5.10 Digitalization for sustainable forest management
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Abstract: We create partially annotated datasets from field measurements for developing models and algorithms for perception and control of forest machines using artificial intelligence, simulation, and experiments on physical testbeds. The datasets, algorithms, and trained models for object identification, 3D perception, and motion planning and control will be made publicly available through data and code-sharing repositories.

The data is recorded using forest machines and other equipment with suitable sensors operating in the forest environment. The data include the machine and crane tip position at high resolution, and event time logs (StanForD) while the vehicle operates in high-resolution laser-scanned forest areas. For annotation, the plan is to use both CAN-bus data and audiovisual data from operators that are willing to participate in the research. Also, by fusing visual perception with operator tree characteristics input or decision, we aim to develop a method for auto-annotation, facilitating a rapid increase in labeled training data for computer vision. In other activities, images of tree plants and bark are collected.

Research questions include, how to automate the process of creating annotated datasets and train models for identifying and positioning forestry objects, such as plants, tree species, logs, terrain obstacles, and do 3D reconstruction for motion planning and control? How large and varied datasets are required for the models to handle the variability in forests, weather, light conditions, etc.? Would additional synthetic data increase model inference accuracy?

In part we focus on forwarders traversing terrain, avoiding obstacles, and loading or unloading logs, with consideration for efficiency, safety, and environmental impact. We explore how to auto-generate and calibrate forestry machine simulators and automation scenario descriptions using the data recorded in the field. The demonstrated automation solutions serve as proofs-of-concept and references, important for developing commercial prototypes and for understanding what future research should focus on.

Operational assessment of forest growth using airborne laser scanning data acquired on the national level.

T5.10 Digitalization for sustainable forest management

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Abstract: Accurate assessments of forest growth are crucial for responsible management of the forest resource, to meet the broad range of challenges the society is facing today. The forest has potential to provide renewable and essential materials, bio-based energy, mitigate climate change by large-scale sequestration of atmospheric carbon, and is also an ecosystem with potentially very high biodiversity. Knowledge about the rate of change (growth), not only as large-area summary statistics, but also as spatially explicit maps with very high resolution, is expected necessary to provide full benefits from digitalization of the forestry in view of current challenges. Today, precision forestry is developing fast and will change the scale of forestry data capture from stand-level to the single tree-level. As one example, this development will most likely revolutionize management planning of the continuous cover forestry gaining popularity today.

The fast development of remote sensing provides today more data about current and past forest states than ever before. Especially, three-dimensional airborne laser scanning data about tree canopies have proven essential for forest monitoring and management planning. In Scandinavia, there are often time-series of such data available on the national level, providing new possibilities to operationally assess and model forest growth with higher spatial accuracy and improved errors compared to traditional growth models. Time-series of 3D data are measurements of the actual changes in forest state, summarizing growth, mortality, as well as silvicultural activities. This, in contrast to traditional growth models often relying on site index assessments only.

This paper reports ongoing activities in the Mistra Digital Forest project, a PhD project financed by the Knut & Alice Wallenbergs foundation, as well as the national forest mapping of Sweden by SLU and the Swedish Forest Agency. Here, new models of forest growth, models powered by time series of 3D tree canopy data in combination with hydrological maps, all acquired using airborne laser, are presented. The new potentials of assessing competition, mortality, and silvicultural treatments as measured by changes in, and the structure of, the forest canopies are explored to construct models applicable for raster mapping as well as on the single tree level.

Optimal tree selection in forest thinning for economic, carbon sink, biodiversity, and scenic beauty benefits

T5.10 Digitalization for sustainable forest management

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Abstract: Thinning is the selective removal of trees to provide the remaining trees with more growing space and growth resources such as water and soil nutrients. Tree selection plays a key role in forest productivity, carbon sinks, biodiversity, and scenic beauty. For example, retaining deciduous trees can increase forest biodiversity and resilience, but it can also reduce the net income of forest owners.

The selection of harvested vs. retained trees and the placement of retention trees has typically been left to the harvester operator, who makes decisions based on his subjective opinion and experience. However, the increasing quality and availability of individual tree inventory data would allow for optimized tree selection considering multiple ecosystem services. Our vision is that the pre-planned tree selection can guide the operator's decisions, but the operator is still responsible for e.g. evaluating the quality of the remaining trees and modifying the tree selection if necessary.

To rationalize these decisions, we formulate the problem as numerical multicriteria priority functions to optimize tree selection for economic benefits, carbon sink, biodiversity, and scenic beauty. Harvesting priority is evaluated across tree, plot, and stand scales, and tree harvesting decisions are made by weighting multiple decision criteria based on the preferences of the decision maker in heuristic optimization. The spatial pattern of the remaining trees, as measured by the Clark-Evans index, limits the possible solutions, so the growth space must be used comprehensively.

This study presents the procedure for tree-level multi-criteria optimization in thinning-stage forest stands. Further studies can also use forest soil data and terrain characteristics in the optimization phase to consider different growth potentials within thinning stands. In general, this research supports precision forestry, where decisions are made at a very local scale, and aims to facilitate the demanding work of harvester operators.

Optimized extraction routes and roadside storage location to maximize efficiency and minimize environmental impact in forest operations

T5.10 Digitalization for sustainable forest management

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Abstract: In recent years, the development towards increasingly high-resolution LIDAR data has enabled a detailed description of terrain, soil, and forest density. In addition, so-called depth-to-water maps measuring the soil wetness can be computed. This information has provided an excellent basis for better planning of a standard two-machine system (harvester and forwarder) before felling so that efficient operations (e.g., low average extraction distance) can be done while simultaneously reduce the risk of soil damage. However, manual planning with all information is very difficult and there is a need for advanced optimization models and methods to consider all information while finding solutions quick. Optimized solutions lead to less environmental impact in several ways, partly less impact on the soil, partly less emissions thanks to reduced energy consumption.

Timbertrail is a decision support tool for planning optimized extraction routes. It is also a very successful example of where research has quickly led to implementation with wide practical use in forestry. Timbertrail is used to plan in detail where the harvesting machines should drive in order not to risk any soil damage. As a further development of Timbertrail, a new service, Log Landing, has been developed with the aim of optimizing where the roadside storage should be placed to provide the most optimal forwarding as possible. Based on detailed information (e.g., houses, road crossings, power lines, terrain obstacles, and heritage areas) about the area along nearby roads and combined with results from Timbertrail, an optimization model provides suggestions for optimal locations where the piles should be placed.

With our models for creating extraction routes and the placement of log piles, we demonstrate how advanced optimization models can be used together with high-resolution data to streamline forest operations and reduce environmental impact. In our presentation, we show how decision support tools are used in practical operation in different parts of the world. We also illustrate how they can be used on a strategic level together with information on the annual variation of rainfall, to create a basis for when different harvest areas are best suited to be harvested to minimize the risk of soil damage.

OPTIVEG: Improving operational and environmental efficiency of forest operations by the development of a machine allocation digital platform

T5.10 Digitalization for sustainable forest management

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Abstract: In Portugal, wildfires are a recurrent and increasing issue. Networks of fuel breaks are a measure to slow the progression of fires. The maintenance of these lanes requires a great input of machinery and manpower, however, in Portugal, forest operation are have an inferior productivity and environmental performance than in other European countries. One of the reasons for this problem is the common mismatch between the equipment used and the specific conditions of the site to intervene – such as vegetation and stand characteristics, slope and other characteristics. The mismatch is in part, due to communication difficulties between the service provider and the forest manager, but also due to the lack of easily accessible technical information on the suitability of different types of equipment under different conditions.

The OPTIVEG project - Optimization of Sustainable Planning for Vegetation Management Operations - of the Transform Agenda – Agenda for the digital transformation of the Portuguese forest sector in a resilient, low-carbon economy, financed under the Portuguese Recovery and Resilience Plan - aims to develop a technological solution to support the process of allocating the most suitable equipment to the operations.

Teams working on the vegetation management of the areas managed by REN – Redes Energéticas Nacionais – the Portuguese transmission system operator are accompanied to collect data of the performance of different machinery working under different conditions. Productivity was measured through time studies and in-build machinery sensors. Vegetation characterization is done with LiDAR and imported to a geo-referenced database. The model is being developed, with established Key Performance Indicator related with site and vegetation characteristics as well as machinery categories. Several social, economic and environmental indicator of operational performance were selected as indicators for operational productivity. An algorithm is being developed by INESC TEC - Institute for Systems and Computer Engineering, Technology and Science to automate the machine selection process. At the end this project will deliver an online platform, where forest managers and decision-makers could receive an output with the most suitable equipment along with estimated costs, productivity, and greenhouse gas emissions, associated with intervening a particular area, for a set of predetermined mechanical alternatives.

Pinus pinea plantations monitoring using unmanned aerial vehicles derived data

T5.10 Digitalization for sustainable forest management

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Abstract: Stone pine (*Pinus pinea* L.) is a Mediterranean species, with high plasticity and low genetic variability. Even though its edible seeds, the pine nuts, are the most expensive nut in the world, it is mainly harvested from natural forests and there are no intensive management techniques. Recently, more than 4,000 ha have been planted in Chile, increasing the demand for technological solutions to obtain field data to guide this crop management, information traditionally field-measured analogically. The use of remote sensing in forest plantations surveys has shown to be a novel alternative for the estimation of dasometric variables through the processing of images captured by Unmanned Aerial Vehicles (UAV), having been studied in the species in Turkey, Italy, Portugal and Spain. This study aims to validate the use of the Light Detection and Ranging (LiDAR) technology for monitoring stone pine plantations in central Chile. The study was performed on two plantations of 13 and 30 years-old. In both sites, trees were identified and georeferenced. Flights were carried out with a UAV equipped with a LiDAR sensor. At the same time, each tree was field-measured for height, DBH and crown diameter. Canopy Height Model (CHM) was obtained from the LíDAR point cloud. From the CHM, values of height, diameter and crown surface of each tree were estimated, and later used to adjust dasometric models, using the field-measured data as a dependent variable. A third of data was used to generate the training dataset and the remaining 70% for validation. Height, stem diameter and crown prediction models were significant with R^2 values greater than 0.8 in both plantations, showing the applicability of this technology to stone pine plantations with different age, size, spacing and slope.

Predicting forest road trafficability using GIS and Remote Sensing based variables

T5.10 Digitalization for sustainable forest management

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Abstract: Mills wish to maintain a year-round continuous flow of fresh roundwood, which is a major challenge during low bearing capacity seasons in Finland, as there are few forest roads in the current network that are suitable for year-round use by heavy-duty vehicles. Since manual determination of forest road conditions is laborious and slow, it is vital to develop faster methods for identifying the properties of these roads using already available or easily accessible data in order to assist route planning and the targeting of road maintenance measures.

This paper describe. how the bearing capacity of forest roads can be predicted using such properties which can be easily measured in the field or extracted using remote sensing data, together with Open GIS variables. The trafficability prediction is very demanding task. The prediction results indicated that operational road width is the most significant variable when assessing the bearing capacity. LiDAR data, various Gamma ray sensors, and falling weight deflectometer measurements were used to understand the quality of the road.

Recent advances in the mapping of wood quality with laser scanning at industrially relevant scales

T5.10 Digitalization for sustainable forest management

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Abstract: We present recent advances in wood quality mapping using fusions of dense airborne laser scanning (ALS), and static and mobile terrestrial laser scanning (TLS and MLS, respectively) with industrial references. Studies spanning several areas with Norway spruce (*Picea abies* H. Karst.) and Scots pine (*Pinus sylvestris* L.) – dominated, mature boreal forest stands in Southern Finland and Sweden are revisited and discussed. The state-of-the-art laser scanning techniques enable the extraction of features that indicate wood quality at variable scales, e.g., crown geometry variables, branching information, stem taper, competition indicators, and stand variables. With such data, we show how wood quality attributes such as knottiness, ring width, and wood density can be predicted to individual trees over entire stands, with respect to the industrial references. We have evaluated the accuracies of the wood quality maps with over 500 sample trees that were tracked from the forest to sawmills. We discuss how the wood quality maps could be used to enhance operational wood procurement planning, and log-breakdown optimization. Our studies also provide insights to the traceability-problem of tree stems from forest to factory, to enable automated identification of corresponding logs along the production chain. The digitalization of wood procurement planning based on industrial data, laser scanners mounted on harvesters and within- and above-canopy flying drones, and nationwide ALS data can facilitate more precise and flexible decision-making regarding the optimal use of wood with various qualities, and the distribution to the most appropriate end-use.

Smart forest inventory using samples of dense airborne laser scanning

T5.10 Digitalization for sustainable forest management

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Abstract: As part of the Mistra Digital Forest Programme 2023-2026, task 1.2, we have developed multi-stage inventory methods. A central part of the approach consists of samples of dense airborne laser scanning (ALS) data, to provide cost efficient estimates of traditional and new forest variables. The ALS data are acquired with about 500 pts/m2 and are used to segment single trees as well as branches and damages. The reference data are collected with harvesters, terrestrial laser scanners (TLS), and field inventories. The other phases include both TLS and wall-to-wall data from ALS of lower resolution, as well as satellite images. This project focus on developing methods for the new variables (e.g., trunk crooks, stem quality, tree species, stem profile etc.), efficient airborne inventory designs, and the propagation of errors across the phases. The overall framework has already proven more efficient than traditional field inventories for, e.g., estimation of stem volume (Persson et al. 2022), and this work extends to more variables and an improved understanding on the uncertainties related to this framework.

Persson, H.J., Olofsson, K., Holmgren, J. 2022. Two-phase forest inventory using very-high-resolution laser scanning. *Remote Sensing of Environment*, Vol 271.

Teaming for Excellence – a Prerequisite for Sustainable Forest Management Today: The Role of Forest 4.0

T5.10 Digitalization for sustainable forest management

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Abstract: Forest ecosystems and forestry face numerous challenges in the present day. These challenges arise from the increased use of timber and bioenergy, uncertainties brought about by climate change and efforts to mitigate it, the intricate dynamics of evolving global markets, rural depopulation, and the growing emphasis on the social values of forests. Effectively managing such a multidimensional system is only possible through the implementation of smart technologies. These technologies enable the acquisition and utilization of information on the processes occurring within and around forest ecosystems, as well as the prediction, prevention, or mitigation of potential risks. By integrating advanced digital technologies such as Artificial Intelligence (AI), the Internet of Things (IoT), blockchain, and big data analytics, which together form the components of the Forest 4.0 concept, forest management practices could potentially find a solution to these challenges. However, the successful implementation of this concept requires collaborative efforts from a diverse range of actors. This presentation aims to introduce the approach of the recently launched Horizon-Widera project Forest 4.0, which is being implemented by a team of Lithuanian and Swedish partners. The primary objective of this project is to establish a Centre of Excellence that will transform forest environment monitoring, data acquisition, and analysis, and extract value from the collected data. Lessons already learned and the challenges that lie ahead will be discussed based on the initial findings in the following research topics: IoT remote sensing and ubiquitous computing for the development of geospatial techniques; IoT monitoring and AI prediction techniques for the development of forest management systems and the detection of forest threats; crowdsourced forest-based data management and visualization; AI techniques for cognitive sensing and multi-modal signals processing in IoT-based systems for predictive analytics; development of decision support tools to assess forest management practice; life cycle assessment and bioeconomic modelling tools for the identification and justification of sustainable forest-based business model innovations. This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No 101059985.

The use of digital decision support tools in Swedish forestry - an overview and outlook

T5.10 Digitalization for sustainable forest management

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Abstract: Swedish forestry is currently meeting challenges like remaining competitive on the global market for forest products, continue increasing sustainability of operations and recruiting next generation's work force. To meet these challenges, forest companies and other actors are relying on the increasing use of different types of digital decision support tools tailored to the needs of forest professionals, machine operators and others. These tools are key in the transformation towards precision forestry where negative environmental impact is minimised and active forest management is creating different types of values for forest owners and the society. The increasing availability of new sources of detailed information about the forest like high-resolution remote sensing data and different types of data from forest machines will serve as a useful basis for developing such tools in combination with other types of data describing the road network, weather conditions etc and advanced statistical modelling and AI.

This study presents an overview of the current use of such digital decision support tools in Swedish forestry. What are the main drivers for the development, which applications are already being used in large scale, who are developing them and what effects have they had on operations and people using them are key questions to be discussed. The study will also provide an outlook describing probable next steps in the development and expected effects connected to the implementation of the tools.

The use of digital technologies to enhance forest operations monitoring and planning: A case study in Portugal

T5.10 Digitalization for sustainable forest management

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Abstract: In the digital era, sensors embedded in forest machinery can be instrumental for enhanced planning and decision support along the forest-based value chains. The combination of a multitude of sensors (e.g. GPS, GPS, humidity, temperature, movement) collect a large amount of data, in close to real time, at low cost and with high precision. The consolidation and processing of such data with adequate business analytic tools, enables to monitor over time the machinery status, operations performance and wood flows, geographically distributed. Such information can be valuable for the multiple agents of the value chain and can help to reinforce trust and transparency. Despite recent technology developments, the collection, consolidation and processing of forest operations data in not new. The StandForD2010 for data standardization and interoperability in in use for several decades, specially in Northern Europe.

In Portugal, forest machinery often has the capacity to collect and store data in the StandForD2010 format. However, this information is seldom used. In Portugal, the harvesting fleet is very diverse in terms of manufacturers and manufacturing age, therefore, compatibility issues arise, together with difficulties in the real time communication of the machineries operating in remote areas with low connectivity coverage. On the other hand, the Portuguese wood-based wood supply chains involve multiple agents, from producers, to third-party contractors and industry players, each should find value in using the data that will be provided by the sensors, as well as agree upon the conditions for sharing that data with the other players.

This research proposes an innovative solution anchored in a novel embedded device for harvesters and forwarders, developed in the logic of “one-size-fits-all”, to avoid compatibility. The information collected with StandForD standards is consolidated and processed in a prototype of a advanced planning system, combining business analytics and optimization methods with friendly graphical-user interfaces. This system enables to monitor on-time operations and also identify deviations in respect to the optimal plan. The integrated solution is being applied in the pulp and paper value chains in Portugal and the preliminary results will be presented.

Towards Digital Twin of Boreal Forests at Individual Tree Level – UNITE flagship approach

T5.10 Digitalization for sustainable forest management

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Abstract: Forest information is typically collected using different inventory techniques and the objective is to provide the fundamental information for all decision-making tasks in the society. Areas of interest are often characterized using descriptive statistics or thematic maps. Until now / At present, country-wide individual tree maps do not exist. This kind of databases and maps would support, especially wood procurement. In our presentation, we propose and demonstrate a country-level Digital Twin of forests at individual tree level. The first one billion trees have already been added to the database using the following technologies: 1) computation of individual tree information using airborne laser scanning point clouds with a point density of 5 pts/m2, 2) developed automatic field reference techniques based on above-canopy drone laser scanning that provides direct stem curve estimates, autonomous car big data and/or harvester mobile laser scanning as well as field measurements, 3) a browser-based 2D viewer for data visualization, 4) utilizing also saw-mill data to attach quality information to trees, and 5) using automated change detection to record the growth of each tree. Tree-level open data will be made available when the system develops. We have created individual tree information with the following characteristics for core tree attributes: 1) Individual tree locations (0.5 m error in the XY plane), 2) Tree height (1 m error), 3) Stem volume and biomass (30% error), 4) Stem diameter (dbh) (16% error), 5) Tree species (80% correctly classified), 6) 88% of trees bigger than 20 cm in dbh are found, and 7) 10-20% of trees with dbh about 10 cm are found. The digital twin platform is capable of visualizing multiple ecosystem services, such as improved biodiversity information, carbon sinks, berry maps and quality of forest roads. By combining individual tree information with cadastral boundaries, road & infrastructure data and other geospatial feature data, a digital twin of forests is formed, applicable to a variety of decision making tasks. Until now, we have implemented in the system improved biodiversity information, carbon sinks, berry maps, and quality of forest roads.

Which Species is this Tree? Using 3D Laser Scanning to Describe the Forest

T5.10 Digitalization for sustainable forest management

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Abstract: Measurements of individual forest trees are expensive and rarely accessible through forest inventory, but to ensure sustainable, efficient and precise harvest operations modern forest management demands detailed information. How can we visualize the tree species distribution of a forest to determine the exact wood volume per species? Person-carried laser scanning is a highly automated technology for measuring single trees in 3D point clouds. However, the complex problem of species classification has not been solved yet, due to a lack of structured data to cover the natural variety within a species. This study presents a machine learning model for classifying nine major Austrian tree species in person-carried laser scanning data. In contrast to other studies, this classification features intensity moments and measurement ratios as predictors. We set up a random forest model on more than 7.000 single tree point clouds and validated using an independent test set. The classification accuracy exceeded 90 % between conifers and deciduous trees and 80 % among all nine trees species. Reliable species predictions for individual tree point clouds increase the importance of person-carried laser scanning data for efficient forest management and lead the way to competition analysis and biodiversity assessment.

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

Beyond Carbon: The Critical Need for a More Holistic View of Forests and Climate

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: Despite a large body of research showing that non-CO_2 climate forcing agents are a critical factor in the biogeochemistry of forest climate interactions, current research overwhelmingly centers on the cycling and storage of carbon (C) and its response to management. Missing, is more comprehensive consideration of other significant climate forcing agents and processes (i.e., CH_4, N_2O, black carbon, biogenic volatile organic compounds; BVOCs, transpiration, and albedo) and their dynamic responses to both localized (management, fire, land use change, infrastructure development, storms) and global (e.g., warming, drying) disturbances. This presentation reviews our current understanding of the sources, drivers, and scale of a wider suite of forest climate forcing agents and explores the demonstrated or expected impact of global and local disturbances on each agent. We highlight remaining uncertainty in non-CO_2 flux magnitudes, a lack of understanding of their responses to disturbance, and the failure to consider corresponding direct and indirect effects on regional and global climate. Given the large contribution of less-recognized agents (e.g., Amazonian trees alone emit ~3.5% of all global CH_4), a continuing focus on a single metric (i.e., C uptake and storage) is incompatible with genuine efforts to understand and manage the biogeochemistry of forests for climate mitigation.

Disturbance impacts on climate regulating services in forest ecosystems

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: Climate change and increases in natural disturbance activity challenge the provisioning of ecosystem services. This is of particular importance considering that a reduction in climate regulating services (CRS) would exacerbate future climate change. Mitigating climate change relies heavily on forests, making the amplifying feedback loop of CRS reductions a formidable obstacle in limiting global temperature rise to below +2 °C. Previous research, policy, and management efforts have predominantly focused on carbon sequestration and storage, largely overlooking other crucial CRS. In this presentation, I first provide a global overview of the effects of disturbances on various CRS, that I subsequently underpin with a few case studies from Central Europe.

Disturbances exhibit diverse impacts on CRS. Carbon sequestration and storage are primarily negatively affected by disturbances, resulting in reduced biomass, gross primary production, and increased heterotrophic respiration. However, in some cases, carbon sequestration can increase in the mid- to long-term as ecosystems progress into more productive stand development phases or transition to faster-growing species. Albedo increases after disturbance as gaps usually reflect more incoming solar radiation than forests. The influence of disturbances on the latent heat flux of forests is highly dependent on temporal scales. In the short term, disturbances reduce evapotranspiration, negatively impacting latent heat flux. However, in the long term, changes in species composition might increase evapotranspiration and, thus, the latent heat flux, particularly if conifer-dominated forests transition to broadleaved-dominated ones. Similarly, the overall microclimatic buffering capacity against extreme weather events is reduced immediately after disturbances, but may recover quickly as stands develop.

Considering that disturbance activity is projected to intensify in the future, it is alarming that disturbances cause an overall reduction of CRS. Therefore, strategies to optimize CRS must incorporate adaptive measures to ensure the future stability of CRS. Yet, few studies have examined multiple CRS simultaneously and projected their future trajectories under novel climate and disturbance regimes. Addressing these knowledge gaps is imperative for the development of robust forest management strategies aiming to improve and safeguard CRS.

EVALUATION OF LAND USE/COVER CHANGE IMPACTS RESULTING FROM MINING ON ECOSYSTEM SERVICES IN BOKÉ PREFECTURE, REPUBLIC OF GUINEA

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: Land use and land cover change (LULC), especially conversion and degradation of forest land, is the key factor causing terrestrial carbon stocks decline and affecting their dynamics in ecosystems. Detecting changes in LULC is extremely important for obtaining continuous and accurate information for any type of development planning. Geographical information systems and remote sensing technologies have shown strong capabilities in detecting LULC. This study, therefore, aimed to analyse the dynamics of LULC and to assess the variation of terrestrial carbon stocks in response to mining. Remote sensing was used to map and quantify LULC changes and the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) model to quantify and evaluate the changes in carbon storage under land use conditions in 1975 and 2020. Maps were classified based on seven LULC categories, including herbaceous wetland, forest, agricultural land, shrubland, water bodies, barren land, and Built-up/Settlement area. The results indicate that Within the period between 1975 and 2020, baren land and Bult up/Settlement related to mining have been identified as the main factors behind the alteration of land cover, which is the key factor of terrestrial carbon stocks decline in the area. Based on these findings, we recommend to science and research institutions to provide relevant policy options for better biodiversity conservation and sustainable development; to the Ministries of Environment and Mining, to integrate mine site restoration into the national environmental policy and to develop a standardised guide for ecosystem restoration in mining areas.

Keywords: Land use/cover changes, Ecosystem services, Mining, Remote sensing, Carbon

stocks, Prefecture of Boké, Guinea.

Even Cooler Insights: On the Power of Forests to (Water the Earth and) Cool the Planet

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: Recent scientific innovations upend classical forest-water interaction models. The principal causal pathways by which tree, forest, and vegetation cover (TFVC) influence local and global warming/cooling are thus inadequately described. TFVC drives hydrologic cycle intensification (precipitation recycling) and the geographic extent and availability of water and water storage across the land surface. This in turn drives increased latent heat production (evapotranspiration (ET)), cloud formation, and TFVC binding of carbon from the atmosphere (carbon sequestration). Previous modeled results identify *surface albedo* and *carbon sequestration* as the principal causal pathway by which TFVC affects global warming/cooling. Surface albedo effects are presumed to overpower carbon sequestration effects toward the outer latitudes. Thus, deforestation is predicted to lead to surface cooling while increasing forest cover results in warming. Observational data, however, suggest the opposite. Land surface temperatures are influenced by the interplay of surface albedo, incoming shortwave (SW) radiation, and the partitioning of the remaining, *post-albedo*, shortwave radiation into latent and sensible heat. The avoidance of sensible heat formation on the land surface is first and foremost mediated by the presence (absence) of water and potential TFVC production of latent heat. The availability of water on terrestrial surfaces is, in turn, mediated by TFVC. Latent heat (ET) itself, however, is not directly linked to *global* cooling/warming. *Global* cooling is primarily driven by carbon sequestration and the top-of-cloud reflectivity associated with cloud formation, both by-products of TFVC driven evapotranspiration (ET), and evaporation (E) on land (and ocean) surfaces. TFVC loss reduces water storage, precipitation recycling, and downwind rainfall potential, and thus drives the reduction of both ET (latent heat) and cloud formation. Deforestation thereby powers warming (sensible heat formation) and further reduces TFVC growth (carbon sequestration). Increasing tree and forest reforestation efforts could therefore, realistically, contribute to global and surface temperature cooling.

Exploring Disturbance Dynamics: Insights from the Austrian National Forest Inventory (ANFI)

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: ***Context***

Climate change significantly impacts disturbance agents, abiotic and biotic, in European and Austrian forests, altering their magnitude and triggering feedback reactions in their structures, communities, and ecosystem services. Disturbances account for 16% of the annual harvest in Europe. In Austria, storms and snow damage 1-3 million cubic meters of timber annually, while bark beetle damage increased up to 3.75 million cubic meters in 2022. Implementing adaptive forest management strategies and utilizing disturbance-based growth models is crucial for effective forest management in Austria amidst these circumstances.

The objectives

The objective of this study is to develop models that illustrate the probabilities of random events such as wind, snow breakage, and bark beetle outbreaks. It includes a dedicated sub-model for wind and snow damage and explores events associated with drought and bark beetles. The study examines event probabilities, dynamics, and identifies trends, interactions, and effects among variables.

Methods

Using a dataset of 343,722 trees from 9,532 plots in the Austrian National Forest Inventory (ANFI) spanning 1981-2021, we categorized disturbance-related damages as "events." By employing approximately 20 sub-models at plot and individual-tree level, including climate data, site conditions, stand characteristics, and individual-tree attributes, we used logistic mixed-effect models to assess the likelihood of random event occurrence and explore intricate relationships.

Main results

- Stand and individual slenderness is a key variable in explaining the occurrence of random events and damage probability.
- Optimizing stand composition by reducing *Picea abies* and *Pinus Sylvestris*, and increasing Fagus sylvatica, *Quercus sp*., and *Carpinus betulus*, mitigates risk and damage intensity at the plot level.
- Interactions among wind speed, maximum stand height, snow and slenderness raise the occurrence of random events and the probability of wind and snow damage. High temperatures make the trees more susceptible to bark beetle outbreaks.

- Moderate interventions reduce tree vulnerability, while excessive interventions increase the risk of random events.

Conclusion

This study emphasizes climate change's impact on disturbance agents in European forests. By modeling random event probabilities and interactions, forest managers can optimize interventions to mitigate risks, enhance forest resilience, and adapt to changing environmental conditions.

From twisters to timber: Assessing the Effects of Tornadoes on Forests in the United States

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: Changes in climate dynamics have been forecasted worldwide, which may have significant effects on forest ecosystems. To gain deeper insights into effects of natural disturbances on forests, we conducted an analysis of tornado-related damage trends for the period 1995-2021, specifically focusing on forested ecosystems in the United States (U.S.). We documented a noteworthy pattern: while recent data collected between 1995 and the present indicate a stable or potentially declining trend in the overall number of tornadoes across the country, the southeastern U.S. has experienced an increase in both the total number of tornadoes and the extent of forest area affected, surpassing other regions over the past three decades. This points to a potential geographic shift in focused tornadic events ("tornado alley") from the midwestern U.S. to the southeastern U.S., which encompasses a larger expanse of commercial timber land (~80 million hectares across 12 states). Furthermore, we observed a 36% increase in forest area damage estimated by the total area covered by tornado tracks over the most recent two decades. These findings highlight the heightened financial implications on the wood products sector and landowners from increased tornado damage in forested areas in recent years. The outcomes of this study contribute to enhancing strategic risk assessments, guiding forest certification processes, and facilitating accurate carbon reporting. They also highlight the importance of adaptive forest management and the need for landowners to monitor and evaluate occurrence, extent, severity, and projections of the scale, frequency, and location of natural disturbances.

Impacts of efficient fuelwood consumption on carbon storage potential in mangrove ecosystems and alternative extraction sites

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: Supplying dead wood for fuel is one of the most important ecosystem services provided by mangroves to the local communities (UNEP-Nairobi Convention and WIOMSA, 2015), but the capacity of the forests to supply dead wood sustainably is unknown, as are the impacts of dead wood removal on carbon dynamics and ecology (Stephenson *et al.*, 2011). The ecological effects of removal of fuelwood from mangrove forests and alternative source in Vanga, Kenya, was investigated following the introduction of improved cookstoves to the forest adjacent communities. Using the Before-After-Control-Intervention (BACI) method, forty households were monitored (twenty as intervention and twenty as control) for a period of 2 months, using standard kitchen performance tests. The objective of the survey was to assess the impact of the introduction of energy efficient cook stoves on the amount of fuelwood used by the forest dependent communities, and how this affects the climate egulation potential of mangrove forests in terms of carbon storage. Further, data collected on fuelwood consumption, as well as on productivity and wood extraction was used to explore the 'leakage' phenomenon, which is very poorly studied; this describes the displacement of extractive or damaging activities away from protected areas into surrounding alternative sites. Here practical guidance was produced on the likelihood of forest management schemes simply displacing damaging activities to unprotected contiguous areas.

Radiative Forcing from Pre-Industrial Land Cover Change: the Capacity of Forest Cover to Modulate Climate

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: Climate-vegetation feedbacks depend on biophysical land cover characteristics such as albedo. This measure of surface reflectance impacts the surface energy balance. However, the narrow temporal extent of direct observations of albedo make it difficult to quantify centennial to millennial scale shifts. Albedo is used to quantify terrestrial ecosystem processes; its magnitude and variability moderate terrestrial biosphere and atmosphere interactions. Networks of fossil pollen data offer an observational constraint on biophysical land cover change that extends throughout the Holocene. We reconstruct Holocene albedo and associated radiative forcing for North America. First, we estimate average monthly blue sky albedo over the 2000-2009 period from MODIS satellite reflectance data products and ERA5 atmospheric reanalysis diffuse and direct radiation. Blue sky albedo –sometimes referred to as actual albedo– represents the overall surface reflectance from combined direct and diffuse incoming radiation. Then using a spatio-temporal network of fossil pollen records and the derived blue sky albedo, we reconstruct albedo. This reconstruction is done in two steps: calibration and prediction. In the calibration step, we develop a statistical model that characterizes the relationship between modern pollen samples and seasonal albedo. In the prediction step, we apply this model to reconstruct albedo from historical pollen records. Finally, these albedo reconstructions are translated to spatio-temporal estimates of radiative forcing using a pre-industrial radiative kernel. This allows us to identify regions that have undergone land cover shifts that have resulted in warming or cooling. This work provides new insight about the nature of climate-vegetation feedbacks and ecotone shifts, and an empirical constraint on ecosystem forecasts.

Regulation and resilience：Panarchy analysis in forest ecosystem of Northeast State-owned Forest Region, China

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: While COP27 proceeds in Egypt, While COP27 proceeds in Egypt, with most attempts to address global environmental issues, it is crucial to consider the significant challenges posed by climate-related changes to human livelihoods, society, and ecosystems. most attempts to take a global perspective on solutions to environmental issues. China has pledged a CO2 emissions peak before 2030 and achieves carbon neutrality before 2060. Additionally, the UN emphasizes the vital role of forest-based mitigation in averting catastrophic climate change. The Northeast State-owned Forest Region (NSFR) in China, with its vast forest resources, holds great ecological and livelihood implications for both China and global climate change issues. However, the NSFR has suffered catastrophic damage due to deforestation, leading China to implement the Natural Forest Protection Program (NFPP) and logging ban policies to restore the ecosystem. Despite these protective measures, concerns have arisen regarding the alarming state of the forest region's quality under long-term strict protection. To maintain the forest ecosystem in a stable state, effective silvicultural measures are essential, as the resilience of the forest ecosystem appears weak and unable to adapt to natural and human disturbances. Moreover, if the natural forest in the NSFR becomes a carbon source instead of serving as carbon sequestration, forest management measures need to be implemented. The fragility of the forest ecosystem may be exacerbated by climate change. To address these challenges, the concept of panarchy provides a framework in environmental science that can inform resilience thinking and adaptive approaches to forest management. Currently, the forest ecosystem in the NSFR is not progressing towards achieving high-quality forest goals. In this paper, we will discuss the adaptive cycle of the forest ecosystem in the NSFR over an extended period and propose a set of broader policy implications. Based on the application of panarchy to the NSFR, we propose a shift in focus from purely protecting the forests to ensuring their functional role in protection.

Taking the temperature of human-modified tropical forests using remote sensing

T5.11 Disturbance impacts on climate regulating services in forest ecosystems

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Abstract: Local-scale microclimatic conditions in forest understoreys play a key role in shaping species distributions and driving ecological processes in these ecosystems. Consequently, understanding what drives variation in forest microclimate is critical to forecasting ecosystem responses to global change, particularly in the tropics where many species already operate close to their thermal limits and rapid land-use intensification is profoundly altering local environments. Yet our ability to characterise forest microclimate at ecologically-meaningful scales remains limited, as tree cover precludes any direct measurement of understorey conditions from beyond the canopy. To address this challenge, we used airborne laser scanning to indirectly characterise fine-scale variation in microclimate across human-modified tropical forest landscapes. We established a network of microclimate sensors across one of the world's largest forest degradation experiments in Borneo, ranging from 80-m tall old-growth forests to oil palm plantations. We then used structural equation modelling to tease apart how topography and canopy structure shape variation in microclimate across the entire landscape. We found that elevation and terrain curvature primarily influenced daily mean temperatures and vapour pressure deficit, whereas canopy height had a clear dampening effect on microclimate extremes. This buffering effect was particularly pronounced on wind-exposed slopes but tended to saturate in strength once canopy height exceeded 20 m – suggesting that despite intensive logging, secondary forests remain largely thermally buffered. Nonetheless, at a landscape-scale microclimate was highly heterogeneous, with daily maximum temperatures ranging between 24.2–37.2°C. Based on this, we estimate that 15% of the landscape is currently sub-optimal for forest regeneration, a figure that we project could rise to 34% by 2100 due to regional warming alone. Together, our results emphasise how emerging remote sensing technologies such as airborne laser scanning can redefine our understanding of the microclimate ecology of tropical forests.

T5.12 Experimental underpinning for projections of forest futures

Adding a limiting nutrient to a boreal spruce forests – what are the impact for trees and ecosystems?

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Nitrogen (N) availability limits growth in most boreal forests. However, parts of the boreal zone receive significant levels of nitrogen deposition. At the same time, forests are fertilized to increase volume growth and carbon sequestration. No matter the source, increasing N in the boreal forest ecosystem will influence the resource situation for its primary producers, the plants, with possible implications for their defensive chemistry and after-effects when their litter is transformed into soil.

In a long-term experiment performed in a spruce (*Picea abies*) dominated forest landscape in Norway, we have looked at how addition of nutrients to mature forests affects chemical defense of trees and the impacts on litter decomposition, soil decomposers and soil carbon concentration.

Briefly, the phenolic defense of the current year needles of mature spruce trees was strongly lowered with increased N availability, which might imply increased vulnerability to pest organisms However, defensive chemistry in previous year needles did not differ between fertilized and non-fertilized forest, and neither that of spruce or bilberry litter or the speed of decomposition of these. On the other hand, nitrogen release increased strongly in litter from fertilized plots and a tea-bag experiment showed faster decomposition in fertilized forests. The organic soil layer of fertilized forests had a lower concentration of condensed tannins, likely due to the shift from bilberry- to grass-dominance in the ground vegetation. Fertilization also led to a less structured nematode community and the abundance of bacterivores relative to fungivores increased, indicating a more bacteria-dominated community. However, at the same time fungal biomass increased upon fertilization The C concentration in the organic soil layer was higher in fertilized plots. Our results infer that anthropogenic addition of a limiting resource for forest growth potentially change the balance between trophic levels, and as such may have cascading ecosystem effects.

AmazonFACE – A first glance on the effects of ecosystem-scale free air CO2 enrichment in the Amazon rainforest

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Atmospheric CO2 concentrations are still rising due to fossil fuel burning and land-use change, and have unambiguously influenced Earth's climate system and terrestrial ecosystems. Plant responses to rising atmospheric CO2 concentrations may have induced an increase in biomass and thus, increased the carbon sink in forests worldwide. Rising CO2 directly stimulates photosynthesis (the so-called CO2-fertilization effect) and tends to reduce stomatal conductance, leading to enhanced water-use efficiency, which may provide an important buffering effect for plants during adverse climate conditions. For these reasons, current global climate simulations consistently predict that tropical forests will continue to sequester more carbon in aboveground biomass. However, several lines of evidence point towards a decreasing carbon sink strength of the Amazon rainforest in the coming decades, potentially driven by nutrient limitation, droughts or other factors. Mechanistically modelling the effects of rising CO2 in the Amazon rainforest are hindered by a lack of direct observations from ecosystem scale CO2 experiments. To address these critical issues, we established a free-air CO2 enrichment (FACE) experiment in an old-growth, highly diverse, tropical forest in the Brazilian Amazon and we here present first results from the experimental plots. We discuss our main hypotheses that underpin the AmazonFACE experiment with a focus on possible effects of rising CO2 on carbon uptake and allocation, phosphorus cycling, water-use and plant-herbivore interactions, and discuss relevant ecophysiological processes, which need to be implemented in dynamic vegetation models to estimate future changes of the Amazon carbon sink.

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AnaEE-FoR2N: introducing the recently established Italian network of nitrogen manipulation experiments in mature deciduous forests

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Anthropogenic activities have significantly altered the global nitrogen (N) cycle, with important implications for the magnitude and persistence of forests carbon sink capacity, and hence the ability of forests to continue mitigating climate change. Increasing atmospheric N input can play a crucial role in enhancing tree growth and forest productivity. However, under N excess conditions, a cascade of negative effects is expected, leading to tree growth decline, increase in soil acidification and N loss pathways. Controlled experiments manipulating N levels have been established globally since the '80s, and they are key to evaluate long-term ecosystem responses to N deposition. However, the majority of them (particularly in Europe) were conducted in conifer forests, mostly via soil N applications, often applying N doses several order magnitudes larger than ambient deposition. There is an urgent need for more realistic manipulation experiments, to provide better understanding of the complex interaction between N and carbon cycling in forests so to support informed policy decisions as well as to contribute to better representation of N cycling in dynamic global vegetation models. Here we present the AnaEE-FoR2N network, which includes 4 N manipulation experiments established between 2015 and 2017 in 3 *Fagus sylvatica* L. (Cansiglio, Cembra and Collelongo) and 1 *Quercus robur* L (Monticolo) forests in Italy. Sites were selected along climate and N deposition gradients. The experimental design across the sites includes four replicated (n=3 plots) treatments: control, soil (as single and double doses) and aerial N additions (as a single dose), the latter representing a more realistic simulation of atmopsheric N deposition. Doses applied (between 20 and 60 kg ha^{-1} yr^{-1}) are in general twice (the single dose) or three times (the double dose) higher than actual atmospheric deposition, thus, simulating expected changes in N deposition, if reactive N emissions (particularly in the NH_x forms) are not reduced. Foliar nutrients and above-ground biomass have been monitoring since the beginning of the experiment. More intensive measurements will be included starting from summer 2024, such as continuous monitoring of tree growth, transpiration, stem humidity and canopy light transmission via TreeTalkers as well as soil GHG emissions.

Atmospheric exchanges of CO2, CH4 and N2O of temperate forest soils under elevated CO2 fumigation at BIFoR-FACE

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Atmospheric exchanges of CO_2, CH_4 and N_2O of temperate forest soils are an important aspect of the net global warming potential and climate mitigation function of forests. However, it's unclear how these fluxes will respond to rising atmospheric CO_2 concentrations (eCO_2) in temperate forests. Increased carbon sequestration under eCO_2 and storage in biomass and soils can influence the activities of soil microbes responsible for greenhouse-gas (GHG) process dynamics and hence net emissions. Understanding the direction and magnitude of these fluxes in response to eCO_2 is critical, given that forests in northern latitudes sequester about 0.8 billion tons of CO_2 yr^{-1}, rates roughly equivalent to the net EU27 + UK emission of anthropogenic CO_2.

The Birmingham Institute of Forest Research established a Free Air Carbon Enrichment Facility (BIFoR-FACE) whereby a mature temperate forest is exposed to +150 ppm CO_2. In this abstract, the focus is on quantifying the GHG flux as influenced by eCO_2 and microclimatic conditions, whilst also partitioning heterotrophic and autotrophic contributions. The flux of CO_2 from the soil has been measured continuously within treatment (eCO_2) and ambient control (aCO_2) arrays since 2017 with capabilities to measure CH_4 and N_2O added since 2020. Initial trends from 2017 - 2020 indicated that eCO_2 arrays had a higher efflux of CO_2 relative to aCO_2 arrays by +20%. However, during 2021 and 2022, eCO_2 arrays have seen a decline in the efflux of CO_2 by -27.5% relative to aCO_2. Lower mean differences between pseudo-root exclusion and zero-exclusion chambers within the eCO_2 arrays suggests a potential decline in the heterotrophic contribution to CO_2 effluxes. Coupled with significantly lower δ13C keeling plot R^2 values from CO_2 efflux rates, this further suggests a potential shift in heterotrophic contributions. Sink potential of CH_4 and efflux of N_2O are also significantly lower under eCO_2 arrays, by -40% and -78% respectively.

Thus, with changing carbon allocation and nutrient acquisition strategies under eCO_2, potential functional changes in the microbially mediated flux dynamics could be occurring. The magnitude of these fluxes will be presented, which will have critical implications for the net global warming potential of temperate forests under increasing atmospheric CO_2.

Carbon and Soil Nutrient Cycling Responses of a Temperate Forest to Seven Years of Elevated CO2 Fumigation

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Forests sequester ~18% of the global carbon dioxide (CO_2) emissions from anthropogenic sources. This "CO_2 fertilization effect" results in a predicted 67% increase in the land carbon (C) sink through enhanced CO_2 capture. The projections of the land C sink by the end of the 21st Century based on simulations of state-of-the-art Earth System Models (ESM) is highly uncertain, with a 25 to 50% reduction in the predicted land C sink when nutrient availability including nitrogen (N) is accounted for. This uncertainty emanates from poor representation of key ecosystem types, particularly mature forests, to changing nutrient supplies under eCO_2.

The Birmingham Institute of Forest Research (BIFoR) established a Free-Air CO_2 Enrichment (FACE) facility in a mature temperate forest in the UK, where fumigation of three forest plots with elevated CO_2 (+150 ppm above the ambient) was started in 2017 and continues to date. In response to CO2 fumigation, trees CO_2 uptake increased by an average of 23%, and the tree basal area increments increased by ~ 28%. Belowground C allocation via litter fall (+14%), root exudates (+40%) and fine root biomass increased. However, the litter fall N content decreased by 12% pointing towards N resorption by trees before senescence. Similarly, the soluble N to C ratios in exudates decreased corroborating the observation that trees conserved N for sustaining the growth response. Soil gross N mineralization rates were 20% higher under eCO_2. These processes sustained larger soil mineral N supply (~25 kg N ha^{-1} y^{-1}) under eCO_2 showing that the trees invested captured C for N acquisition. Whilst microbial biomass phosphorus increased in soils, a consistent treatment effect was not observed.

Overall, the forest sustained high C capture and allocation into biomass and soils. The net implications of nutrient availability for C sequestration will depend on how long upregulation of soil nutrient availability will last in meeting plant nutrient demands before manifestation of nutrient limitation, if any. The ongoing eCO_2 fumigation lasting at least until 2026 will help resolve the feedbacks between C capture and nutrient availability to enable a realistic assessment of the role of forests in climate change mitigation.

Impact of elevated CO2 and heat wave on canopy temperature and leaf heat tolerance of mature Quercus robur.

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Detailed studies to describe leaf and canopy temperature have often focused on a few species under controlled environments. Results from crop systems have reported reduced stomatal conductance under high CO_2 concentrations resulting in higher leaf temperatures. However, there is limited data on the effect of elevated CO_2 in natural ecosystems such as forests. Emerging Thermal Infrared (TIR) camera techniques to collect thermal imagery has recently proven useful for continuous monitoring of the surface temperature of natural ecosystems. In this current study, TIR was utilised to measure the canopy temperature of a mature (> 175 years) oak woodland at the Birmingham Institute of Forest Research Free Air Carbon Enrichment (BIFoR-FACE) facility at Staffordshire, Central England, during the summer of 2021 and 2022. Over the growing season, the daytime (10:00 – 15:00 hours) canopy temperature of oaks under ambient (aCO_2) and elevated (eCO_2) was higher than the air temperature. Oak leaves were further subjected to leaf heating treatments to assess the effects of high CO_2 on their heat tolerance. The canopy temperature of oaks under eCO_2 was ~ 1°C higher than those under aCO_2. The observed canopy temperature was mainly driven by microclimatic factors, which were enhanced by the interactive effect of elevated CO_2. Even though there was no difference in leaf tolerance for oaks under eCO_2 and aCO_2, there was an increase in the leaf heat tolerance of oaks after a heat wave event in July 2022. High canopy temperature deviation from air temperature impacts plant processes and ecosystem interactions, especially under eCO_2. Output from the long-term canopy temperature monitoring will be useful for validating and improving earth system models, which hitherto have utilised air temperature as a proxy for leaf or canopy temperature. Additionally, information on the leaf tolerance of species will be critical to informing policy on tree species for forest management programmes.

Legacy and resilience of a mixed beech/spruce forest under experimental drought

T5.12 Experimental underpinning for projections of forest futures

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Abstract: This paper summarises 10 years of experimental drought and subsequent recovery in a temperate mixed forest in southern Germany. The study objects are about 100 European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*) trees, each about 80 years old, growing in 12 experimental plots under monospecific or mixed interactions each (kroof.wzw.tum.de). The aim is to determine the physiological and morphological acclimation of the trees to drought and their resilience, including competitive and facilitative interactions from the rhizosphere to the stand level.

Trees were exposed to summer drought for five consecutive years, with complete exclusion of precipitation throughfall in the growing season. During the first two summers, drought stress was highest with a pre-dawn leaf water potential around -2.0 MPa, reducing physiological (e.g. leaf gas exchange, phloem transport) and morphological (e.g. root and stem growth) parameters by up to 80%. In subsequent years, leaf area acclimation in spruce reduced tree water use and thus increased soil water availability. Reduced drought stress was evident at several levels in parallel, including biomass increment, physiological responses, and mycorrhizal community composition. Overall, trees growing in mixed stands recovered better than those with monospecific interactions.

Subsequent drought release was initiated by controlled irrigation (90-100 L/m^2 of ^{2}H-labelled water over 2 days) to study the drought resilience of trees and stands over several years. During the first weeks of drought recovery, the allocation of new photoassimilates from the canopy to the rhizosphere was traced by whole-tree ^{13}C-labeling. Physiological parameters such as tree water potential or xylem sap flow recovered within hours to days, including sugar transport along the stem as an important prerequisite for restoring tree functionality. The restored canopy-rhizosphere coupling significantly promoted spruce root growth through preferential C allocation below ground, which also recovered within a few days. Other morphological parameters, such as whole-tree leaf area, recovered much more slowly and took several years. Even after 4 years, the long-term legacy of drought was still evident in the reduced water use of previously drought-stressed trees during a renewed drought period due to morphological and physiological effects.

Next Generation Experiments and Monitoring Networks for Forests Under Global Change: CLEANFOREST WG4

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Forests experience multiple concurrent effects from global change, such as climate extremes and atmospheric pollutants (e.g. carbon dioxide, nitrogen, sulphur). Key questions in forecasting the future environment are the effects of multiple interactive drivers at the same time rather than responses to changes in one factor, and the prediction of effects on whole ecosystems as opposed to disparate response variables. The CLEANFOREST COST Action unites research knowledge and link researchers working on both atmospheric pollutants and effects climate extremes at all scales in urban and peri-urban forests.

Our working group in the COST Action will advance the state of the art of experimental and monitoring approaches to understand forest responses to global change. We link three other working groups in the action looking at deposition trends, ecophysiology, and biogeochemistry and ask: where do we go next? How can the next generation of experiments and observations be designed? We aim to bring together different approaches used to understand the effects of deposition, moisture, and their interactions on eco-physiological parameters, forest health, growth, diversity, and biogeochemical processes. We specifically bridge the gap between experimental treatments and observational monitoring and identify where methods limit, where important knowledge gaps can be tackled in future.

Currently we have subgroups 1) investigating the effect of climate extremes events which occurred in past forest nitrogen deposition experiments 2) bridging existing monitoring networks working on forest ecosystem response to climate extremes and atmospheric pollution 3) examining how experimental timescale on affects observed responses from global change experiments.

We welcome participation in these activities, our working group and the COST ACTION in general.

Nutrient limitation in soils regulate the effects of elevated CO2 on soil N cycling at BIFoR-FACE (UK) and Euc-FACE (Australia)

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Increasing atmospheric CO_2 concentrations in the atmosphere due to human activities, is projected to enhance photosynthesis and carbon storage of forest ecosystem. However, it is unclear how nutrient limitation will constrain the projected CO_2 fertilization effect. Therefore, it is essential to evaluate how nutrient limitation will affect the response of forests to rising CO_2 concentration and how it will feedback on nutrient availabilities and more especially nitrogen (N) which can become limiting with time.

The purpose of this research is to evaluate the response of N cycling processes to elevated CO_2 fumigation in a N-limited northern deciduous temperate forest and a phosphorus (P)-limited Eucalyptus dominated forest. The research was conducted in two Free Air Carbon Dioxide Enrichment (FACE) facilities: BIFOR FACE located near Birmingham, UK and EucFACE in New South Wales, Australia. Furthermore, EucFACE (P-limited forest) received partial phosphorus fertilization to study its effect on N cycling.

We employed a ^{15}N pool dilution method to assess gross protein depolymerization and gross mineralization at both study sites, along with the measurement of nitrous oxide emissions and extracellular soil enzyme activities.

Preliminary data from the N-limited forest (BIFOR FACE) indicate that elevated CO_2 increased belowground carbon allocation, resulting in higher dissolved organic carbon, microbial biomass, and microbial respiration. However, the additional carbon belowground solely stimulated gross ammonification (by 32%) and ammonium immobilization (by 18%), whilst gross nitrification was downregulated (by 35%) and N_2O production was un-affected under elevated CO_2. This suggests that root exudates selectively influence microbial communities for nutrient acquisition, toward a tightening of the nitrogen cycle to meet the higher nitrogen demand. However, how long the N supply will be maintained in the face of declining nitrogen deposition in future climates remains uncertain. In the phosphorus-limited forest, nitrogen depolymerization and mineralization remained unaffected by elevated CO_2 due to phosphorus constraining the plant's response (Andresen et al., 2020). However, the response of these processes when phosphorus limitation is relieved is currently under investigation.

Results from this research aim at improving our understanding of forest response to future climate by unveiling the role of nutrient limitation in future C uptake.

Response of Oak Forest ecosystem to manipulated drought and nutrient limitation

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Drought is one of the global change drivers which plays a significant role in forest adaptation and mitigation potential by its impacts on forest ecosystem functioning and health. Experiments can provide vital insights that are needed for model development and future projections. We have been carrying out a manipulated drought and ring barking experiment to quantify the response of Oak Forest ecosystem to environmental stresses such as drought and limited nutrient supply.

Bac-Stop is a fully replicated field manipulation experiment with rain exclusion shelters around 32-year-old sessile oak trees on sandy soils to create drought effect and ringbarking as a proxy for water and nutrient deprivation. The trial comprises 3 environmental treatments (Drought, Ring barking and Control) in 6 blocks and 8 trees in each treatment per block, total of 144 trees, being intensively monitored since May 2020. Soil moisture and temperature are monitored using theta probes, and tree physiological responses are monitored by TreeTalkers, which are sensors mounted on the trees measuring hourly tree sap flux, tree growth, tree humidify index, canopy development and condition, air temperature, air relative humidity and tree oscillation. Soil physical and chemical properties and tree fine roots and foliar morphological and nutritional traits have been measured. First results suggest immediate drought impacts on soil moisture down to tree rooting depth compared to Control. Both tree growth and Stem Humility Index have significantly declined in the first Autumn in the Drought treatment (3 months after drought started) and continuously from July 2022 (12 months after drought started). Foliar, soil and roots analysis suggest reduced photosynthetic capacity and carbon uptake and nutrient imbalances related to Drought and Ring barking, which links to the decrease in tree growth. Multispectral band data (12 bands of near infra-red and visible spectra) is being analysed now to investigate the conditions of the canopies using vegetation indexes such as NDVI, etc. Summer drought 2022 simulated similar magnitude of drought in Control as in the Drought treatments, confirming the validity of the Bac-Stop experiment in monitoring real climate change conditions and tree responses in the future.

Root Dynamics Under Elevated CO2 in a Free Air Carbon Enrichment (FACE) Experiment

T5.12 Experimental underpinning for projections of forest futures

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Abstract: Evidence supporting a carbon fertilisation effect, where increasing levels of carbon dioxide (CO_2) in the atmosphere lead to photosynthetic enhancement in trees, suggests that forests can sequester more carbon under elevated CO_2. However, it remains largely unclear where and for how long this carbon is stored within the forest ecosystem. To sustain photosynthetic enhancement under elevated CO_2 concentrations, trees are likely to require higher intake of water and nutrients from the soil, which should stimulate root growth. This ongoing study (2022-2026) investigates the hypothesis that fine root biomass and turnover rates will increase, and proliferation will be higher at greater depths, as a consequence of elevated CO_2.

This study is carried out at the Birmingham Institute of Forest Research (BIFoR) FACE experiment, the only FACE experiment in a mature, temperate forest simulating atmospheric CO_2 concentrations to those predicted to be the mid-century planetary norm. Changes in fine root biomass and depth distribution were measured across elevated and ambient CO_2 treatments. For each treatment, we had 12 replicates consisting of soil cores to a depth of 1 vertical metre, deeper than the standard 30cm, because elevating CO_2 has previously shown changes in fine root depth distribution. Dry weight of fine roots and morphological traits were assessed, notably through high resolution scanning. Changes in fine root growth rates are calculated from minirhizotron images taken at monthly intervals over a 2 year period, with 15 replicates per treatment.

Fine root biomass was not significantly higher under the elevated than ambient CO_2 treatment but, at the time of writing, interim findings focused on analysis of two-thirds of the 1-metre cores, show indication of change in root allocation in this system under elevated CO_2. Fine root biomass declined approximately exponentially with depth under both elevated and ambient CO_2 conditions, but this slope of decline was lower under elevated CO_2. This suggests that trees invest in increased root proliferation at greater depths under elevated CO_2. It is vital that the consequences of increased atmospheric CO_2 on plant carbon allocation are understood to improve the accuracy of models projecting the future of forests as global carbon sinks.

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

A proposal for the 2025 Italian Forest Inventory

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: The design of the last two Italian National Inventories was based on a three-phases sampling scheme. In the first phase, a 1 km × 1 km grid was superimposed to the national territory and a tessellation stratified sampling (TSS) was implemented by randomly and independently selecting a point in each quadrat while in the second and the third phase subsamples of the first phase points are selected by suitable stratified sampling schemes.

Since 2005, the Italian National Inventories has been performed every ten years with the aim of obtaining estimates of totals and densities, and their precision, of those variables which are important for assessing the state and the evolution of forest areas in Italy. However, nowadays, there is a growing need to rapidly monitor short-term evolution. Therefore, a modification of the Italian National Inventory design is required to carry out an annual inventory, which must be sustainable in terms of available resources.

To this end, it is proposed to consider a one-phase sampling scheme based a suitably customized version of TSS and to visit only a portion of sampled points on the ground each year, so as to complete the visit of the entire sample in five years. In particular, TSS is performed on a grid obtained by suitably grouping an adequate number of 1km x 1km quadrats and by randomly selecting a point among the first-phase points of the previous inventories in the new grid. Furthermore, as regards the criterion for selecting the points to be visited each year, it is suggested to subdivide the new grid into regular polygons and to systematically visit each year the sampled points contained in the quadrat having the same position in the polygons. The proposed makes it possible to produce annual estimates of totals and densities, with estimates of their precision, and estimates of their changes between years. Finally, maps representing the spatial pattern of the variables of interest can be obtained together with maps of the corresponding precision.

A regional forest inventory network and its effects on capacity buiding, local development and forest governance

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Regional or national forest inventory programs generate critical data for forest management and conservation at strategic levels, as well as for forest governance, landuse and territorial planning purposes. However, their role as subsidiaries of the development of qualified and specialized field crews, data analysts and young (post-)graduate researchers does not appear to be fully appreciated. In this sense, forest inventory programs can strengthen institutions such as universities and (local) research agencies. Data acquisition, processing and analysis/interpretation is underpinned by the generation of a substantial amount of knowledge about multiple topics on forestry. Such knowledge enables society to develop scientific and technological independence, which could lead to actions aimed at enhancing social equity, well-being, and sustainable use of natural resources. Here, we present an example of this type of endogenous development promoted by a state-level forest inventory and monitoring program called "FlorestaSC", which is carried out by local senior and young Brazilian researchers, and is mostly funded by the state government. It aims the monitoring of forest cover (by use of remote sensing techniques) and of forest composition, diversity and structure (by means of 500 systematically located 0.4 hectare field plots, now measured for the third time since 2007). Estimations of biomass and carbon stock and changes, species distribution modelling under climate change effects, determination of threatened tree species and of priority areas for conservation and secondary forest management recommendations are the main topics, that are relevant for implementing a new forest policy framework and forest and land use governance. As a result of a friendly data-sharing policy formulated at its very beginning, the FlorestaSC program has active a network of scientific partnerships with multiple research groups and institutions from Brazil and abroad. These partnerships allow for an intense knowledge sharing experience that have led to integrated research proposals, advanced data analysis, contributions to global databases (e.g., GFBI, sPLOT, TRY), capacity building, and high-impact scientific publications. Such relevant outcomes facilitate continuous fundraising and enhance the credibility of the information generated by the program for the local government and society.

An empirical model for assessing the hindering factors of thinning in the planted forests in Japan using tree-level NFI database

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Planted forests in Japan, comprising about 25% of the nation's total land area, have an important role in timber production and ecosystem services. Since most planted forests in Japan are unsuitable for timber production, it is important to induce them to provide ecosystem services through continuous cover forestry. However, the stand density of the large portion of the planted forests is not controlled through thinning, even though the normal tree planting method in Japan densely plants the seedlings (3000 per ha) with the assumption that they will be thinned after they reach a specific age. The stands without thinning are likely to provide poorer ecosystem services (e.g., reduced quality of harvested wood, soil runoff), and promoting thinning is an important issue in the forest policy. The factors that limit thinning in a large area of plantation forests are expected to be the combination of different types of variables, such as vegetation structure, location, history of silvicultural operation, and socioeconomic elements. However, a detailed analysis of the factors hindering thinning is still needed.

Therefore, this study aims to reveal the factors that influence the occurrence of thinning in planted forests under overcrowded conditions across Japan.

The third (2009-2013) and the fourth (2014-2018) Japanese National Forest Inventory databases are employed as field plot data. The database is made from the sample survey that assumes grid points at 4 km intervals throughout the country. First, from the single-tree data within the plots in the third term, we extracted plantation forest stands of which species is any of the six plantation species. Then, overcrowded forests are selected using the Relative Yield Index as the indicator of crowdedness (n=2,437). From the selected dataset, we clarify the relationship between changes in the basal area between the third and the fourth term and forest structure (e.g., age, species composition), environmental factors (e.g., climate, topography, landscape), and socioeconomic factors (e.g., conservation policy, size of the forest industry) using the hierarchical modeling framework. The result of this study is expected to be utilized to predict the spatial pattern of the transition of planted forests in Japan.

Analyzing the distribution of mixed forests using the national forest inventory data in Sweden and Finland

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: The distribution of mixed forests has not been informed well while the definition can vary by country. The question on how to measure and quantify mixed-forests is still an important issue. In this study, we compared the definitions of mixed forests by varying the mixture proportion and analyzed the distributions of mixed forests with main factors. The used materials were the National Forest Inventory (NFI) data from Sweden and Finland. The definition of mixed forests was analyzed on the basis of stand basal area instead of stem number to take different tree sizes into account. The studied sites were limited to the forest areas that are available for wood production. As a result, the total area of mixed forests in each country was increased gradually as the threshold criteria for being monoculture (the minimum proportion of a dominant pure species in a stand) were tighten. As the criteria were changed from 65% to 85%, the proportion of mixed forest area was turned from 24% to 49% in Sweden and from 21% to 42% in Finland. The 75% threshold criteria were applied to present the rest of the results since it has been also used in other studies and NFI results. In the results, the mixtures with pine-spruce, spruce-birches, and pine-spruce-birches were the most frequent stand types in both countries. Out of the mixed forest area, the proportion of peatland (peat thickness ≥ 30 cm) was small with less than 10% compared to mineral soil in both countries. The proportion of mixed forest area increased as the vegetation zone moved from north boreal to hemiboreal and the stand development reached at a mature stage. It revealed that the proportion of mixed forest will decrease in the future if there is no appropriate action for forest management planning. Overall, the possibility and degree of harmonization to use the NFI data across the countries were able to be examined. The results are expected to be used as a reference to find an adequate definition of mixed forest and to provide basic information of the distribution by main factors.

Approaches for integrating a space-based biomass map with national forest inventories in the tropics

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: The field of space-based biomass has experienced significant advancements in recent years, resulting in the availability of various global or large-scale biomass products. Concurrently, countries in the tropics have made remarkable progress in establishing their National Forest Inventories (NFIs), with some currently facing challenges to complete their first round of measurements or conducting re-measurements. This presents a timely opportunity to explore how space-based biomass data can support ongoing NFIs. Here, we will share insights gained from integrating national forest inventories with space-based biomass data in diverse contexts, specifically focusing on the estimation of subnational aboveground biomass emission factors. Drawing upon examples from two NFIs implemented largely in tropical humid forests (in the Peruvian Amazon and Guyana), as well as two NFIs implemented largely in tropical dry forests and woodlands (in Tanzania and Mozambique) and a global biomass map, we will discuss the best practices for developing country-specific strategies for the integration of NFIs and space-based biomass data. These practices consist of tailoring approaches to meet country-specific needs, exploring different map-to-plot assessment strategies for each biome, and defining the model-assisted estimator, which heavily relies on a country's NFI sampling design and plot configuration. Through the aforementioned examples, we aim to provide lessons learned for effectively combining NFIs and space-based biomass data for national reporting purposes. Furthermore, we will also highlight the challenges encountered in these integration exercises. The presentation will reflect on the potential of utilizing space-based biomass data to enhance the accuracy and reliability of biomass estimation in NFIs, contributing to more comprehensive reporting of a country's forest carbon stocks.

Assessing the influence of the minimum sampling size and element piece in deadwood stocks

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Deadwood plays a relevant role in maintaining forest ecosystem functionality, serving as a refuge for many species and acting as a determinant of carbon pool and nutrient cycling. However, its presence has been associated with an increase in forest fire damage as well as other perturbations. Consequently, the interest in deadwood has arisen during the last decades leading several countries to incorporate deadwood sampling in their National Forest Inventories field tasks. However, the differences among countries in deadwood protocols, such as minimum sampling size or deadwood elements sampled (stumps, snags, logs, branches, etc), may hamper the comparison among countries. To address this issue, we aim to evaluate every deadwood component's contribution to the overall deadwood stock and explore the influence of the minimum sampling size on overall deadwood stock. These analyses are conducted for the main forest types defined in Spain using the deadwood data obtained from the Spanish National Forest Inventory. Our findings reveal that the lying and standing components of deadwood store the largest amount of biomass, whereas the stumps and accumulations played a minor role in terms of biomass storage The total deadwood stock exhibited a nonlinear decrease as the minimum sampling size increased. Our results provide relevant insight for the harmonization and comparison of deadwood data among countries as well as for the development of standardized methodologies for assessing deadwood stocks. Finally, this research allows more accurate evaluations of the ecological functions and dynamics of forest ecosystems.

Building regional capacities in Latin America and the Caribbean for harmonizing forest information

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Latin America and the Caribbean (LAC) recognizes the importance of networking for enhancing forest information. During the Thirty-first meeting of the LAC Forestry Commission (COFLAC) in 2019, delegates recommended to the Food and Agriculture Organization of the United Nations (FAO) provide support for building-up the National Forest Inventory (NFI) network in this region. In 2020 the initiative was presented to 11 countries, led by the Brazilian Forest Service with collaborative support from FAO and the Institute of Forestry Sciences of the Higher Council for Scientific Research of Spain. The first collaborative work is the publication about the state of the art of the National Forest Inventories in LAC[1]. The publication paved the way for the next harmonization efforts, focused on three prioritized variables: forest area, volume, and aboveground biomass.

This paper describes the harmonization process of forest definition for NFIs in LAC, highlighting the paramount importance in terms of unified reporting for international assessments, such as the Global Forest Resources Assessment (FRA), the Nationally Determined Contributions (NDCs), the progress reports on climate change, and for the mechanism of Reducing Emissions from Deforestation and Forest Degradation (REDD+). During the study consultations were conducted with 23 LAC countries regarding the thresholds for the main criteria used to define forests, including minimum area (0.5 ha), canopy cover (10%), and tree height (5 m). The analysis revealed that 40% (9) of the countries reported forest areas below the minimum area threshold, 35% (8) reported canopy coverage above the threshold, and less than 1% (2) reported tree heights below the minimum threshold. The reasons reported for not adhering to the FRA thresholds are special situations in forest ecosystems, technological limitations, and the opportunities and potential use of FRA criteria for the countries.

The study discusses the challenges for the LAC region to broaden the harmonization results with those responsible land use and land cover monitoring and securing adequate funding resources to operationalize the FRA definition. Addressing these challenges may need additional time for the interpretation using new thresholds, and for updating the time series of the greenhouse gas inventories.[1] https://doi.org/10.4060/cb7791en

Collaborative network of permanent forest plots in Portugal: knowing the present to be able to predict the future

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Forecasting forests growth and yield facing climate and global changes is increasingly challenging. Yet the ability to accurately predict forest development remains the basis of forest management. In Portugal, numerous research projects from universities, forestry companies and public entities, across different forest systems, tree species and stand structures, which included the installation of plots, have generated important datasets. However, given the long timeframe needed for planning and difficulties in securing funding for proper monitoring, so far, there has been no comprehensive overview based on a broader survey of Portuguese forests. For the first time, in Portugal, the Experimental Forest Plots Network Project, included in the TransForm Agenda[1], aims to establish a network of permanent plots, covering the main forestry species and the various associated silvicultural systems to represent the diversity of forest systems and stand's structure and yield across distinct forest regions. It will be possible to assess the responses to climate change in different forest species and silvicultural systems. It will also contribute to providing complementary data to the National Forest Inventory (NFI) so that Portugal can join the European ICP Forests plot network, and thus contribute to providing data and information to the national and European scientific community on the state of the Portuguese forest. A new governance model and information sharing processes will be defined specifically for this purpose. This innovative project will create a unique opportunity to enhance, in a collaborative way, sound knowledge about the forests in Portugal. It is also expected that the leverage of synergies will contribute to significantly increase the decision-making capacity.Key words: permanent forest plots network; climate change studies; international forest knowledge; ICP Forests European; National Forest Inventory.

[1] This study was developed under the Mobilizing Agenda "TransForm -Transformation of the forest sector towards a resilient and low-carbon economy", supported by the PRR-Recovery and Resilience Plan and the European Next Generation EU Funds.

Collaborative Networks for Trustworthy Forest Data: The Role of Forest Inventory Networks in the FAO-FRA Capacity Development Programme

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: The Food and Agriculture Organization of the United Nations (FAO) has monitored global forests through its Global Forest Resources Assessments (FRA) since 1948. These assessments serve as an invaluable source of information regarding forest resources, their management, and use, and serve policy formulation and decision-making processes at various levels.

Over time, the FRA has undergone a transformation from an FAO-led exercise to a country-driven process where the officially nominated FRA National Correspondents are directly involved in the data collection, analysis, processing, documenting, and reporting of their data and metadata to FAO. Complemented by enhanced technical methodologies, including digital reporting and review, remote sensing, and provision of tools for statistical time-series modeling, this approach has increased global capacity to measure and monitor forests and more accurate and transparent reporting.

In addition to countries' active participation in the FRA process, networking among the FRA National Correspondents and their collaborators is key for successful FRAs and continuous improvement of quality and consistency of the data reported to FAO. Regional forest inventory networks (FINs) are major contributors to these efforts, as already demonstrated by the excellent results achieved at the European level (ENFIN [1]), and in North and South America (NAFC[2] and red IFN-LAC[3]).

These networks facilitate enhanced collaboration and knowledge sharing among countries, supplementing the existing FRA capacity-building program by promoting the adoption of best practices in forest inventory and assessment. By serving as conduits for exchanging knowledge and experiences, they can boost technical capabilities and harmonize forest data across regions, fostering a comprehensive understanding of global forest resources.

The forest inventory networks can assume multiple roles within the FRA capacity-building program. They can offer platforms for countries to exchange experiences and advocate for proven methodologies and innovative approaches in forest assessment. Furthermore, FINs can support standardizing assessment methodologies and indicators, facilitating meaningful comparisons between countries.

This paper will elaborate on the potential synergies between the FRA capacity-building program and the NFI-Networks.

[1] European Network of National Forest Inventories http:/ /enfin.info/

[2] North American Forestry Commission https://www.fs.fed.us/global/nafc/inventory/aboutus.htm

[3] Network of National Forest Inventories of Latin America and the Caribbean

Collaborative Solutions for Reliable Forest Data: The potential role of a Global NFI Network of Networks

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Networking has emerged as a powerful tool in national forest inventories, bringing together countries, experts, and organizations to share experiences and improve national forest inventory practices. This paper emphasizes the importance of establishing a network of networks for national forest inventories, leveraging collective knowledge and experiences to enhance:

1. *Capacity development* by establishing regional NFI networks, including workshops, training programs, and technical exchanges. These initiatives foster the development of a skilled workforce and facilitate the transfer of expertise across countries and regions, ultimately enhancing the overall quality of national forest inventories.
2. *Knowledge sharing* is pivotal in networking national forest inventories, enabling participating countries to exchange experiences, address common challenges, and celebrate successes. This exchange of information enhances the efficiency of national forest inventory processes by promoting harmonized methodologies, standardized definitions, and shared tools.
3. *Harmonization of data collection and reporting practices*. Acquiring common data protocols, quality assurance standards, and data-sharing mechanisms ensures forest data's consistency, comparability, and reliability. This harmonization process enhances national, regional, and global data transparency and facilitates informed decision-making by policymakers, researchers, and stakeholders.
4. *Transparency* is vital to accountable forest management, and networking in forest inventories might be crucial in promoting data transparency. Through promoting the open sharing of forest data, methodologies, and results, networking enables peer review processes and collaborative platforms for feedback and improvement. This iterative process enhances forest data's transparency, credibility, and usefulness.

Additionally, networking provides a platform for sharing technological advancements in national forest inventories.

On a global scale, establishing a network of networks for national forest inventories aims to strengthen the process of regional networking. Nowadays, three regional NFI networks are working to improve forest data: the European National Forest Inventory Network (ENFIN), the monitoring and inventory working group of the North American Forest Commission, and more recently, the Latin American and the Caribbean Forest Inventory Network (IFN-LAC). By leveraging the collective expertise and experiences of existing networks and potential future networks, this

initiative fosters collaboration, promotes harmonized methodologies, and contributes to global efforts to understand forest dynamics, assess climate change impacts, and implement sustainable forest management practices.

European National Forest Inventories and their potential for large scale monitoring and reporting – Experiences and Visions

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Forest and forest related policies in Europe demand huge efforts in monitoring and reporting. National Forest Inventories (NFIs) provide information for a large set of indicators for this purpose on the national scale. Due to different environmental and social conditions leading to different forest policies at the national scale, the NFIs are designed to primarily focus on the national needs. They employ statistical sampling which means that they can also be used on a super-national scale with specific estimation techniques. For this the national definitions of the indicators have to be analysed in comparison to a common definition and the transformation path from the national to the international scale has to be developed. This is the harmonisation process on which the European National Forest Inventory Network ENFIN has been working for the last 20 years.
Due to increasing quality of remote sensing (RS) data sources new options and challenges for this process have emerged. On one hand, European scale Earth Observation data can provide a standardized data source for developing maps at very large scales but they still have comparably low resolution and usually do not contain 3D information. On the other hand, RS data collected on the national scale have very high resolution, but harmonization is required before using them at the European scale. In any case, the ground truth data for training and validation – usually based on NFIs – have to be harmonized. The best results can be achieved with a suitable combination of all three data sources.
Finally the combination of remote sensing wall-to-wall data and statistically sampled field data with known designs are an interesting field for the compilation of maps and improved estimations at different spatial scales. The different approaches from the past and for possible future developments will be presented with selected examples.

Integration and Publication of Forest Inventories and Land Cover Maps with Semantic Web Technologies

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Modern forestry management increasingly relies on the use and publication of large datasets, such as forest inventories, land cover maps, and stand characterization. However, these datasets are generated and published by different agents, following different methodologies and different formats and schemas. Working with integrated data is currently a challenge in forestry research.

Semantic Web technologies have emerged in the last decades as a solution to publish heterogeneous data in an interoperable way. These technologies include the Resource Description Framework (RDF), the Web Ontology Language (OWL), and the Protocol and RDF Query Language (SPARQL), standardized by the World Wide Web Consortium (W3C). They enable the publication of self-describing data that can easily interlink with other sources. The concepts and relationships between them are described using ontologies, and the data can be published as Linked Data on the Web. This data can be downloaded or queried online using a SPARLQ endpoint. Linked Open Data (LOD) promotes globally and openly accessible Linked Data and has been gaining traction in the last decades. National and international agencies promote the publication of governmental data as LOD, and research fields like biosciences or cultural heritage make an extensive use of Semantic Web technologies.

The European Cross-Forest project [1] addressed the integration and publication of forest inventories and land cover maps data from Spain and Portugal with Semantic Web technologies. The result is a set of ontologies and LOD datasets that integrate all their data. This data is linked to other sources such as the National Center for Biotechnology (NCBI) taxon ontology [2], DBpedia [3], and Wikidata [4]. All the results (ontologies, tools, and LOD datasets) are publicly available with Open Access license in GitHub [5] and queryable through a SPARLQ endpoint [6]. The Forest Explorer [7] allows navigating the data using an interactive map. Current lines of research include adding the temporal dimension to the data, allowing to follow the evolution of forests through time, and integrating additional forestry and geographical data, such as regional or stand inventories, or spatial planning information.

[1] https://crossforest.eu
[2] https://bioportal.bioontology.org/ontologies/NCBITAXON
[3] https://www.dbpedia.org
[4] https://www.wikidata.org
[5] https://github.com/Cross-Forest

[6] https://crossforest.gsic.uva.es/sparql
[7] https://forestexplorer.gsic.uva.es

Latin America National Forest Inventories: similarities and differences

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: National Forest Inventories (NFI) play a crucial role in providing forest information for decision-making processes related to national policies, programs, and projects in numerous countries worldwide. While in the past the main purpose was to guarantee the availability of forest resources, today NFIs also needs to meet other aspects such as climate change, biodiversity and conservation, non-wood forest products and disturbances, meeting the increasing demand for both national and international level. To ensure the quality of information, it is important that countries seek to improve comparability through harmonization initiatives, especially across the borders where similar forest types are shared. The objective of this study is to evaluate the similarities and differences between national forest inventories in Latin America and the Caribbean (LAC) to support the harmonization of variables of common interest and improve collaboration in the region. The evaluation was developed in the framework of the Latin America Forest Inventories Network (IFN-LAC) analysing the NFI´s methodologies of 20 LAC countries, thematic questionnaires sent to the countries IFN-LAC focal points on specific aspects of the methods and virtual meetings held to discuss specific topics with a view to harmonizing variables. Most countries plan their NFI to be permanent and continuous (86%), with 5-year cycles (76%), and there are countries with cycles between 4-10 years, while some prefer its implementation for a single evaluation over time (14%). Some countries (33%) adopt the strategy of carrying out the cycle measurements in panels that define annual sub-samples for data collection. The systematic distribution of sample units predominates among the countries (43%), with some combining random distribution and stratification (29%). Permanent sample units have been preferred by the countries (76%), but temporary plots (14%) and a combination of both are also used (10%). Cluster plots predominate in the region (67%), with circular (50%) and rectangular (25%) sample units being preferred. Remote sensing methods are mainly employed to improve NFI planning (80%). Countries in the LAC region are actively developing their national forest inventories and, by establishing a collaborative tecnical networks, it is possible to significantly improve the availability and quality of information within the region.

Logarithmic transformation or weighted nonlinear fitting approach?

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Logarithmic transformation of both response and predictor variables is a common approach used to fit allometric models. It has been recommended that logarithmic transformation should be used for populations with lognormal residuals (i.e., multiplicative errors), whereas weighted nonlinear models should be used for populations with normal residuals (i.e., additive errors). However, in practice, the distribution of model residuals is rarely tested to find which fitting method should be used. Here, using virtual populations of trees for three species (i.e., European beech, Norway spruce and Sessile oak) with normal and lognormal distributions of aboveground biomass (AGB) residuals logarithmic transformation and weighted nonlinear approaches were applied to investigate what are the consequences of interchanging the fitting methods on population estimates. Using weighted nonlinear approach for populations with lognormal distributions was as accurate predictor of population AGB as the logarithmic transformation. However, using log transformation approach for populations with normal residual distributions, showed that, for small sample sizes and with populations that exhibit large residual AGB variability, log transformation is a biased estimator. The bias was positive and relatively similar for all three tree species, suggesting that logarithmic transformation tends to overestimate the true population biomass by up to 2.5%. Nevertheless, using a correction factor based on the calculated mean of back transformed residuals rather than on commonly used estimated mean, resulted in a reduction of this bias up to insignificant levels. Therefore, weighted nonlinear approach can be safely used to populations with either normal or lognormal distributions, whereas, when using logarithmic transformation care should be taken if distribution of residuals is not lognormal, especially when sample size is small and residual variability is large.

Monitoring and reporting of transparent forest data and information under the Paris Agreement: The role of National Forest Inventory networks

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: The Framework Convention on Climate Change (UNFCCC) recognizes the critical role of forests as terrestrial carbon sinks for combatting climate change and calls for transparency of climate actions, including those in the forest sector. The Paris Agreement continues to uphold the principle of transparency. It established the Enhanced Transparency Framework (ETF) with the aim to build mutual trust and confidence among countries in their monitoring and reporting of climate actions and to track progress of such mitigation actions. Forests play a key role in all aspects of the implementation of the Paris Agreement. Numerous countries, both developed and developing, have identified forest and land use-related mitigation and adaptation measures and actions as part of their climate targets in their nationally determined contributions to fulfill the goal of the Paris Agreement.

The world is now in an era where transparency of data and information and actions are indispensable for ensuring coordination among relevant ministries and agencies and effective decision-making at all levels. Transparent, robust and comprehensive data and information on greenhouse gas emissions and climate actions are essential for informing national policies, plans and strategies and helping countries meet their international commitments on climate change. The same applies to forest data and information and its reporting to multilateral environmental agreements. Additionally, robust institutional arrangements, including for national forest inventories (NFI) as part of national forest monitoring systems and GHG management systems, form the basis for ensuring transparent data and information from these processes and systems and for meeting the requirements for reporting under the ETF.

The aim of this review analysis is to highlight the importance of transparency in monitoring and reporting and for building trust in climate actions. The analysis will provide an overview of the requirements and necessary elements for monitoring and reporting on the forest and land use sector in the ETF and the challenges faced. This background will serve as a basis for stimulating discussions and exploring potential collaborative solutions offered by strong institutional arrangements and collaborative networks (such as NFI networks) and to facilitate identification of effective capacity-building needs of developing countries.

Monitoring benefits of boreal forests in West and East: provisioning ecosystem services as proxy variables

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Background: The ecosystem service concept was introduced to highlight the importance of composition, structure and function of representative ecosystems for human well-being. There are many approaches to monitor the benefits of forest landscapes. However, existing monitoring methods need to include not only mapping and quantification of provisioning ecosystem services, but also other ecosystem services.

Aims: This study (1) reviews monitoring methods developed to map and quantify provisioning ecosystem services in boreal forest landscapes, and (2) describes how such methods can be used to assess also other ecosystem services. Boreal forest landscapes can be found in North America, Nordic countries and Russia.

Methods: We reviewed literature using sources in both English and Russian. Forest mensuration to survey the amount of timber has a long history of development. Tree growth is only measured comprehensively in areas under intensive forest management. Hence, approaches to monitor forest biomass are more developed in the Western countries compared to Russia. The current trend in monitoring of provisioning ecosystem services is moving towards the use of remote sensing data combined with digital analysis in forest management. However, differences between managed and naturally dynamic forests provide a challenge to applying these techniques more generally. We argue that results from monitoring of provisioning ecosystem services can also be used as a proxy to estimate other ecosystem services. For example, timber volume, tree species composition and diameter at breast height determine the amount of biomass, and thus carbon stock. To model supporting (or habitat) services and thus biodiversity, tree species and age classes derived from National Forest Inventory data can be used. However, non-marketable ecosystem services such as regulating and cultural ecosystem services require further research to validate the precision of existing models.

Conclusions: To conclude, provisioning ecosystem services have various trade-offs and synergies with other ecosystem services. Thus, in order to minimize efforts and costs related to monitoring, other ecosystem services could be modelled using existing National Forest Inventory data, comprehensive forest management unit plans, and methods to mapping and quantification of provisioning ecosystem services.

New Zealand's Forest Inventories – can they provide valuable forest data from a remote corner of the globe?

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: New Zealand has so far played a minor role as a participant to multi-national NFI networks. Reason for this is that NZ did not have a specific National Forest Inventory but rather more regional or estate focused surveys with often varying methods and objectives. However, driven by the need to nationally quantify the role of forests to mitigate climate change, the New Zealand Government committed itself since 2002 to monitor its indigenous forests and intensively managed plantation forests. The starkly different forest types led to the development of many specific methods and techniques, but also common sampling standards for those two types of forests. We will present a number of methodological developments, that have relevance for forest inventories that need to accompany a wide range of forest types – from temperate old growth rainforests to subalpine to plantation forests – and the capture of forest metrics such as above ground biomass and carbon to accurately and precisely characterise various forest types and the changes within. In the future technology such a Terrestrial Laser Scanning will become important for forest inventories to enable the homogenization of data and analysis. Important common foundations for forest inventories across such a wide range of forest types are discussed and we provide results from the current annual inventories in planted and indigenous forests of New Zealand in context with the wider global picture.

Toward comparable species richness estimates across plot-based inventories

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: To understand the state and trends in biodiversity beyond the scope of monitoring programs, biodiversity indicators must be comparable across inventories. Species richness (SR) is one of the most widely used biodiversity indicators. However, as SR increases with the size of the area sampled, inventories using different plot sizes are hardly comparable. This study aims at producing a methodological framework that enables SR comparisons across plot-based inventories with differing plot sizes. We used National Forest Inventory (NFI) data from Norway, Slovakia, Spain, and Switzerland to build sample-based rarefaction curves by randomly incrementally aggregating plots, representing the relationship between SR and sampled area. As aggregated plots can be far apart and subject to different environmental conditions, we estimated the amount of environmental heterogeneity (EH) introduced in the aggregation process. By correcting for this EH, we produced adjusted rarefaction curves mimicking the sampling of environmentally homogeneous forest stands, thus reducing the effect of plot size and enabling reliable SR comparisons between inventories. Models were built using the Conway–Maxwell–Poisson distribution to account for the underdispersed SR data. Our method successfully corrected for the EH introduced during the aggregation process in all countries, with better performances in Norway and Switzerland. We further found that SR comparisons across countries based on the country-specific NFI plot sizes are misleading, and that our approach offers an opportunity to harmonize pan-European SR monitoring. Our method provides reliable and comparable SR estimates for inventories that use different plot sizes. Our approach can be applied to any plot-based inventory and count data other than SR, thus allowing a more comprehensive assessment of biodiversity across various scales and ecosystems.

United States forest land area: why land cover and land use estimates differ

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: Tracking distributions and changes in forest land area is essential for monitoring resource conditions, trends, sustainability, and zero net deforestation commitments. Land cover describes conditions at a given time and land use describes longer term social and economic intent for which land is used. Forest land area estimates may differ significantly between land use and land cover information sources, leading to disparate conclusions. Furthermore, gross gains and losses of land area may be masked when reporting only net change. While remote sensing-based estimates from national land cover maps have suggested net losses in United States forest cover area during recent decades, in situ sample-based estimates of forest land use from the USDA Forest Service (USFS) Forest Inventory and Analysis (FIA) Program show net gains during the same period. Much of this discrepancy is attributed to underestimation of gross gain in forest cover, resulting in overestimation of net cover loss; this is a common challenge in remote sensing-based land cover products. We present United States forest land use and land cover estimates and discuss differences.

Using NFI data on mound occurrence and forest variables to evaluate how forest management practices have impacted red wood ants (Formica rufa group)

T5.13 Forest without borders: National Forest Inventory Networks and their potential for large scale monitoring and reporting

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Abstract: In boreal coniferous forest ecosystems, red wood ants (RWA) are ideal targets for conservation efforts. They are highly visible, through their construction of large mounds, and function as a keystone species that provides protection and resources for many associated species. Recently, there has been an international call to monitor and protect RWA populations. In Finland and Switzerland, National Forest Inventories (NFIs) have previously been used to register RWA mound occurrence, in order to evaluate distribution and habitat requirements for RWA.

In our study, we make use of the The Swedish National Forest Inventory (NFI) which celebrated its 100th anniversary in 2023. For the last 20 years, the NFI has also been registering RWA mound occurrences. During the 2021-2023 seasons, we have added sampling of RWA specimens to the Swedish NFI measurements. From the collected specimens, the RWA species are identified, and the species identity for the registered mounds can then be mapped. From this data, we can establish a correlation between the distribution of RWA mounds and long-term environmental data collected from the same sites. This correlation enables us to predict the forest variables that play a significant role in shaping the habitat for the different RWA species. By analyzing both present-day environmental data and historical records, we can identify forest management practices and stand development types that positively impact the *Formica rufa* group ants. These connections between management practices and RWA population dynamics also allow us to forecast future changes in RWA populations by modeling the future development of Swedish forests. Furthermore, we can compare our variables with those from studies conducted in other European countries, thereby highlighting similarities and differences in RWA habitat requirements across regions. Ultimately, these findings can be used to establish new guidelines for forestry and logging practices that promote the conservation of wood ants, and thereby many other species associated with RWA mounds.

T5.14 Gender Equality in Forestry: Past, Present and Future

A gender perspective on the organizational culture in Swedish forestry education

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: The Swedish forestry education has traditionally been dominated by men. Women were excluded with entry requirements until the 70-ties and it is only during the last decades that the percentage of female students has reached approximately 30%. This male dominance still has its effect on the content of the education program as well as its way of execution. During a period of 9 years, 277 students were asked to describe what the education program promoted as proper values for a Swedish forestry professional as part of their final exam on an organizational course. The absolute majority mentioned the dominance of the clearcut forest management model in the content of the program while other models were hardly covered. Female students were especially critical to the dominance of production forestry compared to conservation forestry or other eco-system services than timber production. To be a member of the corps of forestry students, demands are being made on attitudes towards political questions such as the number of wolfs allowed in Sweden or the consumption of meat. Although the university has introduced compulsory codes of conduct among the students as well as gender awareness courses among teachers during the years of study, no change in the descriptions of the students can be found. Discussions with teachers show that they find this subject difficult to incorporate in their teaching. The majority of students have a meritocratic view on how gender should be regarded in the recruiting process of young professionals and most seem to expect that gender issues will seek to matter as more women enter the sector

Data Justice and Forest Governance

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Data sets about forests, their use and dynamics are becoming larger, with greater spatial precision in their detail as well as greater temporal frequency in their availability and updating. Digitised forest governance depends upon the effective use of large data sets. But large data sets, generated through machine learning, algorithms and intensive use of diverse remotely sensed data also bring challenges of data justice. These data are, of necessity, simplifications. But sometimes bias can be built into the omissions systematically. Further, different actors with interests in forest governance vary in their capacity to access, comprehend and act upon large datasets, potentially reinforcing social injustices. The challenge of data justice approaches is to identify how these biases and access inequalities can adversely affect diverse forest residents, users, managers and visitors. In this paper we present initial findings into the risks that data justice approaches highlight, with reference to concrete examples, what dangers they pose to whom, and how they might be mitigated.

Digital Economy Enabling Natural Forest Protection Project in China

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Digital technologies such as 5G, Internet and big data provides a new impetus for natural forest protection. Since the implementation of the Natural Forest Protection Project in 1998, it has played a vital role in the protection and restoration of natural forest resources, the improvement of forest quality and the construction of ecological civilization. The natural forest ecosystem is complex and there is a mutual feedback effect between natural change and project implementation. The implementation of natural forest resource protection project in China lacks an effective evaluation method to distinguish natural change and project implementation effect. Digital technology enables the implementation effect evaluation and management decision-making improvement of natural forest protection projects through natural forest resource change tracking, resource supervision perception and digital ecological restoration, and provides better naturalization implementation paths and schemes for natural forest resource protection and restoration and sustainable management.

First indigenous women volunteer wildland fire brigade in Brazil: From spectators to effective agents of integrated fire management

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Greater efforts to include both indigenous communities and women in integrated fire management can bring insights to the use of fire in wildland fire management. However, women are commonly discriminated against in the analogous hypermasculine culture documented within wildfire management. We sought to present the case of the Xerente indigenous women working as volunteer firefighters in a savanna ecosystem transitioning to the Amazon rainforest. 2021, twenty-nine women created the first women-only indigenous volunteer wildland fire brigade prompting a landmark for all indigenous women in Brazil. Based on a singular case study design, we collected data from in-depth interviews, document analysis, and participant observation. We found that fire management training and new technical skills acquired led the Xerente women to go beyond fire suppression within the Xerente Indigenous Land in Brazil. The Xerente women became effective agents in climate action strategies, particularly those related to environmental education connecting efforts of Prevfogo/Ibama with the understanding of the villages about integrated fire management. Also, these women were crucial to implement restoration activities and strengthen food security as they collected seeds and produced local plant seedling species. Implications of this case include pioneer initiative in the Brazilian context in shifting gender roles in a male-dominant strategy to mitigate and suppress wildfire; working closely with male allies, the Xerente women also secured fire management tools and equipment to perform their tasks; and the Xerente women can serve as role models for other indigenous women claiming space for their voices and recognized actions on climate change mitigation and adaptation.

Gender and Bioenergy; Factors Influencing Adoption of production and Conservation Technologies in lower Eastern Kenya

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: ABSTRACT:

This paper examines the influence of gender aspects in adoption and continued use of biomass energy production and utilization technologies in Eastern Kenya. The region suffers deforestation, environmental degradation and threatened species as result of overexploitation of tree resources for woodfuel production. The government of Kenya and development partners has developed and promoted energy conservation technologies in the region for increased access to sustainable energy resources in rural areas geared towards achievement of sustainable development goals (SDGs) relating to increased access to clean and affordable energy, the eradication of poverty, environmental sustainability, climate action as well as gender equality and the empowerment of women. Despite these efforts, adoption and continued use of improved bioenergy technologies has been low. The objective of the study was to determine gender aspects influencing adoption of sustainable bioenergy production energy saving technologies at household and community levels. The study was carried out in selected sub-counties of Kitui County using a survey design. Structured questionnaire and thematic guidelines for group discussions were used to collect data from 192 respondents and community groups. SPSS and Excel were used for data analysis. Results revealed that, at zero point zero five percent level of significance, adoption of improved technologies were positively correlated to income and awareness levels of the consumers. Inadequate awareness on benefits of improved and efficient bioenergy technologies among men, biased land and tree resources ownership, cultural roles and responsibilities, lack of inclusive decision making in most households and over dependance on men and subsistence farming for financial support by women were indicated as key factors influencing adoption of improved technologies. The study concludes that though women are culturally responsible for food and cooking energy security at household level, high poverty among women and lack of awareness on the socio-economic benefits among men affects adoption and continued use of improved abd efficient bioenergy technologies. The study recommends financial empowerment of women, inclusive decision making and mainstreaming gender at all levels of project implementation for increased awareness and adoption of bioenergy conservation technologies for environmental conservation and improved livelihoods.

KEY WORDS: Gender, bioenergy, improved technologies, adoption

Gender and Indigenous Equity in the Forest Stewardship Council (FSC)

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Diversity and gender equality are important focal points in FSC's work, both related to the certification scheme and within the FSC membership and the secretariat's staff structure. The FSC Global Strategy 2022-2026 shows a holistic approach in demanding support for increasing inclusiveness in all of its three strategies.

At the international level, FSC established the Permanent Indigenous Peoples Committee (PIPC) as an advisory committee to the FSC Board of Directors on Indigenous Peoples' involvement in FSC. In parallel, the FSC Secretariat works with the independent FSC Indigenous Foundation to create innovative solutions to support Indigenous communities.

FSC International also established a Diversity and Gender Task Force (DGTF) with a Board representative and has a Senior Manager, Gender and Diversity guiding FSC's diversity and inclusion efforts. The DGTF and the Senior Manager have sought to contribute to the equal distribution of power and influence between economic, social, and environmental interests, and also between women and men, regardless of their age, gender, race, religion, sexual orientation, or ethnic background.

We will give examples about the ongoing activities of the PIPC and DGTF, and we will present an analysis of publicly accessible forest management reports, showing how certified forest operations have taken action towards more inclusiveness in order to conform with FSC requirements and to maintain their certificates. In addition, we will explain how and when gender and diversity specialists and researchers can engage effectively in FSC processes to contribute certification requirements leading to more gender and Indigenous equity in forest management, while responsibly delivering forest products and services.

How to achieve gender equality and diversity in forest-related sectors? Bridging the education–practice gap with a Massive Open Online Course (MOOC)

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Gender equality and diversity are crucial elements of sustainability transitions as expressed within the United Nations Sustainable Development Goal 5: Gender equality. Despite their importance, gender equality and diversity concepts and training are often missing in forestry curricula. Gender insensitivity and a limited set of fully trained educators limit progress in fully implementing these concepts throughout forestry curricula. Consequently, forestry professionals often have limited capacities to assess, articulate, and address gender and other social inequalities embedded in forestry and forest-related domains (e.g. bio-economy, agriculture). This serious gap

compromises the relevance of forest science education and forestry practices across the globe, as voiced through the International Forestry Students Association's (IFSA) Open Letter in 2022. The IUFRO Task Force (TF) on Gender Equality in Forestry strives to reduce this educational gap by developing and offering the first Massive Open Online Course (MOOC) on Gender Equality and Diversity in forest-related sectors under the sponsorship of SLU Global and the University of Padova. Online education represents an opportunity to make the best competencies within the IUFRO TF available worldwide to forestry students, professionals and interested parties alike. Thanks to the module-based structure, course materials are easily integrated into universities' own curricula. The focus on cases of best practices and practical tools for advancing equality, diversity, and inclusion make the course useful also for professionals in vocational training. We present the results from the first offering of the MOOC in spring 2024 and address lessons learnt for future offerings of the course.

Learn How to Gain Traction on Gender Diversity and Inclusion in the Forest Sector

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Starting in 2018, the Free to Grow in Forestry initiative focused on creating a sector-wide approach to addressing the gender diversity gap in Canada's forest sector. The goal was to create a national action plan aimed at increasing the number of women in senior executive roles and in technical positions.

This public-private funded partnership brought together representatives from the public, private, not-for-profit, academia and Indigenous communities to unite their efforts toward this goal and to create a new shared vision for the sector – one where Canada has a diverse and inclusive workforce that provides the foundation for a thriving forest sector and healthy communities. The national action plan focused on three pillars of work:

- Gathering data on gender diversity in Canada's forest sector for the first time
- Identifying best practices that can improve workplace culture
- Creating a narrative and communication shareables that can shift the image of the sector to be more welcoming of all people.

We achieved far more than what we set out to do with the National Action Plan and the momentum created turned this from an initiative to a global *movement*. (See Free to Grow in Forestry: www.freetogrowinforestry.ca.)

Within Canada, executives across the public, private, not-for-profit and academia circles are no longer questioning that gender diversity adds value to their bottom line. They recognize diverse thinking creates innovative solutions and have shifted gears into leading the change.

The focus now and in the future is learning about "the how":

- *How* do you create an inclusive workplace culture where diversity is recognized as a business imperative?
- *How* do you become an effective ally so that individuals who may have previously been excluded are now confident with bringing their "whole selves" to work?
- *How* do you reduce the polarized thinking on diversity and inclusion and other obstacles, so you can get on with innovating, creating better business outcomes, and a thriving workplace environment?

Come join me to get the answers to these questions and more.

Promoting gender equity and women empowerment considering workplace and maternity barriers: the Brazilian Forest Women Network working groups

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Historically, the forest sector has been largely male-dominated. In Brazil, while women's participation in the sector has recently increased, gender equity is still not widely discussed. To address this issue, the Brazilian non-governmental organization, Rede Mulher Florestal (RMF; Forest Women Network), was founded. RMF promotes respect for diversity and equal opportunities for women in forestry through four thematic working groups (WGs), with the following strategic objectives: (i) promoting education, training, and extension actions led by the Education WG, (ii) creating an environment for discussion and implementing actions aimed at equality and women's empowerment led by the Equality and Empowerment WG, (iii) identifying actions aimed at supporting maternity and diagnosing the challenges and incentives to motherhood for women in the labor market led by the WG Maternity and Women in the Workplace, and (iv) identifying barriers to the presence of women in decision-making and pointing out strategies to increase the presence of women in these spaces, led by the WG Women in Decision Making. The WGs have been promoting gender equity in the Brazilian forest sector by holding thematic workshops with members and non-members, conducting semi-structured questionnaires for women in decision-making and mothers working in the forest sector throughout Brazil, and implementing a mentoring program for female members. Through these actions, RMF has been able to address issues related to gender equity within organizations in the forestry sector. The workshops led by the Education WG have focused on mapping the challenges, strategies, and verifiers for gender equity in the sector. Additionally, RMF has identified barriers to gender equity and developed good practices to promote diversity in the forestry sector. Overall, the Rede Mulher Florestal has made significant contributions to promoting a forestry sector that values diversity and gender equity. In its nearly five years of existence, the organization has helped to generate unprecedented data on gender and contributed to a wider discussion on the importance of gender equality in the forest sector.

Rooted Inequalities in Forest Education: Insights from a students' perspective

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Gender inequalities, harassment and sexism still persist in forest education, and often, specific masculine or feminine qualities are attributed to certain roles, tasks, positions or professions. Even though gender in forestry is increasingly addressed by research and organisations, the role of gender-aware forest education is not yet seen to its full extent. Outdated understandings of gender roles displayed by cis-heteropatriarchy prevail in education and research and result in a non-integration of other genders. More FINTA* within the forestry sector and an intersectional perspective on discrimination are essential for the future development of the sector and society at large.

The International Forestry Students' Association - IFSA - is the biggest international network of students of forestry and related fields. The organisation is managed by students and follows its mission to enrich its members' education. Within education, gender continues to play a decisive role in forestry and IFSA actively highlights the importance of the topic and demands key stakeholders to take proactive steps towards a more gender-aware learning environment.

In 2021, IFSA published an open letter emphasising the role of education for a more gender equal forestry sector. Its publication triggered conversations both outside of IFSA and amongst its members. Appreciating the importance of the topic and leading to sharing experience, these conversations opened up spaces which are partly not available in the universities themselves. This presentation will contribute outcomes, insights and impressions from focus group discussions among IFSA students to the session. They suggest that while the unique experiences vary, there is a common theme across different countries and regions that not all genders have the same opportunities in education and personal development. Overall, students identified a lack of gender equality and diversity in the forest curricula.

With this presentation, IFSA introduces a students' perspective into the academic discourse. Informal exchanges at meetings and guided discussions within the frame of the IFSA Gender Sub-Commission's work offer IFSA members an inclusive and trustworthy space for exchange about experiences they have made. Additionally, the Sub-Commission contributes to the development of a Massive Open Online Course (MOOC) on Gender Equality and Diversity in forest-related sectors.

The Evolution of Equity, Diversity, and Inclusion in Canada's Forest Sector

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Most major forest sector organisations in Canada have made public commitments to promoting equity, diversity, and inclusion (EDI), specifying women, Indigenous peoples, new Canadians, youth, and other groups, yet Canada's forestry sector continues to lag behind other employment sectors in recruiting and retaining a diverse and inclusive workforce. In this paper, we present data from forest sector policy documents, the Canada Census, and interviews with present-day workers in the sector to illustrate how EDI has been framed over time, persistent challenges faced by equity-deserving groups, and constructive advice for making forestry equitable and inclusive.

We make three key observations. Firstly, women's employment outside the home and pay equity issues were initially framed as human rights issues. The early emphasis on women has transitioned to a broader framing on equity and inclusion or belonging, while contemporary arguments for change emphasize the contributions and benefits of EDI for the private sector. Secondly, early conceptions of inclusion focused on women – typically white and middle-class – with little interest for other equity-deserving groups. Academic research and government data reflected this focus, inadvertently overlooking employment trends and the needs of groups such Indigenous Peoples, People of Colour, and LGBTQ2+ people. The absence of disaggregated data hindered an understanding of these issues and hampered progress. Thirdly, employers, educators, and other organisations are now becoming increasingly active in promoting awareness and progress in EDI. In forestry, however, current employees from equity-deserving groups report many of the same barriers revealed by researchers in the 1990s, Forestry education also lags in its representations of forestry work and its advancement of equity issues. Canadian experience illustrates that advancing EDI in the forest sector remains an on-going challenge, posing questions about how best to accelerate the transition towards a diverse and inclusive workforce.

The Potential of Artificial Intelligence and Enabling Technologies for the Management of the Brazilian Amazon Rainforest: A Decade of Lessons Learned

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Our research investigates the relevance of Artificial Intelligence and its Enabling Technologies (AIET) in the conservation and management of the Brazilian Amazon Rainforest (BAR). Historically, technology has accelerated business and economic transformations, fundamentally reshaping society. The impacts of technology can vary across stakeholders and evolve, either empowering or disempowering different groups. AIET holds transformative potential for forest management and conservation.

Our goal is to characterize the transformative potential of AIET, identify associated risks, and determine who may be affected to minimize those risks. AIET can enhance agility, interoperability, and decision-making support within and across sectors such as carbon markets, supply chains, and the implementation of infrastructure and command and control actions. It can also contribute to more efficient biodiversity conservation practices. Understanding the distributive impacts of AIET in the BAR is crucial due to the significant disparities in access to information, technology, and political and economic power among actors and stakeholders.

This research aims to bridge the gap between technological advances and their adoption in the BAR. We examine AIET applications aligned with the Action Plan for Deforestation Prevention and Control in the Legal Amazon (PPCDAm) and REDD+ initiatives. Specifically, we focus on characterizing AIET, including technologies and techniques like Random Forest, satellite and bioacoustic sensors, cloud computing, internet of things, and big data, which have assisted REDD+ initiatives in halting deforestation and catalyzing sustainable forest transitions in the BAR. Additionally, we develop a comprehensive mapping of stakeholders involved, technological synergies, and main actors applying AIET in the BAR, using the International Database on REDD+ projects and programs (ID-RECCO) as a starting point.

By reviewing the literature on forest-related AIET applications in global south rainforests and conducting interviews with i) AIET Users and Implementers in Forest Management, ii) Forest Users and Stakeholders, iii) and Forest Administrators and Policy Experts, we explore the challenges, risks, outcomes, and opportunities of applying AIET to create, implement, and improve economic instruments in the BAR region, in alignment with the PPCDAm's 4th axis and its lines of action.

WoFo - Women in Forestry International

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: We are aware that forests are essential to sustain life on Earth, and it's time to say that women are crucial for the sustainability of forests.

To address the climate crisis and shift to real sustainable development, we must engage all human resources, knowledge and perspectives available, involving all people.

These ideas together with intensification of women's networking in forestry led to establishing Women in Forestry International (WOFO), an umbrella organization established to promote the interests of women in the forest and wood sector internationally.

WOFO is a result of a collaboration between women from several countries and was registered by founders from six countries: Austria, Germany, Iceland, Poland, Slovenia, Ukraine

The mission of WOFO is to be a leading international organization that brings together women in forestry and to make them stronger, more visible, and heard.

The main goal of Women in Forestry International is to connect existing networks for women in forestry, to support the creation of new networks and initiatives, and to make them more influential and integrated at the national and international levels.

Each existing women's organization or network in the forest area is welcome as well as individuals or other organizations which support gender equality and share WOFO's interest and values. Thus different types of membership are foreseen.

Joining WOFO International allows its member to:

- build relationships and exchange ideas with other women in the forestry sector
- share skills, information, and expertise
- empower and support women in the forest-based sector
- collaborate and open linkages between networks and initiatives of women in forestry
- make women in forestry visible and audible – to speak and be heard in forestry and the forest-based sector
- improve the performance of your organization or network and become a partner in international processes and discussion

Women and timber management: From assigned cook to strategic decision-maker of community land use

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: Numerous studies on community forest and land use show clear benefits of including women in natural resource management. Women's empowerment in collaborative timber management, however, is understudied and rarely achieved on the ground. We focused on women's participation in seven community-based timber projects within three Brazilian Amazonian extractive reserves, asking: 1. What resources (actual allocations, future claims and expectations) have shaped women's roles in collaborative timber management? 2. How do community women perceive their role in collaborative timber management? 3. Have community members and partner organizations perceived gender equity in collaborative timber management? Over 15 months, we carried out in-depth interviews with 52 respondents, conducted participant observation, and led focus group discussions that included community concept drawing activities. We uncovered that while these collaborative timber management projects still centered on male workers, in two of the three extractive reserves, empowerment processes ultimately opened spaces for greater engagement by women overall in strategic administrative and logging coordinator positions. We added to the scholarly conceptualizations of women's empowerment, demonstrating that 'power through' _can lead to more permanent empowerment levels. Although normative values associated with gender (i.e. men stronger than women) were subtly embedded in the actual allocation of both human and social resources (capacity building and networks, respectively) for collaborative timber management, integration of a few women in male-centered training efforts provided venues for transformative agency towards women's placement in strategic timber management positions. Supporting such transformative processes to empower women in community land use and forestry requires awareness of gender-based discriminatory attitudes and practices on the part of men and women, as well as innovations by policymakers, community members, government, and non-governmental organizations.

Women in forest conservation and the bioeconomy market

T5.14 Gender Equality in Forestry: Past, Present and Future

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Abstract: The socio-bioeconomy model through Community-Based Forest Management has already been widely discussed and implemented in the Brazilian Amazon. The connection between sustainable forest resources uses and both the cosmetic and pharmaceutical market is an important economic and social development strategy for local populations that, through their traditional management practices begin to generate a diversified economy linked to the forest resources use seasonal calendar.

Forest-based women are engaged within this strategy by the multiple use of natural resources through seeds and fruits collection to feed their families and provide medicinal plants and vegetable oils that corroborate with traditional medicine in these territories. However, women’s role in the use and management of natural resources is often invisible in their territories, weakening their participation in the family economy and in the governance of their territories. With the development of biodiversity value chains and the opening of the global markets for forestry products, women begin to play a significant role in sustainable forest management, nature conservation, income generation and social reproduction of families.

The study addresses five community territories in the Amazon and four biodiversity value chains, namely copaiba, patua, passion fruit and forest restoration. In this summary, we will present the experiences accumulated by the institution in the process of strengthening value chains linked to the productive inclusion of women in different processes of community enterprise, from forest management to socio-productive management and commercialization of production.

Our study highlights the role of women in socio-biodiversity value chains linked to high value-added markets, revealing the relevant of women’s role in forest restoration chains and in the sustainable management of forests products, strengthening low carbon strategies and high social impact economies that contribute to gender equity in traditional Amazonian territories.

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

Disentangling Norway Spruce Responses to Bark Beetle Infestation and Drought Stress by Continuous Eco-Physiological Monitoring and Field Spectroscopy

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: In recent decades, there has been a significant rise in the occurrence and severity of insect-caused forest disturbances, such as those caused by spruce bark beetles. These disturbances, driven by climate change, have led to widespread tree mortality on a global scale. Understanding and effectively managing conifer defense mechanisms is crucial in order to prevent bark beetle outbreaks. However, accurately differentiating between canopy responses caused by bark beetle infestation and other stressors, like drought, is essential for precision pest management. This study focuses on a manipulation experiment conducted in the Latemar Forest, located in the Eastern Italian Alps. The objective of our experiment was to unravel the initial indicators of drought stress and bark beetle attacks at the individual tree level. To achieve this, we employed continuous monitoring techniques, combining physiological measurements and spectroscopy, to observe the response of Norway spruce trees to drought and infestation over a manipulation experiment. The manipulation involved two treatments: drought stress induction and bark beetle attraction. Our monitoring approach involved the use of an Internet of Things (IoT) device capable of recording various environmental parameters, including radial growth, sap flow, air temperature, and relative humidity. In addition, we regularly monitored soil moisture content, needle chemistry, and needle spectral signatures. By analyzing this comprehensive dataset, we were able to track changes in the trees' response mechanisms throughout the growing season and distinguish between the effects of bark beetle infestations and drought stress. In fact, the contrasting temporal behavior across the two treatment groups of sap flow and needle spectral properties provided valuable information for distinguishing among the two treatments. Our results shed light on the eco-physiological processes that impact Norway spruce trees under bark beetle and drought stress. Given the projected increase in the frequency of abiotic and biotic disturbances due to climate change, our findings contributed to a deeper understanding of the complex interactions between trees and their environment. Ultimately, this knowledge will support early damage recognition and inform future management strategies aimed at mitigating the impacts of climate change on forest ecosystems.

Does stand structural diversity increase disturbance resistance?

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: Diverse forests are often considered to be more resistant (defined here as the ability of ecological systems to persist through a disturbance event) than structurally homogeneous stands. However, the relationship between diversity and forest resistance has often been examined only for biotic disturbances and in terms of tree species diversity, while other disturbance agents and the effect of diversity in structural attributes on resistance have received much less attention.

We used data from plots that were disturbed by storm, fire, snow or biotic disturbance from the French, Spanish, and Finnish National Forest Inventories to quantify the plot-level relationship between stand structural diversity and disturbance-induced tree mortality. We tested whether diversity in tree diameter, basal area and species composition, as well as trait-based disturbance sensitivity and climate, were related to disturbance resistance at the plot level.

In this communication, we present empirically derived examples of the relationship between structural diversity and disturbance resistance. We also discuss how this information can be interpreted to increase forest resistance in the face of global change and changing disturbance regimes.

Drought-impacts on Europe's forests: Was 2018-2022 unprecedented?

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: Forests globally are under increasing pressure from climate and land use change. Of particular concern are climate extremes, such as droughts. Recent drought events in Europe (2018-2022) were likely unprecedented and amplified by simultaneously extreme dry and hot conditions. Ample evidence suggests that these recent drought events have had substantial impacts on Europe's forests. A systematic assessment of the recent drought impacts on Europe's forests is, however, missing. We thus do not know whether the observed impacts of recent drought events on forests in Europe were, in fact, unprecedented or within the past range of variability. We here compile evidence from a pan-European forest monitoring system based on Earth Observation to (i) show that drought is an important driver of tree mortality dynamics, (ii) quantify the recent wave of tree mortality caused by the 2018-2022 drought/heatwave events in light of the recent range of variability, and (iii) assess how increasing drought-related mortality could impact the structure of Europe's forests in the near future.

Emerging biotic risks to European forests and the state of national disturbance monitoring systems

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: The forest disturbance rate has dramatically increased across Europe, which has been corroborated by remote sensing and terrestrial forest inventories. Insects and pathogens have considerably contributed to this increase, accounting for ca 50% of total forest damage after 2010. Except for the prominent tree-killing insect in Europe *Ips typographus*, reports about "unexpected" mortality events caused by organisms previously considered insignificant have become increasingly frequent. Compiling and evaluating such observations is essential for identifying emerging biotic risks in Europe and adapting current monitoring and risk management systems. However, these data are scarce because no harmonized monitoring system exists in Europe, and available information is compiled from national reports with different detail, temporal and geographical coverage, and methodology.

This research aims to identify changes in forest disturbance patterns across temperate and boreal Europe at the level of insect and pathogen species, identify organisms and processes that may require attention in future monitoring and management, and evaluate the capacity of national forestry agencies to detect emerging changes in forest biotic risk. Species-specific two-decadal forest damage series from 24 European countries were evaluated. National forest monitoring systems were assessed from the view of their temporal and geographical coverage, data consistency, level of biological

detail (e.g., herbivore and host species), and other attributes.

Ips typographus was the prominent species that considerably increased its activity across Europe though deceleration due to host depletion was reported, for example, from Hungary. Increasing pine mortality from *I. acuminatus* and *Tomicus spp.* was another distinct feature recently identified across different environments. The importance of drought as a driver of biotic impacts consistently increased across Europe. Only several countries operate systems able to detect emerging risks and deviations from the historical trends at the species level. Actions improving Europe`s forestry preparedness to face increasing biotic risks need to be taken, such as harmonization of national disturbance monitoring systems, focusing on species-level data that allow understanding of emerging ecological changes, and open provision and sharing of data.

Evaluation of Sentinel-2 time-series ability to detect dieback intensity of silver fir, Norway spruce and scott pine stands on European mountains

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: Conifers have undergone a sharp increase in mortality in European temperate forests over the past decades. The monitoring of changes in tree health is a major challenge to evaluate the dynamic of dieback and the vulnerability of the different stands to climate change. To achieve this, image times series acquired with Sentinel-2 satellites are particularly suitable thanks to their frequent revisit time and fine spatial resolution. However, their capacity to identify species and the dieback stage is limited. Consequently, we aim to combine Sentinel-2 times series with field assessment in order to quantify the extent of forest decline at national scale.

We have coupled about 250 Sentinel-2 images with more than 3.500 field assessments of trees dead branches, leaf and needle loss spread over four years of monitoring (2018-2022), to evaluate the health status of *Abies alba, Picea abies* and *Pinus sylvestris* located in French mountain forest systems. For each of the studied species, we linked the evolution of different vegetation indices obtained from remote sensing to the stand health assessed in the field. We compared their ability to identify different dieback stages for pure and mixed stands and for different ecological gradients. The most suitable vegetation indices for each species was then used to quantify the dieback surfaces evolution over the whole French mountains.

This study establishes the base for a cost-efficient monitoring method to evaluate the dynamic of stress symptoms for different coniferous species, suitable for broad forest areas.

Evolution of the bark beetle crisis in Norway spruce forests: A spatial and temporal remote sensing analysis in Belgium and North-eastern France.

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: In 2022, Europe emerged from eight of the hottest years on record, leading to significant spruce mortality across Europe. The particularly dry weather conditions of 2018 triggered an outbreak of bark beetles (*Ips typographus*), causing the loss of thousands of hectares of Norway spruce (*Picea abies*) stands, including in southern Belgium and north-eastern France.

A methodology for detecting the health status of spruce was developed based on dense time series of satellite imagery (Sentinel-2). The time series of satellite images allowed the modelling of the spectral response of healthy spruce forests over the seasons: a decrease in photosynthetic activity of the forest canopy causes deviations from this normal seasonal vegetation index trajectory. These anomalies are caused by a bark beetle attack and are detected automatically. The method leads in the production of annual spruce health map of southern Belgium and north-eastern France. The resulting map are used to assess the damage caused by bark beetle and to study the relation between the dieback and environmental conditions.

Lasted six years (2017-2022), bark beetle has destroyed 12.2 % (23,674 ha) of the spruce area in southern Belgium and north-eastern France. This study area is composed of three bioclimatic areas: Plains, Ardenne and Vosges, which have not been equally affected by bark beetle attacks. The plains were the most affected, with 50% of spruce forests destroyed, followed by the Ardenne, which lost 11.3% of its spruce stands. The Vosges was the least affected region, with 5.6% of spruce stands lost.

Forecasting invasion patterns to minimize the impacts of invasive forest insects and pathogens at large scales

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: Urban and forest trees are crucial to future global wellbeing, but are at high risk of mortality from invasive insects and pathogens. To plan effective mitigation, managers must know which tree species in which communities will be at the greatest risk, as well as the likely impact of possible management intervention options. This presentation will cover recent projects relating to forest health in the face of forest insect and pathogen invasions and climate change. Firstly, I will discuss a recent optimal control framework to determine the ideal management strategy for urban tree persistence in the face of emerald ash borer *(Agrilus planipennis).* We found that the best management strategy always included a combination of site-focused (biological control) and spread-focused (quarantine) management measures, and that failing to use a mixed strategy could result in losses of upwards of one million street trees in the next 30 years. Secondly, I will discuss a game-theoretic approach used to understand the optimal interprovincial transfer of funds to control cross-border spread of a climate-assisted expanding species, the mountain pine beetle *(Dendroctonus ponderosae),* in Western Canada. I will end with more recent work on forecasting native forest tree range shifts in response to climate change, for use to plan effective protection measures via combined forecasts of the impact of invasive pests and pathogens and climate change. We expect that the northward movement of many tree species will facilitate the acquisition of effective protected areas minimizing these dual risks in less costly regions in the future. We highlight the need for ground-truthing of tree distributions to minimize uncertainty in these predictions.

Immediate and lasting effects of the 2018 hot drought on beech forests: challenges and opportunities for detection, monitoring, and assessment

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: Changes in regional and global hydrological cycles and temperature regimes have profound implications for forest health, functioning, and growth, ultimately influencing their role in carbon sequestration. In 2018, a severe hot drought affected large parts of central Europe, resulting in forest damages, particularly premature leaf senescence in deciduous tree species. This study conducted a specialized survey on selected plots of the Swiss National Forest Inventory from late summer 2018 to 2023 to investigate the immediate response of beech (*Fagus sylvatica* L.) forests to the hot drought, assess potential lasting effects in subsequent years, and evaluate the effectiveness of standard forest health monitoring protocols in detecting these effects. Our focus was on three vitality indicators: (i) severe crown transparency, (ii) severe leaf browning, and (iii) growth in terms of basal area increment.

During late summer 2018, the frequency of damaged beech trees exhibiting severe leaf browning and crown transparency was significantly higher compared to long-term baseline monitoring data. The occurrence of crown damages was primarily influenced by factors such as previous growth, species composition, tree size, and precipitation deficit. In 2018, tree growth was substantially lower compared to the long-term average, particularly for trees displaying severe crown transparency or leaf browning. However, more favorable weather conditions in 2019 resulted in a significant recovery of crown conditions and growth. The ongoing monitoring of these trees in subsequent years offers valuable insights into their medium-term health development and aids in identifying delayed reactions of tree vitality, including the potential occurrence of mortality.

Our findings indicate that severe crown transparency and leaf browning observed in late summer 2018 reflected a rapid drought-induced canopy deterioration in beech forests, leading to an immediate reduction in growth. Notably, these immediate effects were not captured adequately by the standard long-term forest health assessment. Therefore, we discuss opportunities to adapt the design of forest damage monitoring protocols without compromising data comparability over time.

Mapping of drought and bark beetle induced spruce mortality and forest structure changes based on aerial imagery. From local to regional scale.

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: In recent years an accelerated spruce dieback has been observed in mountainous forests of Europe. Hot summer and warm snow-free winters, consistent with expected climate-change scenarios, conditioned the spread of bark beetle infestations.

To learn more about the dynamics of bark beetle infestations and forest dieback an area wide mapping and quantification of dead trees in time series is necessary. Remote sensing is the tool of choice for area-wide, large-scale detection of deadwood and forest damage. Because of their high spatial resolution (10-50 cm; 20 cm for our study area), area coverage of hundreds to thousands of square kilometers and spectral resolution that includes an infrared (I) band in addition to red, green and blue (RGB), aerial imagery offers an adequate data basis for tree-level deadwood detection at local and regional scales.

Based on orthophotos and digital surface models (DSMs) from image matching of stereo aerial imagery, a method for single-tree deadwood mapping was developed for the spruce dominated stands in Baden-Württemberg, Germany. Process automation enabled upscaling of deadwood mapping from the local (single reserves, visual interpretation) to the regional scale (natural and administrative regions) and data analysis across all forest management types.

We present an example of deadwood mapping results at the regional scale in Black Forest from two time series (2018-2020 and 2021) along with remote sensing-based maps of associated forest structures such as forest cover, tree cover, forest height and forest height heterogeneity, forest height types and canopy gaps. These data can be used to conduct analyses of tree mortality, forest dynamics, and provide insights into the processes of insects‘ infestation and spruce dieback in the wake of climate-change induced droughts and heat waves at local and regional scales. It can also serve as a reference for satellite-based deadwood or forest dieback maps with coarser resolution at larger spatial scales.

Panel member

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

Barbara Bentz[1]
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Abstract: I am a panel member for this session.

Panellist for discussion session

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

Helen Nahrung[1]
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Abstract: invited as panellist by session organisers:
We want you as a panelist! Panel discussions stretch 30 min and **reach out to a large audience**. They address topics of general interest with substantial outreach and aim to stimulate debates that last way beyond the actual event.

Post-disturbance landscape structure and regeneration composition in Central Europe imply high future risks

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

Tomáš Hlásny[1]
Roman Modlinger[1], **Prosper Washaya**[1], Martin Leiner[1], Daniel Tyšer[1], Martin Slavík[1], Lukáš Bílek[1], Peter Surový[1]
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Abstract: The ongoing bark beetle outbreak in Central Europe, the Czech Republic, is currently Europe's most severe natural disturbance. Nearly 100 mil of m^3 of Norway spruce trees were killed during the last five years, representing ca one-quarter of total biotic damage in Europe. The practiced management included heavy salvage logging that severely affected the environment, including amount and structure of disturbance legacies. Here we focused on the disturbance core area that is nearly 10 000 km^2 large, and lost more than 40 % of the forest. We conducted a multi-scale assessment of the post-disturbance landscape structure, focusing on the pattern of disturbance legacies and regeneration conditions, which can decisively determine the structure and composition of the emerging forest generation.

First, the entire core area was tessellated into a hexagonal grid with a hexagon diameter of 7 km; this value was determined through the incremental spatial autocorrelation analysis. The proportion of disturbed forest and several landscape metrics (mean patch size, patch size variability) were identified for each hexagon. The disturbance mapping was based on a classification of optical and Synthetic Aperture Radar data from the Sentinel mission. Second, a pair of 8 ha study sites was selected in a representative subset of hexagons. A post-disturbance landscape mosaic was mapped on each site based on an optical image taken from a drone. Main disturbance legacy categories were identified, such as the surviving advanced regeneration and mature trees, patches of standing and downed dead trees, etc. Third, a ground sampling was conducted in 2×2 m plots located in a center of the previous sites, evaluating a species composition of the regeneration layer and its vertical differentiation.

The results imply considerable homogenization of the forest landscape. Although forest regeneration locally shows an increased diversity, Norway spruce remains abundant. This likely accounts for regeneration browsing by game, which favors non-spruce species, spruce dominance in a seed bank, and spruce planting despite its poor prospects. We conclude that the risk of developing a low-resilience forest generation dominated by vulnerable spruce is high; avoiding this development requires fast and large-scale corrective actions.

Remote sensing in alien invasive pest monitoring in forests in Croatia

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: Monitoring of pests, native or alien invasive, is a one of key activities in prevention of damages in forests. Conventional monitoring methods (pheromone traps, visual transects, glue rings etc.) are time consuming and require significant financial inputs. Development of remote sensing sensors, GPS technology and geographic information systems (GIS) support novel approach towards detecting pests which has the potential of accurately measuring pest damage and populations on a whole area basis. Accurate and efficient monitoring of insect populations is a key point to improve pest control and mitigate damage. Technical limitations of remote scouting, especially resolution of satellite and aerial images, have until recently precluded wide scale adoption. Recent technological advancements have increased resolution of visible and NIR sensors while also decreasing size and cost providing more affordable ways to assess forest health. Therefore, usage of small aerial vehicles or drones equipped with multispectral sensors could provide a better insight into forest health and damage caused by pests. Recent technology advancements have the possibility of live multispectral images in normalized difference vegetation index (NDVI), where differences in chlorophyll concentration are seen, which provides a valuable information for scientists directly in the field. With a relatively low-cost platform we have insight on the area with better resolution than with those from satellite. Surveys of invasive alien and quarantine pests in forests are being conducted in Croatia. European food safety authority (EFSA) is recommending usage of unmanned aerial vehicles (UAVs) as a versatile remote sensing-based toolkit for monitoring forest health and occurrence of forest pests. Using DJI Mavic 2 Pro UAV we have inspected forest area in Croatia for detection of disturbances caused either by abiotic or biotic agents. Disturbances are easily detected by smaller vegetation index value from those which are without any disturbance.

Using spectral pathways to study epidemiological spread of insect and disease disturbances in forests

T5.15 Global forests in a hotter and drier world: Assessing forest damage and tree mortality from climate change-accelerated insect outbreaks and infectious diseases

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Abstract: Management of problematic insect and disease disturbances requires the early detection of outbreaks, rapid mapping of spread, attribution of outbreaks to an agent, and predictive modelling.

The increased density and availability of Earth Observation data facilitates the early detection of forest disturbances. However, remotely detecting biotic disturbances before they are visible to the naked eye typically requires observations with a level of spectral and spatial detail that is only obtainable using airborne platforms, but not from spaceborne sensors.

Distinguishing whether stress symptoms are caused by biotic or associated abiotic agents, such as drought, can be challenging. Using remotely sensed spectral pathways and radiative transfer models to infer changes in specific physiological canopy attributes has proven useful in this regard. Furthermore, combining remote-sensing based detections of physiological anomalies with epidemiological spread models has proven helpful to estimate whether plant stress is associated with a pest outbreak or not. Nonetheless, identifying the specific biotic agent that is causing stress, typically requires further contextual information and on-the-ground analysis. Deep and machine learning models that can analyse spectral, temporal and spatial pathways of forest disturbances simultaneously and alongside ancillary geospatial data, e.g., on meteorology, provide novel opportunities for significant progress in attributing detected disturbances to causal factors.

Some obstacles to progress in using remote sensing to understand epidemiological spread of insect and disease disturbances, particularly at continental scale, are relatively low-tech. They include the availability of detailed maps showing host and reservoir plant distributions and the collection of high-quality reference data on outbreaks and how they progress through time and space. Such reference data are particularly needed to make optimal use of deep learning models, as these tend to require large volumes of training data.

More complex challenges include the need to better understand plant-physiological and plant-defense responses to particular pathogens, that are at the basis of any spectral signal associated with infection. Finally, there are challenges in better representing the accuracy of remote-sensing-based predictions, because they may be highly scale-dependent, and because they should be propagated through epidemiological models that use these predictions.

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

A low-cost and portable near infrared spectrometer connected to a smartphone for identifying Dalbergia, Diospyros and substitute species in Madagascar

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Rosewood and palisander, known as Dalbergia wood, along with ebony from the Diospyros tree, are highly sought-after precious woods from Madagascar. These woods are globally traded and valued, but their overexploitation has led to their scarcity. Therefore, it is crucial for forestry services to possess the capability to identify these wood species as they leave the forest, during transportation, at the point of sale, and prior to export, ensuring only authorized species are exploited. Previous studies have demonstrated the potential of using near infrared (NIR) spectroscopy in laboratories to identify precious wood species through wood samples, yielding promising results. However, utilizing portable NIR devices directly in the field requires addressing perturbations caused by external factors that can affect their performance in wood species identification, such as wood moisture and sample shape. To address these concerns, wood cores were collected from seven Dalbergia species, nine Diospyros species, and six other potential substitute species from Menabe and Masoala forests. Initially, the wood samples were stabilized at different humidity levels to account for the fluctuations in humidity encountered in the field. Subsequently, corrections, including orthogonalization of external parameters (EPO), were applied to the training models. Furthermore, the study investigated the calibration transfer between different NIR instruments to correct for variabilities resulting from instrument changes. Additionally, calibration transfer between different sample types, specifically cores and wood blocks, was considered to ensure field applicability regardless of the wood's shape. Finally, an easy-to-use smartphone application was developed using Userland, Linux, and R software. This application enables easy data acquisition, transfer, and analysis by utilizing a miniature NIR spectrometer connected to the smartphone via Bluetooth. Depending on the species being identified, the discrimination accuracy varies from 70% to 100%. This innovation enables cost-effective and user-friendly application of NIR technology in the field for wood species identification, particularly beneficial in financially limited developing countries.

Advancing Ancient Egyptian woods identification

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Despite the abundance of preserved wooden objects and archaeobotanical remains from pharaonic times and their unequalled historical and cultural value, their wood identification has only rarely been undertaken today. Moreover, the restriction on removing samples from archaeological excavations in Egypt hinders the possibility of studying them locally due to facilities' long waiting lists and difficult access. Therefore, we designed a combined macroscopic and microscopic wood identification key for Egyptian objects, including only timbers used during the third millennium BCE, one of the peak epochs of wooden object production in Ancient Egypt. Our wood identification key suggests a step-by-step process that at first only applies easy-to-observe macroscopic characters that require no sampling. Then, the identification key aims at the most accurate level of identification reachable, including targeted microscopic features and underlying the limits of the process and suggesting possible solutions. The new identification key works as a base for an initial screening and wood species identification of Egyptian objects and will soon be tested on museum collections. This guided wood identification procedure allows the revealing of new insights into the use of ancient Egyptian timbers, which enables further innovative research in both wood anatomy and Egyptology.

An automated timber identification system for Guibourtia ehie and two Melicia species

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: To strengthen the Ghanaian capacity in timber identification, we developed a wood identification image-based artificial intelligence (AI) model for Black Hyedua (*Guibourtia ehie* (A. Chev.) J. Leonard), Iroko (*Melicia excelsa* (Welw.) C. C. Berg; *Milicia regia* (A. Chev.) C. C. Berg.) using the Xylorix platform. Fifteen to twenty authenticated heartwood samples of each species of Odum and Black Hyedua were collected across Ghana. For each sample, about ten transverse cuts were made using heavy duty utility knives. Ten macroscopic images were captured per cut at different orientations using the Xylorix Harvester mobile application and verified. Corresponding AI models were built and evaluated using a new batch of images collected from specimens which are not used for model training. Two types of datasets, i.e. positive and negative datasets were collected for each of the models Odum and Black Hyedua. Positive dataset represents images of wood species that should be identified correctly as the target wood species by the trained model, while negative dataset represents images of any other wood species. In total, 889 images of 431 positives and 458 negatives were tested with the Odum model, while 1,088 images of 431 positives and 657 negatives were tested with the Black Hyedua model. The test results for Odum indicated an average precision value of 0.96 and an AUC-ROC value of 0.96. The test results for Black Hyedua model also exhibited similar patterns with 0.99 and 0.98 AUC-ROC and average precision, respectively. The performance plots for both models also showed higher prediction values for positives and lower prediction values for negatives with minimal overlaps. Field testing with the Odum and Black Hyedua models have shown satisfactory results. These AI models, once integrated into Xylorix platform, will allow any enforcement officer to turn their smartphone into a wood anatomist, and hence have the ability to verify or identify relevant wood species in the field in a matter of a few seconds. In this way transparency in timber trade will be greatly enhanced and contribute to curbing timber trafficking in Ghana.

Anatomical characteristics of Balfourodendron riedelianum (Engl.) Engl.

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Wood anatomy is the branch of biology that studies the xylem in order to know it and give it a correct use in industrial processes (Giménez et al. 2005). Therefore, the general objective of the research is to describe the macroscopic and microscopic anatomical characters of the wood of *Balfourodendron riedelianum* (Engl.) Engl. The research was carried out in the Wood Technology Laboratory located in the Forestry Engineering Department, Faculty of Agricultural Sciences, National University of Asuncion. Samples of wood and plates available in the xylotheque of the institution, collected from different sites in the Eastern Region of Paraguay, were used. The macroscopic and microscopic characters of the three cutting planes (transverse, tangential and radial planes) of the species *Balfourodendron riedelianum* (Engl.) Engl. were observed, the macroscopic characters were observed through a stereoscope with a magnification of 32x and the microscopic characters through a microscope with three different magnifications (4x, 10x and 40x). All the characteristics were noted in the corresponding spreadsheets. The species presents a wood with uniform diffuse porosity, vessels in radial pattern, with a grouping of pores, mostly radial, multiple (2 and 3 vessels) and in smaller quantity solitary pores and grouped in 4 vessels, also presents content. It does not present axial parenchyma in bands and the fibers are septate and non-septate. There is a visibility of the rays and these are uniseriate and multiseriate, composed of two or more types of cells (heterocellular) and does not present stratification. Comparing the two types of characters (macroscopic and microscopic), it is concluded that there is a significant difference in the observations, for example, the grouping of pores, in macroscopy can not be observed more than 2 vessels, contrary case in microscopy, where up to 4 vessels are observed. This is due, in addition to the different graduations, to the different parts of the tree that were used to make the specimen and the slide respectively.

App macroHOLZdata and CITESwoodID: Computer-aided identification and description of internationally traded and CITES-protected timbers

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: The knowledge about recognition and utilization of the most important internationally traded timbers is of prime importance to forestry and wood industry as well as timber trade and even control authorities. As an important tool for this purpose, the databases **macroHOLZdata** and **CITESwoodID** developed at the Thünen Institute for Wood Research has been programmed as mobile Apps for smartphones and tablets. The databases enable the user to identify/localize trade timbers by means of macroscopic wood structural features. In addition, the digital learning tools allow access to a data pool with timber specific information on properties, utilization, and other relevant characteristics.

In detail the Apps **macroHOLZdata** and **CITESwoodID** offer:

- an interactive identification of 150 important trade timbers (macroHOLZdata) and 53 CITES-listed timbers (CITESwoodID) based on macroscopic features which can be observed with the unaided eye or with a hand lens,
- numerous high-quality illustrations of wood characters and timbers alike featuring transverse and longitudinal surfaces,
- a database with pertinent information on wood properties, processing, and utilization (macroHOLZdata)
- a textbook with definitions, explanations, procedures, etc. for most features used in the description.
- internationally available (iOS and Android) using tablet PC and smartphones

The Apps are primarily designed for all institutions, companies and individuals involved in international trade and control of wood and wood products to combat illegal logging. They are also well suited for education and advanced training of students and for timber industry in the fields of wood identification, wood properties and utilization. The application and features of the databases are presented on the basis of practical exercises.

Automated wood species identification in microscopic images of fibrous materials using machine learning / AI

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Illegal deforestation is a global problem that affects us all. The laws designed to prevent this are only as good as they can be controlled over a wide field. Meanwhile, the global production of paper and fiberboard is constantly increasing. The wood species composition of a small amount of these materials is currently analyzed at great expense by highly qualified wood anatomists. In order to improve this time-consuming process, our latest research project was initiated. The goal of this project is to simplify the application of the controls worldwide by using machine learning. To achieve this, a methodology for the systematic generation of a large image dataset of macerated wood references was developed. For the dataset, stained specimens of vouchered wood samples were prepared. Overview scans of entire slides allow the display of as many individual cells as possible in five focal planes in one image file. The first dataset contains more than 2,000 of these huge microscopic images of hardwood and softwood genera. These images form the basis for a modern image recognition software that uses deep neural networks to detect and correctly identify the contained species. The final solution will be the first approach for the fully automatic identification of the most common wood species in fibrous materials. A modular and generalizable combination of artificial intelligence solution is used to achieve this goal.

The presentation will show how microscopic images of fiber samples can be analyzed with these algorithms by using a specifically designed graphical user interface. It will close with a comparison between wood anatomists and artificial intelligence.

The project is carried out by the Thünen Institute of Wood Research in cooperation with the Fraunhofer Institute for Industrial Mathematics (ITWM) and funded by the Fachagentur Nachwachsende Rohstoffe e.V.

Digitizing a xylarium beyond shared meta-data: the importance of quantitative wood anatomy, images and chemistry

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Xylaria are big institutional collections of wood samples that serve as scientific reference material. They are a result of long-term collecting efforts of multiple expeditions in the past, often in regions that are nowadays difficult to explore for logistical, conservational, or political reasons. Xylarium specimens have been key for comparative wood anatomy and establishing databases supporting botanical identification of traded timber.

Strong tendencies in actual state-of-the-art research include the rising importance of quantitative approaches and the substantially improved means for producing, sharing, and analyzing images. At the same time there is a growing interest in combining microscopic observations of wood with chemical assessments. These trends urge for coordinated efforts of digitizing the invaluable information held in xylarium samples, apart from sharing metadata that are available for many xylaria.

Quantitative features typically show variability, contrary to most of the qualitative characteristics commonly used in wood identification. There is indeed variability within species, but also within a single tree, e.g. vessel element or tracheid dimensions vary from pith-to-bark, in the height direction and according to different organs (trunk, roots, branches). More emphasis on quantitative features implies a statistical approach that typically needs study material consisting of more specimens than a classical wood anatomical description. This is a good reason for strengthening the network efforts between xylaria.

There are also engaging perspectives for a bigger role of image-based assessments. Capturing a maximum of wood anatomical information in a collection of images involves taking pictures from the three principal angles, at different magnifications, different fields of view and using as well optical light, electron beams and X-rays. This digitizing process results in a multitude of images. Handling high resolution images in a standardized and efficient way is still challenging, but necessary to fully exploit the opportunities of deep learning.

Beyond wood anatomy, several chemical analyses are also relevant for identification and provenance determination, including measurements of metabolites, stable isotopes and elemental assessments.

Concerted actions will be key to share data that are maximally Findable, Interoperable and Reusable (FAIR principles).

In search of species level identifications for African CITES timber species: potential of combined methods and importance for provenancing

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) aims at regulating the trade of selected species. Appendix II groups species that are not necessarily threatened with extinction but in which trade is controlled to avoid utilization incompatible with their survival. High-value African timber genera *Afzelia* spp., *Khaya* spp. and *Pterocarpus* spp. entered the appendix recently, joining previously listed e.g., African *Dalbergia* spp., *Pericopsis elata* and three *Guibourtia* species.

Apart from document checks, wood sampling is needed to verify both labelling and origin of African timber genera. Several identification methods are more developed than current provenancing methods. Complementary to the ongoing development of last-mentioned methods, exact botanical identification up to the species level is an often overlooked source of information for provenancing. Currently, different species within genera remain hard to distinguish using only one method. We provide an overview of combined methods that substantially help to identify African CITES genera up to species level (e.g., wood anatomy combined with DART for *Afzelia* sp.). If certain species are associated with well-defined distribution areas, knowledge at this species level provides valuable information on provenance. Our first objective is to develop sample protocols allowing for multiple analyses and combine results to determine the potential for species level identifications (DART TOF mass spectrometry, wood anatomy, stable isotopes, genetics…).

Knowledge on the CITES species also benefits from analyses of lookalikes. The decision on listing all species of a genus as CITES is often based on the risk of (un)intentionally mislabeling true critical species as lookalikes. Our second objective is to provide a data-based definition of the term 'lookalike', by creating indices of similarities based on InsideWood species descriptions. First, a set of macroscopic features is tested on reference wood samples. Then, a combination with more subtle microscopical features is made to determine sound criteria for lookalikes of African CITES species.

Our results confirm the power of joining forces for sound identifications. Hands-on tools are being developed to assist stakeholders without scientific background (e.g., apps using AI, sample protocols) and results are translated into recommendations for future CITES-listings.

New advances in DNA-based methods for modern and archaeological woods identification in China

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Scientific and accurate wood identification is an important basis of wood science and its relevant disciplines. The rapid development of DNA-based methods for wood identification is expected to break through the limitations of the traditional wood identification method based on wood anatomy and realize the identification of wood at the species level. Both modern and archaeological woods face difficulties including high levels of DNA degradation and complex composition of inclusions that hinder DNA acquisition from wood cells, and the establishment of stable and efficient DNA identification methods for wood is still a worldwide demand and challenge. In this paper, we focus on three typical wood materials, i.e., modern wood rich in extractive, ancient architectural wood, and waterlogged archaeological wood, for investigation on establishing a stable DNA identification method at the species level using obtained DNA sequence information. This work will offer scientific guidance and technical support for the conservation of forest resources and understanding of wooden heritage.

Origin Traceability of Santalum Wood Using Stable Isotope and Mineral Elements

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: The purpose of this study is to analyze the feasibility of tracing the origin of woods based on stable isotopes and mineral elements, and to clarify the influence of heartwood and sapwood on the accuracy of wood origin identification. In this study, *Santalum* wood samples from major growing areas of China, namely Dongfang of Hainan Province, Zhanjiang and Zhaoqing of Guangdong Province, and Australia, were selected as the research objects. Five stable isotope ratios ($\delta^{13}C$, $\delta^{2}H$, $\delta^{18}O$, $\delta^{15}N$ and $\delta^{34}S$) and 38 mineral elements contents of heartwood and sapwood samples were determined by stable isotope ratio mass spectrometer (EA-IRMS) and inductively coupled plasma mass spectrometer (ICP-MS), and the origin discrimination was carried out by stoichiometric method. The results showed that there were significant differences in stable isotope ratio and mineral element content between sapwood and heartwood of *Santalum*. Therefore, the sampling radial positions of wood samples should be fully considered in practical application to obtain the best discriminant accuracy of origin traceability. The average cross-validation accuracy of the method based on the orthogonal correction of stable isotope ratio partial least squares discriminant analysis (OPLS-DA) was 80% for the four geographic origins, and the average accuracy of the method based on the mineral element content was 96%. Isotope ratios of $\delta^{13}C$, $\delta^{18}O$ and $\delta^{2}H$ and mineral elements including Mo, Pd, Cr, Cd, Ti, Sr, Ca, Sn, Sb, La, Rh, Nd, Pr, Sm, V, Pb, Gd and Ce are the key indicators for origin tracing of *Santalum* wood samples. This method can trace the origin of *Santalum* woods in large-scale geographic space, and provides an effective method for combating illegal timber harvesting and conserving species diversity.

Phytochemical analysis of Pterocarpus species by chromatographic and spectrophotometric techniques for complementing existing way of identification

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: *Pterocarpus santalinus* L. f., commonly known as Red sanders, yields economically important high-priced wood. Due to its high price and rich hue, illegal harvesting and trading of Pterocarpus heartwood appears to be widespread. The identification of authentic *P. santalinus* wood is difficult because it shares morphological and anatomical similarities with other Pterocarpus species. Moreover, the Convention on International Trade in Endangered Species (CITES) has limited resources to guide the identification of Pterocarpus wood. In this study, chromatographic and spectrophotometric analysis of heartwood of *P. santalinus* Linn collected from trees grown in eight different locations was carried out. Thin layer chromatography (TLC) fingerprints of methanolic extract of *P. santalinus* heartwood revealed distinct spots at retention factor (Rf) 0.94 (light brown), 0.91 (purple), 0.79 (blackish-brown), 0.75 (light purple), 0.60 (yellow), 0.51 (dark red) and 0.28 (brownish red) in normal phase. High performance liquid chromatography (HPLC) analysis indicated at least 11 common peaks at retention time (tR) of 3.1, 3.5, 8.9, 11.1, 12.8, 13.5, 14.9, 15.7, 17.9, 18.3, and 26.5 (minutes). Ultraviolet visible spectrophotometric analysis of methanolic extract of heartwood exhibited consistency in major absorbance peaks at ~280 nm, ~320 nm, ~472 nm and ~505 nm. Similarities in chromatographic pattern between the *P. santalinus* samples from different locations were evaluated using principal component analysis (PCA). The developed fingerprints of methanolic extract of *P. santalinus* heartwood were also compared with those of *Pterocarpus marsupium*, *Pterocarpus soyauxii*, and *Pterocarpus macrocarpus*. The results demonstrate that HPLC and TLC fingerprints can supplement wood anatomy and other techniques in accurate identification of above *Pterocarpus* species. Spectrophotometric analysis can be helpful to differentiate *P. santalinus* from *P. macrocarpus* and *P. marsupium*, but *P. santalinus* and *P. soyauxii* could not be distinguished. Usefulness of these techniques for discrimination of some of the commonly occurring species in *Pterocarpus* genus was assessed.

The role of multi-stakeholders' dialogue in addressing timber trafficking: implications for science-based wood identification methods in Ghana

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: The implication of stakeholder dialogue for science-based wood identification is currently under-researched. A multi-stakeholder's dialogue was organized to raise awareness and understanding of stakeholders about timber trafficking issues in Ghana, and it implication for science-based wood identification in Ghana. This study was inspired by Delphi methodology, a structured and iterative process used to gather and distill expert opinions on a particular issue. The stakeholder dialogue revealed three emerging issues. First, stakeholders identified the following issues to be hampering efforts to combatting timber trafficking in Ghana: weak law enforcement due to inadequate personnel, lack of capacity in science-based wood identification methods, weak coordination among law enforcement and CSOs and community, porous borders, political interference, and lack of clear guidelines to process trafficked illegal timber. Rural poverty and livelihoods issues appear to be a critical driver for illegal timber activities in Ghana. Demand for cheap timber and conversion of forest lands for other uses also promote illegal timber logging in Ghana. Variations in definition of legal timber and disparities in timber trade tariffs among the West African countries were being exploited by illegal timber traffickers. Furthermore, data on illegal timber trade or crimes, timber species, and number of successful prosecutions are not readily accessible, even if available. Second, the stakeholders suggested enhancing the capacity of law enforcement agencies by developing and deploying science-based wood and charcoal identification methods in Ghana will contribute to combatting illegal logging in the West Africa, particularly African Rosewood (*Pterocarpus erinaceus*). Although African Rosewood is banned in Ghana, the forest fringe communities continue to convert it into charcoal and trafficked. In the absence of applicable charcoal identification tools, Africa Rosewood is threatened due to overexploitation in the West Africa. In addition, improving intra and inter-agency cooperation, and developing a decision guide for handling trafficked timber and charcoal. Also, empowering forest fringe communities and CSOs and promoting livelihood programs could contribute to reducing illegal logging. Third, critical recommendation was the need to engage Ghana's neighboring countries by organizing a subregional dialogue to discuss and agree on common principles to combat transboundary timber and charcoal trafficking.

The twofold role of wood anatomy on a local Congolese timber market: a tool for species level identification and a direct link to the nearby forest.

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Tropical rainforests in the Democratic Republic of the Congo (DRC) are harvested continuously for international and local timber trades. Statistics on internationally traded species are reported, but knowledge on local timber trade is scarce. As a collaboration between Congolese and Belgian researchers, a study was performed on timber locally processed and sold on markets in and around the city of Kisangani in the Tshopo province (DRC).

A total of 116 timber samples were gathered in Kisangani markets and subsequently sanded, photographed, microsectioned and identified. Apart from this process, detailed inventory data including tree species taxonomy, geographical distribution, abundances and diameter was gathered in contiguous 0.5 ha sampling plots lined up on a 79 km long transect line in the Yangambi forest near Kisangani. The standing volume was estimated using volume tables. Furthermore, growth increment data of these tree species was gathered in adjacent permanent monitoring plots.

The objective of this research is thus twofold: exploring the potential of classical wood anatomy to identify African timber up to the species level and comparing the identified species to the composition of the surrounding forest to gain insights on the impact of local logging.

Several topics on wood anatomy are discussed: the difficulties during the identification process, the use of supporting data to improve identification (for example the locally used names and geographical restrictions), the number and causes of misidentifications on local markets and the benefits of species level identifications to assist in combatting illegal timber trade.

Concerning the impact of local timber markets in the neighboring forests, the data we gathered enables us to select species that may be threatened by local exploitation. At the same time, lesser-known species on the international timber market arise in local markets. These species require further research to assess their opportunities as they could lower the pressure on the internationally traded timbers. This shows how wood anatomy forms a promising go-between to study the link between local timber trade and forest use in the tropics and highlights the importance of the botanic identification of timber to evaluate the carrying capacity of tree populations for logging.

The use of near-infrared spectroscopy in the traceability of commercial cargo of Cedrela odorata from origin to the final consumer in Brazil

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: The traceability of commercial timber cargo is one of the preventive measures to combat illegal timber trade in Brazil. Even though there are simple or complex methods to determine the origin of wood, there is no standard procedure stablished yet. NIRS technology combined with multivariate data analysis have proved to be a fast and efficient methodology for species identification, as well as a promising tool for geographical origin determination. This study aimed to track a commercial cargo of 19,114 m³ of *Cedrela Odorata* from the legal extraction area in the Amazon region (Jamari National Forest) to the final consumer located in the city of Ubatuba (São Paulo), which totalizes 3,100 km covered by land. The cargo was packed and transported by truck to protect it from weather. The NIR spectra obtained at the origin were used to create a SIMCA model, which was applied to the spectra obtained at the destination of the cargo. It reaches a compatibility rate of 81%. That means that most of the samples were within the model acceptance area and were high compatible with the initial cargo. When applied to *C. Odorata* samples from other origins, the number of samples within the acceptance area did not go over 32%. When testing the model on other species (*Erisma uncinatum*, *Swietenia macrophylla*, and *Micropholis melinoniana*), this rate was no more than 34%. These latter values corroborate the practicality, precision, and reliability of the NIR instrument for in-field tracking of wood cargo.

Keywords: NIRS; illegal logging; chemometrics; tropical wood.

Tropical timber integral research in southern Ecuador: Characterization, identification and scientific advances.

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Southern Ecuador is a region recognized for its biodiversity and richness in forest species; however, it faces different challenges of deforestation due to overexploitation and lack of information on native species to monitor and regulate the timber trade at the national level. In this context, this study focused on the characterization and similarity of timber in 100 forest species (96 broadleaf and 4 conifers) through the analysis of 141 variables related to their physical and organoleptic properties, and anatomical characteristics (qualitative and quantitative).

An unsupervised data analysis (dendrograms) was used to analyze the clustering of the species according to their properties. In addition, a principal component analysis (PCA) and correlation matrices were used to evaluate the significance of the analyzed characteristics and their interaction between species.

The results identified four distinct groups of woods. The first group consists of semi-heavy species (*Grias peruviana, Weinmannia fagaroides, Clethra revoluta, etc.*), the second group includes hardwoods such as *(Myrcianthes discolor, Lafoensia acuminata and Chionanthus pubescens, etc.*), the third group corresponds to soft woods (*Heliocarpus americanus, Ochroma pyramidale, Ochroma pyramidale, etc.*), and the fourth group, the largest, is made up of porous woods (*Inga densiflora, Salix humboldtiana, Cedrela montana, Piptocoma discolor, etc.*).

We also found a direct relationship between the basic density of the wood and characteristics such as color, cell wall thickness of the fibers, the presence of solitary vessels, number of vessels per mm2, the presence of rays of two different sizes and different patterns of axial parenchyma.

These findings are relevant for species identification based on wood density, highlighting the high variability of wood characteristics among forest species in southern Ecuador. This allowed the identification of unknown species with a potential for use similar to the species that are currently highly exploited, emphasizing the importance of generating more information on a greater number of species to facilitate decision making in sustainable forest management in Ecuador.

Use of DNA in tracing the geographic origin of planted tropical timber Neobalanocarpus heimii (chengal) in centurion planting trials

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: In the context of forensic forestry, the unique features of DNA within a timber could be used to facilitate the identification and determination of origin. With the aim to manage and utilize forest genetic resources in a sustainable manner, extensive DNA databases for various important tropical tree species, including *Neobalanocarpus heimii*, have recently been developed at the species, population, and individual levels using chloroplast DNA (cpDNA) and short tandem repeat (STR) markers. To use these DNA databases for forensic applications, as recommended by the UNODC Best Practice Guide for Forensic Timber Identification, four laboratory standard operating protocols (SOPs) for *N. heimii* were developed as a guide to generate forensic evidence for judiciary purposes. In this case study, as the origin of the planted timber species at Forest Research Institute Malaysia (FRIM) was mostly unknown, our objective was to trace the origin of *N. heimii* stands on the FRIM campus using SOPs and DNA databases. FRIM was once a former mining area, but it has been successfully transformed into a man-made forest since the 1920s. Using four chloroplast DNA (cpDNA) and ten nuclear short tandem repeat (nSTR) markers, we generated DNA profiles for 111 *N. heimii* individuals from four planting trials. Our findings showed that the DNA approach can be used to trace the geographic origins of species. The origins of the *N. heimii* on the FRIM campus are diverse, including northern, western, southern, and eastern Peninsular Malaysia. Each of the four planting trials demonstrated a high level of genetic diversity equivalent to natural stands. Thus, these planted *N. heimii* should be regarded as a valuable germplasm bank for the conservation of the species' genetic resources as they constitute a substantial gene pool of diverse origins.

Using genetics to identify species in the highly diverse and closely related subfamily Dipterocarpoideae in Southeast Asia: how far can we go?

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Illegal logging is a major global issue driving deforestation and biodiversity loss. As such it is imperative that scientific tools to identify timber species are developed. Tropical forests on the island of Borneo are amongst the most heavily logged in the world and are dominated by species in the subfamily Dipterocarpoideae, the largest subfamily of the Dipterocarpaceae. Species in this family are of major importance in the timber trade and are used for wood, essential oils, balsam and resins. The use of DNA identification methods as a tool for demonstrating compliance in the timber supply chain has grown in the last decade, improving the traceability of tropical hardwoods and supporting legal and responsible forest utilisation. But for groups where species resolution has been challenging, such as the subfamily Dipterocarpoideae, what level of discrimination can be achieved using these methods? For the eight most species rich genera of Dipterocarpoideae, including the complex genus *Shorea*, we have explored the potential of chloroplast and nuclear DNA markers to identify economically important traded timbers from Indonesia and Brunei. First, we compared phylogenies based on the analysis of chloroplast and nuclear data to resolve the complex evolutionary relationships for the species in the subfamily. We then describe the taxonomic resolution achievable using these markers and present DNA identification tests aimed at different end users. We present the most efficient chloroplast genome regions for species identification that can be used to rapidly verify timber identity using Sanger sequencing or similar methods. We also present an array of the most discriminatory single nucleotide polymorphisms (SNPs) for when further discrimination is required and high-throughput sequencing is available. The development of tests using more than one type of marker provides options for a wide range of end users and will ideally increase the uptake of DNA identification tests to rapidly verify timber identity and support a strong and vital international tropical timber trade.

Utilizing NIR light for the non-destructive identification of wood species

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Near infrared spectroscopy (NIRS) is an effective and non-invasive method for investigating the properties of materials and it can be used for the identification of wood species. We have utilized NIRS for the identification of wood species used in ancient and culturally significant wooden Buddhist statues, and we were able to achieve a successful separation of wood species using multivariate analyses. We could separate the samples into softwood and hardwood using the full range of NIR wavelengths (830-2500 nm). Furthermore, we obtained higher accuracy using relatively shorter NIR wavelengths (830-1150 nm) than longer ones (1150-2500 nm), for the separation of two look-alike conifer species (*Torreya nucifera* and *Chamaecyparis obtusa, Chamaecyparis obtusa* and *Chamaecyparis pisifera*, *Cryptomeria japonica* and *Thuja standishii*). To determine the factors which can be used to separate the species of wood, light transmittance and reflectance were measured in 21 conifer species using a spectrophotometer equipped with an integrating sphere and light within a wavelength range of 500-1200 nm. Transmittance values varied not only among different species, but also between the sapwood and heartwood in certain species. The intensities increased from about 600 - 700 nm and showed peaks or shoulders in the ranges of 870 - 900 nm and 930 - 950 nm, and at around 1100 nm in all samples. Differences between the spectra of sapwood and heartwood were observed within several species and the patterns of difference were the same between species within the same genus. Peaks at around 1100 nm were observed in both the sapwood and heartwood of all samples. Maximum conductivities of light at these peaks were relatively lower in wood species with helical thickenings (genus *Pseudotsuga*, *Torreya*, *Taxus*). Based on these results, it can be seen that the anatomical characteristics of wood influence the transmittance of light, and make the positive separation of wood species possible with the use of NIRS.

Valorizing xylaria using computer vision-based wood identification: a case study on the INERA-Yangambi xylarium

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: Xylaria provide crucial reference materials for botanical studies, wood anatomical research, and forensic investigations. However, the accuracy of specimen identification within these collections is not always guaranteed, as specimens with dubious origins can enter collections, risking research integrity. Ascertaining the taxonomy is therefore crucial.

Although a full wood anatomical assessment could theoretically identify all specimens, this process would be impractically time-consuming, requiring years of intensive microtomy work. Artificial intelligence offers a faster, more economical solution. Computer vision-based wood identification uses wood images as diagnostic information to develop models that can distinguish timbers. This method enhances the reliability of xylaria, thereby increasing the trustworthiness of the research performed on them.

The objective of this study was to classify 58 Congolese wood genera through precise multiclass classification. The Xception architecture was leveraged on macroscopic cross-sectional RGB images, utilizing the SmartWoodID database derived from the Tervuren xylarium as training data. A total of 1700 specimens were divided into training (80%) and test (20%) datasets while maintaining species balance. Images were cropped into square patches with a side length of 5.42mm. Five-fold crossvalidation was used for evaluation, and the most performant model was applied to the xylarium of the INERA-Yangambi research center.

Performance was assessed by calculating recall scores for all genera across folds for all patches, and for aggregated results per specimen. The predicted genus for each specimen was determined by majority vote on patch predictions and compared to the specimen's recorded genus. In total, 193 specimens of the INERA-Yangambi xylarium were classified. Among these, 57 specimens were misclassified at the genus level.

This research demonstrates that AI can significantly enhance the accuracy and reliability of xylaria, facilitating more dependable botanical and wood anatomical studies.

World Forest ID - The world's largest geolocated reference database; designed to tackle deforestation with science

T5.16 IAWA-IUFRO Symposium: Advancing Methods and Applications of Wood Identification

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Abstract: The illegal timber trade is the most profitable natural resource crime, valued at USD 50-152 billion per year, with up to 90% of tropical timber in global supply chains potentially illegally sourced. In addition, conversion to agriculture is the main driver of tropical deforestation, causing loss of biodiversity, livelihoods and ecosystem function. World Forest ID is a U.S. non-profit organization developing the world's largest georeferenced database of timber and agricultural samples, with the ambition to create a new global standard for credible, science-based verification of species and origin. World Forest ID emerged from a consortium of partners which included the US Forest Service, World Resources Institute (WRI), Royal Botanical Gardens, Kew, and the Forest Stewardship Council (FSC). Our reference database houses (1) geolocated physical wood and forest risk commodity samples collected globally, and (2) analytical data against which species identity and harvest origin claims can be verified. As of April 2023, we have collected over 23,000 wood samples (>9,000 trees, >60 countries and >350 species) and over 1,000 soy, cocoa and coffee beans (> 6 countries). The scientific methods used by World Forest ID affiliated labs include Stable Isotope Ratio analysis, DART-TOF Mass Spectrometry, Trace Element analysis, DNA analysis and wood anatomy (manual and machine vision). These different data types are then combined in machine learning models, together with species distribution and satellite data, to increase the accuracy of both species identity and harvest origin determination. As collections for World Forest ID continue to be carried out across the globe, the reference database and data analysis models become an increasingly valuable tool for both enforcement and industry stakeholders.

T5.17 Inclusion of environmental variables and ecological services as part of the decision process in intensive silviculture: lessons from around the world

A Bio-physically Driven Dominant Height Model for Loblolly Pine Plantations

T5.17 Inclusion of environmental variables and ecological services as part of the decision process in intensive silviculture: lessons from around the world

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Abstract: Dominant height (DH) models are commonly used as a productivity drivers for growth and yield systems due to the relative independence of dominant trees average height pattern with respect to stand density. However, scientists have well identified that growth trajectory of DH over time doesn't follow a stationary progress over successive years, being subject to, sometimes, severe stochastic fluctuations. These fluctuations are naturally expected by plant physiologists, as they represent the interaction between the soil physical and chemical properties, and yearly weather variations. One of the main sources for such variations correspond to changes in light interception capacity between sites and within a rotation cycle. To improve projection stability for intensively managed plantations, a model was built to describe even-aged stand leaf area. According to literature, such model, together with incident light, would result in a better productivity indicator. Our leaf area index model incorporates a delay component meant to reflect the influence of past years in carbon accumulation, through a delay differential equation formulation. The height model was calibrated simultaneously with a dominant height model that included leaf area and estimated annual intercepted light as independent variables. Calibrations were done using satellite derived leaf area indices and long-term permanent sampling plots for loblolly pine. Our model showed that sites with higher foliage production capacities correctly influenced higher dominants heights than sites with lower. This empirical model resulted in an easy tool that can be incorporated into traditional growth and yield systems.

A climate driven growth and yield system for clonal Eucalyptus plantations in Brazil

T5.17 Inclusion of environmental variables and ecological services as part of the decision process in intensive silviculture: lessons from around the world

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Abstract: There has been a renewed interest in implementing systems to forecast *Eucalyptus* plantation productivity using environmental variables, mainly due to the expansion of planted areas to drier sites and predicted climate change. Brazilian *Eucalyptus* plantations are distributed over a very wide climatic range covering many soil classes; therefore, there is a need to include site-specific predictors to allow for a more comprehensive interaction between climate variability and tree growth. That is why a group of 10 companies in Brazil with universities and research institutes started the IPEF-ModProd Cooperative Research Program aiming at producing growth and yield systems that include different clonal *Eucalyptus* genotypes as well as climatic predictors that will allow future spatialized estimates for stand productivity under changing climate. This work presents a growth and yield model that relies on three ecological indicators for the water balance: water deficit, excess water, and available water based on a 60-year (1960-2020) dataset. The model was calibrated to 30 sites for 300+ plots covering more than 3,500 km from north to south of Brazil. Ten different genotypes were included, allowing for specific values for each. Indicators were summarized for each site, accounting for spatial and temporal variations. Variations were an integral part of the system, allowing for better calibration in the parameters. Our new framework increased the site's accuracy and allowed us to include climate (either static or dynamic), with explicit uncertainty associated with productivity prediction.

Changing silviculture tactics if water instead of nitrogen became the limiting factor in the boreal forest

T5.17 Inclusion of environmental variables and ecological services as part of the decision process in intensive silviculture: lessons from around the world

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Abstract: The forests in the conifer dominated boreal northern Europe are primarily managed for fibre and high quality timber. Forests available for wood supply in Sweden are predominantly planted stands with Norway spruce (Picea Abies) or Scots pine (Pinus Sylvestris), with long rotations of 50-80 years. Most of the management guidelines used by contractors, companies and the forest agency, originates from experiments and empirical data from the years 1950-2000. The models and guidelines are usually nationwide, using latitude as the covariate explaining for site variation in climate and soil productivity. During recent years we have demonstrated an increased precision in growth and yield modelling and silvicultural guidelines, when replacing fixed attributes of region or latitude, with spatial and temporal dynamic variables. Examples of such variables are water availability, soil moisture indices and available photosynthetic active radiation.

Decades of forest research in Sweden have proved an increased growth with treatments with applied nitrogen fertilization, but similar response have not been demonstrated with irrigation alone. Therefore, limited nitrogen availability has influenced the management guidelines, in terms of tree species selection, spacing, thinnings and rotation length.

However, the recent years with repeated droughts and subsequent secondary stressors on the two major tree species, indicate the need of a shift in management guidelines for conifer plantations in northern Europe, to be able to adapt to water and nitrogen as the limiting factors for sustainable growth and tree health. We have studies on both seedlings and mature trees where water availability and/or precipitation to a certain degree explain results of survival, growth and tree health. Therefore, we suggest new strategies for forest management in Sweden, where the risk of water stress have a significant impact on silviculture tactics.

Modeling radiata pine plantations above and belowground carbon sequestration under contrasting soils at harvesting age.

T5.17 Inclusion of environmental variables and ecological services as part of the decision process in intensive silviculture: lessons from around the world

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Abstract: The increasing demand to mitigate climate change effects have fostered the adoption of forest plantations as strategies to ensure a sustainable timber supply and serve as carbon sinks. This study focuses on the critical need to understand and quantify the whole rotation long-term effects of Pinus radiata plantations as above and belowground carbon sinks and drivers of soil carbon stocks under contrasting soil-site conditions. We model the relationship between forest productivity at harvesting age and whole site (plantation & soil) carbon sequestration.

We selected 10 sites on volcanic ash soils (Paleudalf) and sandy soils (Xeric Psamments) and quantified the accumulated carbon in aboveground biomass and belowground biomass using local allometric equations and in situ measurements of forest floor (litter and surface residues) and mineral soil (up to 1 meter deep). Our findings indicate that plantations on volcanic ash soils showed a significant correlation between stand volume and total site carbon stock ($r2=0.73$, $p< 0.001$), with an average of 444.1 Mg C ha^{-1}. Carbon was primarily accumulated in the mineral soil (57%), followed by total biomass carbon (40%). At sandy soils a significant correlation between stand volume and aboveground biomass carbon was observed ($r2=0.71$, $p< 0.001$), with an average total carbon of 315.8 Mg ha^{-1} distributed 51% in aboveground biomass (51%) and 43% in the mineral. Carbon in the forest floor at both sites was less than 6%.

Our study underscores the importance of incorporating soil and climate attributes into forest productivity models. Our findings provide a deeper understanding of the potential of Pinus radiata as a carbon sink for climate change mitigation and lay the groundwork for the development of models estimating intensively managed forest plantations whole site carbon accumulation and base lines for intensively managed plantations sustainability.

Modelling of radiata pine productivity using 3-PG to estimate the effect of subsoiling, fertilization, and weed control on a gradient of soils

T5.17 Inclusion of environmental variables and ecological services as part of the decision process in intensive silviculture: lessons from around the world

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Abstract: Understanding the site-specific effects and intensive silviculture on forest plantations is essential to maintain and improve productivity and carbon sequestration, especially in the context of climate change. Therefore, evaluating the long-term effects of early silvicultural treatments serves to justify these practices and model forest productivity. *Pinus radiata* D. Don is one of the most planted conifers in the world, however, few studies have evaluated the effect of early silvicultural treatments on forest productivity up to harvest age. Our objective was to evaluate rotation length growth responses of radiata pine to soil preparation, fertilization, and weed control at three contrasting sites and evaluate the 3-PG (Physiological Processes Predicting Growth) model on prediction of long-term silvicultural responses. We evaluated sites in the central valley of Chile, corresponding to an excessively drained dry sand (DS), a well-drained and compacted red clay (RC) and a well-drained highly fertile recent volcanic ash (RV) soil. These soils-sites represent a broad range of site conditions where radiata pine is planted in Chile. Stands were established in 2000 with 4 blocks in a split plot factorial design that included soil preparation (subsoiling vs shovel) as main plots, and fertilization at planting (only B vs NPKB) and weed control (none vs 2 year banded) as factorial randomized treatment plots within the main plots. Annually diameter at breast height and height were measured, and survival and cumulative volume were estimated for each treatment. Rotation age results for cumulative volume showed that early gains from weed control were increased over time at the DS site (20% gain), maintained over time for RC site (8% gain) and lost over time for RV (7% loss). Fertilization had the greatest response at the RC site (8% gain), small responses at the DS site (2% gain) and negative responses at the RV site (4% loss). Interestingly, subsoiling showed null or negative responses at the three sites and negative effects increased over time (decreasing to a 20% loss at RV site). Given site-specific responses and silvicultural treatment, we will model productivity using 3-PG and the effect of these silvicultural practices and implications under climate change scenarios.

Productivity of Norway spruce and Scots pine in Sweden

T5.17 Inclusion of environmental variables and ecological services as part of the decision process in intensive silviculture: lessons from around the world

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Abstract: Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* L. Karst.) are the two most important commercial tree species in Sweden. Despite the rich tradition of silvicultural research and experience in cultivating both species, there is still a lack of comprehensive studies comparing their growth at the same sites. This study aimed to examine differences in productivity between the two species in Sweden based on a set of long-term plots established to investigate stand production of both species. The single-species plots were planted in close proximity, thus ensuring very similar site conditions. Long-term stand development was simulated from the inventories performed in 102 locations with species comparisons, representing a wide range in fertility (100-year site index range 15-38 m) and geography. Productivity was assessed in terms of full-rotation mean annual increment (MAI). On average, Scots pine yielded 35.4% higher MAI compare to Norway spruce at low and medium fertility sites, whereas at high fertility, Norway spruce had a 13.4% higher MAI. Results from this study indicate that from a production point of view, Norway spruce should only be planted on the most fertile sites exceeding a site index of ~31 m. This outcome is contrary to majority of the previous findings and general recommendations for forestry management in Sweden.

Relationship between topography and growth of Colombian Pine in the Colombian Andean zone

T5.17 Inclusion of environmental variables and ecological services as part of the decision process in intensive silviculture: lessons from around the world

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Abstract: Colombia, known for its diversity of native woody tree species, predominantly relies on exotic pines and eucalyptus for commercial reforestation due to their established technological packages ensuring long-term productivity. However, the use of exotic species remains a controversial topic, requiring the study of native timber species for future commercial reforestation projects. *Retrophyllum rospigliosii* (commonly known as Colombian Pine), a native conifer with promising morphological characteristics, emerges as a viable candidate for commercial reforestation. To evaluate its suitability, Smurfit Kappa-Carton de Colombia established an experimental 12-hectare plantation in the department of Cauca (southwest Colombia) in 1998. This study aims to assess the relationship between topography and the growth of *R. rospigliosii* in the Colombian Andean zone, employing topographic variables to estimate its site index. Height growth data from 30 plots which has been subject to ongoing monitoring for the last 20 years, were utilized to derive site index information, and eight topographic variables were generated using a photogrammetric digital elevation model. The site index equation was modeled using the Bertalanffy model, yielding an R^2 value exceeding 98%. This model was used to generate three site index classes ranging from 9.2 to 16.6 meters. Principal component analysis identified aspect, profile curvature, and plant curvature as the most important topographic variables, explaining 86% of the site index variability. Remarkably, areas with a western aspect and convex curvatures exhibited higher growth, suggesting that *R. rospigliosii* thrives in microsites with reduced light and nutrient availability due to lower water flow. Given the difficulty of controlling topography through forest management practices, the species' selectivity for specific microsites and its relatively low growth rate, the practical feasibility of using *R. rospigliosii* in commercial reforestation appears questionable. Consequently, further research is needed to explore alternative native timber species that better meet the requirements of large-scale reforestation projects in Colombia.

Vegetation Management Effects on Early-Seral Native and Non-Native Vegetation Abundance, Species Richness, and Diversity in the Pacific Northwest

T5.17 Inclusion of environmental variables and ecological services as part of the decision process in intensive silviculture: lessons from around the world

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Abstract: The long-term productivity and success of forests are strongly dependent upon seedling performance during the first few years following planting. Given that the Pacific Northwest of the United States (PNW) experience severe summer droughts that result in intense competition for soil water resources, competing vegetation management (VM) is critical for successful seedling establishment. However, to ensure sustainable forestry, it is necessary to understand the effects of silvicultural treatments, particularly VM, on ecosystem services such as native and non-native species richness, diversity, and abundance. The Competition and Site Interactions Experiment (CoSInE) began in 2016 to understand the effects of VM regimes on seedling physiology, growth and survival, as well as early-seral vegetation community characteristics across the diverse landscapes of the PNW. CoSInE includes 11 sites installed in Oregon and Washington States, that each involves 8 treatment plots with a combination of a pre-planting herbicide application and a post-planting herbicide application during the first and second growing seasons. An inventory of height, diameter, and health status for all 64 Douglas-fir seedlings within each treatment plot was conducted annually during the dormant season. During the peak of each growing season, an assessment of vegetation abundance and height by species is conducted in the five 3 m^2 permanent vegetation plots installed within each treatment plot. The effects of the VM regimes across all sites on native and non-native species richness, vegetation abundance, and diversity of different growth forms (forbs, ferns, graminoids, shrubs and brambles) throughout the first 5 growing seasons were evaluated. While results were site-specific, they suggest that, across all sites, by growing season 5 for all native and introduced species, there was no VM effect on abundance and species richness but continued effect on diversity. For native species, there was no VM effect on species richness and diversity but continued effect on vegetation abundance. Results on each growth form will be presented. Our results indicate a short-term effect of VM on reducing early-seral vegetation abundance and diversity, generally ranging 1 or 2 years after herbicide application.

T5.18 Initiatives and Equity for Forest Education in a New Era

BioEquality – gender equality in the Nordic bioeconomy

T5.18 Initiatives and Equity for Forest Education in a New Era
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Abstract: The BioEquality project addresses gender inequality in the Nordic bioeconomy, it focuses particularly on forestry and agriculture which are two of the region's most gender-segregated sectors. Digitalisation and increased automation of heavy work could benefit gender equality in the sectors. However, this has not yet happened. The project therefore aims at exploring how the digital transformation impacts gender equality among young individuals in the Nordic bioeconomy and how digital development can be leveraged to advance gender equality.

It is believed that to create opportunities for influence and participation in the digital development of the bioeconomy, it is necessary for tomorrow's employees -whom are today's students- to gain a deeper understanding of this problem and be involved in identifying and implementing solutions. To support this objective, various methods were implemented. A systematic literature review, interviews and focus groups with experts led to the redaction of an academic article as well as a handbook. It is specifically designed for teachers and students in forest and agricultural education. The method handbook consists of easily accessible texts, videos, podcasts and other material aiming to create a common understanding of the subject and its challenges and facilitate conversations to create participation and ownership over the issue.

A second phase of this project, currently in its pilot phase, aims to invest further in the future of forestry and agriculture by focusing on a younger audience, namely students between 12 and 15 years old. Study visits are offered to learn more about how AI is used in agriculture and forestry. The visits are organised at technology testbeds for the digital bioeconomy, i.e. environments where businesses, academia and other organisations can interact in the development, testing and introduction of new products, services, processes, or organisational solutions. By visiting the testbed and experiencing digital innovations pupils will get a deeper understanding of what it means to work with AI and digitalisation in the bioeconomy. Expected results are an increase in young girls' interest in studies in digitalisation and hopefully in the future, a decreased gender gap in the sectors.

Current Status of Forest Science Education in Undergraduate Universities in Japan

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: In the new era, where global trends are shifting towards sustainable forest management, this study highlights the current state of Japanese forest education to introduce regional differences worldwide.

The Japanese school education system has been controlled by the Ministry of Education, Sports, Science and Technology. In 1991, universities underwent educational reforms that were implemented by the Ministry. This study conducted a nationwide survey in 2021 to investigate the status of forest science education in universities and colleges.

The survey included faculty members from 27 schools, with 25 having existing forestry curricula and two being newcomers. These schools were categorized into three types based on their education system for university faculties and departments: eight schools had specialized forest science divisions within departments, ten schools had dedicated forest science courses in departments of agriculture, and seven schools had forest-related specialized subjects in comprehensive divisions in departments of agriculture.

Approximately 6,000 (0.2% of the total number of university students) students were enrolled in forest science-related programs, with a male-to-female ratio of 6 to 4. Around 400 teachers, including those specializing in wood science, were involved in forest science education. Roughly half of the graduates entered the workforce, while about 40% continued their studies in graduate school. Around half of the graduates from forest science courses pursued careers in forest management, including positions in government agencies, forestry associations, and private companies, such as forestry extension supervisors and professional engineers.

The curricula of 30 educational courses across 24 schools offered a variety of subjects, with 400 required subjects and 714 elective subjects. Educational programs were classified into three types based on their inclusion of forest science content: 12 schools offered diverse forest science content as required subjects, 10 schools provided various forest science content as electives, and 4 schools offered only a limited number of forest science subjects. Determining the key elements of forest science education was challenging due to the differing approaches.

In conclusion, it is necessary to reexamine forest science education in undergraduate universities and include essential content that aligns with social demands, particularly in the context of professional human resource development.

Developing an inclusive and interdisciplinary training program on "forest-based climate solutions"

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: Forest-based climate solutions are being promoted globally to provide benefits such as sequestration of atmospheric carbon, habitat for species, and improvement of rural livelihoods. Yet scientific uncertainties, governance challenges, and a limited workforce constrain the development and implementation of effective policies and initiatives for forest-based climate solutions. To address these challenges, we are developing an inclusive, interdisciplinary training program on forest-based climate solutions at Oregon State University. In this talk, we will describe the design of this program, including our incorporation of current pedagogy on inclusive and effective education in science, technology, engineering, and mathematics (STEM), as well as the expected learning outcomes for participants. Key features of the program include i) cohort- and team-based learning focused on research projects relating to forests, society, and climate change, ii) the engagement of faculty and participants from five different colleges across the university (the Colleges of Forestry; Earth, Ocean, and Atmospheric Sciences; Agricultural Sciences; Business; and Education), iii) field-based workshops and intensive bootcamps to develop key skills, and iv) internships at policy and research institutions. We will also discuss our plans to make the program inclusive and accessible, including recruitment, retention, and support of students from under-represented groups, and engaging Oregon State University's online education platform, the Ecampus. Our talk will exemplify our efforts to create a modern, inclusive, and interdisciplinary program that is responsive to a growing theme (forest-based climate solutions) within global forest education.

EUROSILVICS: Open-access repository for education support in silviculture and forest ecology

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: Increasingly, academic teaching in silviculture and forest management is part general BSc and MSc programmes in environmental sciences, land use, and resource conservation and management. As a result, dedicated teaching and disciplinary knowledge in silviculture and forest management may receive less attention. While this allows emphasis on problem solving skills and academic competences, it also calls for alternative means to provide access to classical forestry topics such as silviculture and forest management. The EUROSILVICS project, funded by the Erasmus+ Collaborative Partnership programme, is carried out to make traditional, disciplinary knowledge in silviculture and forest management available for use in a wide array of teaching, ranging from academic programmes in forestry and forest management, to professional teaching and vocational training in forest ecology, silviculture and forest management.

EUROSILVICS creates a common digital resource for higher education in forestry, based on a repository with educational material of the participating institutions made available as an Open Access Library for Learning. Education material in national languages will be reviewed, and translated into English to allow for international use. The project involves 6 European universities: Leuven University (prof. Bart Muys, BE), Ghent University (prof. Kris Verheyen, BE), the Austrian University of Life Sciences BOKU (prof. Hubert Hasenauer, AT), Eberswalde University for Sustainable Development (prof. Peter Spathelf, DE), and the Swedish University of Agricultural Sciences SLU (prof. Gustaf Egnell, SE), and is coordinated by Wageningen University and Research WUR (prof. Frits Mohren, NL).

The project is centred around the establishment of a dedicated open access platform for forestry education material, both basic and applied, including supplementary material as exercises, excursions, and links to relevant websites. The project includes a robust review and editing procedure for quality assurance, links to other open sources and to repositories of professional associations, and outreach to individual users as well as other institutions involved in forestry-related education.
The project runs from 2022 and 2025, and aims to contribute to education in forestry in Europe and elsewhere, and to wise and sustainable management and use of forests as nature-based solutions for resource supply in the bioeconomy and for climate mitigation.

Forestry Capacity Building in Climate Change

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: With the Paris Agreement on Climate Change becoming effective in 2016 with the membership of 195 nations, the global society firmly entered the epoch of climate change. Nations initiated the setting of voluntary greenhouse gas reduction targets, subsequently necessitating the development of reduction strategies tailored to each sector. Globally, major greenhouse gas emitters encompass electricity and heat production, agriculture, forestry, land use, construction, transportation, industry, and various other energy sectors. Currently, the forestry sector contributes to 14% of the total carbon emissions, a relatively modest percentage compared to other sectors. However, it is also among those sectors with the most significant potential for reduction, anticipated to decrease present emissions by 75% by 2030. Indeed, the forestry sector stands as the solitary mitigation agreement achieved during the Paris Agreement, and it remains the only greenhouse gas sink acknowledged by the United Nations. In a carbon-neutral scenario projected for 2050, the forestry sector is expected to generate approximately two million new jobs. Although modest when compared to other sectors, this figure underscores the importance of human resource development, particularly given the anticipated impact of the forestry sector on climate change. Therefore, as each country develops climate change and carbon-neutral scenarios, addressing the issue of human resource development for the forestry sector becomes crucial. Grounded on this premise, this paper intends to articulate how future talent development in the forestry sector can be approached, employing AFoCO's roadmap as a guiding framework.

Forestry Education in the AI Era: Challenges, Opportunities, and the Transformative Impact of AI on Teaching and Learning

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: In the rapidly evolving era of Artificial Intelligence (AI), forestry education faces both challenges and opportunities. This talk will explore the implications of AI and online teaching methods on forestry education, highlighting the potential for transformative learning experiences and the need to address associated challenges. The presentation will discuss the role of AI in forestry education and its impact on traditional teaching approaches- how AI technologies, such as machine learning algorithms and data analytics, can enhance forest-related research, management, and decision-making processes; how AI can assist in bridging gaps in access to education, facilitating remote learning, and fostering collaboration among students and professionals; and how AI-based tools can enhance forest monitoring, conservation planning, and sustainable management practices. Additionally, the talk emphasizes the importance of adapting forestry education to leverage the benefits of AI while mitigating potential risks. It calls for a balanced approach that combines technical skills, critical thinking, and ethical considerations in preparing future forestry professionals for the challenges and opportunities in the AI era.

High-Quality Education Equity in China Forestry Higher Education: A Practical Research from the Perspective of Sino-Foreign Cooperation in a New Era

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: Teaching quality is the key to talent cultivation in universities. The past decade has witnessed the trend of the China higher education from popularization to universalization, thereby the focus of forestry higher education in China has been transitioning from education equality to education quality. Based on collaborative cultivation of international innovative talents and international collaborative innovation in scientific research, Chinese forestry-related universities are striving to promote the adjustment of the connotation, form, and global layout of Sino-foreign cooperative education. And by establishing a Sino-foreign cooperative education platform, efforts have been made to introduce international advanced discipline construction experience and achievements, strengthen the construction of basic disciplines, emerging disciplines and interdisciplinary disciplines, ensuring the continuous improvement of the quality of world-class forestry higher education in line with China's national conditions and benchmarks. Via the integration, coordination, and exploration of not only local consciousness and cultural feelings, but also global perspective and modern concepts, a set of high-quality teaching quality assurance system, which is generally recognized by students and their parents, has been established for the entire process of student development, in response to new challenges of imbalanced and insufficient forestry higher education, helping to promote the comprehensive green transformation of economic and social development in a new era.

Innovative Sustainable Forest Management Education in the Asia-Pacific Region

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: The concept of Sustainable Forest Management (SFM) has emerged globally as an essential element for the sustainability and conservation of the world's forests. Regional gaps exist in how to continually and equitably update forestry professionals and practitioners around the world with new knowledge of SFM and new technologies to manage natural resources and implement effective policies. Providing global access to open and credential high-quality education resources and opportunities becomes extremely important to narrow the regional gaps and improve SFM practices.

To address the challenges, a joint educational online program entitled Innovative Sustainable Forest Management Education in the Asia-Pacific Region was initiated in 2014. Content experts from regional forestry universities in the Asia Pacific Forestry Education Coordination Mechanism (AP-FECM) network were invited to develop coursework and formed an international collaborative development team with broad knowledge of SFM. A total of 14 online graduate certificate courses were developed with their fundamental content as Open Educational Resources (OER).

As the only SFM online program of its kind, since 2016, the joint educational program provides world-class forestry education resources created and supported by leading professors and experts from internationally recognized universities around the world. Its OER courses reached out to over 15,000 learners from over 90 international economies and its instructor-led repurposed OER Courses by AP-FECM had over 3800 learners from over 135 universities, based on our records before and during Covid-19 Pandemic until 2020.

As a key unit to operate and manage the project, the Executive Office (EO) of the AP-FECM is responsible for continuously encouraging global utilization of the curriculum and increasing international recognition of the project. Phase III of the project will be on agenda in 2023 to have another handful of courses developed. More relevant content experts are sincerely invited here to join the great effort toward promoting Sustainable Forest Management and increasing equity in forest education around the world.

INTERNATIONAL COLLABORATIONS TO COPE CHALLENGES OF FORESTRY EDUCATION IN NEW ERA: A SUCCESS STORY

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: This study examines international collaborations on forestry education of Bangladesh and focused the contributions on gender equity and strengthening the capacity of students to cope the challenges of forestry sector from local to global scale. Forestry education of Bangladesh had a serious setback on gender equity before 1985. As no female student was admitted in Institute of Forestry and Environmental Sciences, University of Chittagong (IFESCU), the pioneer national institution on forestry education. A paradigm shift of forestry education took place in 1985 when FAO and UNDP lead initiatives came enforce as a collaboration project at IFESCU. The collaboration opens the door for female students successfully and introduced a new curriculum to meet the demand of pro-people forestry as earlier forestry education of Bangladesh built on British colonial regimented, white-collar mechanism. On the other hand, another serious impediment faced by the forestry education at IFESCU during COVID19 pandemic, when all the (in person) class room activities were stopped for 565 days and lead the academicians to think alternate ways like using online platforms particularly accustomed to flipped classroom (good example(s) google classroom, zoom platform). Again, IFESCU embraces collaboration initiative with Asia Pacific Forestry Education Coordination Mechanism (APFECM) and participated APFCEM designed and University of British Columbia delivered online courses particularly on sustainable forest management, geospatial sciences and helped to redesign new curriculum introducing new arena of knowledge on global change, biodiversity conservation, forest-people conflict management, landscape level restoration, geo-spatial technological interventions, invasive species management, carbon management and trading, panel wood and wood processing to meet the global to local demand. More than 2000 graduates with 367 females were passed from IFESCU, employed and successfully served at home and abroad. This study discussed all prospects and constraints of collaborations. And concludes that international coordinated collaboration mechanisms may pave the way of success for developing nations to get global standard of graduate to meet the future demand in new era, The collaborations act as knowledge bridge between developed and developing world with generic nature, may be implemented another part of the world.

Proposing innovative competence-based training experiences to enhance forest management through a blended approach.

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: Biodiversity loss is one of the most pressing environmental challenges that humanity is facing. Within the European context, the Bird and Habitats Directives are pivotal to preserve and restore biodiversity by creating a network of protected areas across the EU territory, called Natura 2000. These Directives have been recently strengthened through the EU Biodiversity Strategy to 2030 which commits to restore forest ecosystems and protect old-growth forests. Nevertheless, their implementation state is considered insufficient due to the lack of skills to plan, manage, and restore Natura 2000 sites. Increasing the capacities of protected area managers through training is seen as a crucial aspect to achieve effective biodiversity governance. LIFE ENABLE (LIFE20 PRE/DE/00009) project aims to build practical skills among Natura 2000 and Protected Areas managers to address current and future challenges in nature management by creating a European competence-based training system called "European Nature Academy". Through the analysis of previous learning activities, the identification of knowledge and skill gaps, and the acknowledgement of the most successful training approaches, LIFE ENABLE aims to create new training opportunities to empower managers to address their needs. One of the courses developed within LIFE ENABLE is the "Forest Course" which aims to increase the capacities of managers working in forest habitats. The course is focused on forest ecosystems, including forest species and habitats and their ecology, and considering the planning and management of Natura 2000 sites. The initiative aims to develop, deliver, and test innovative training approaches, which combine blended learning with field experiences. Learners can improve their knowledge on jurisdictional, managerial, and ecological aspects characterizing forest-protected areas and apply newly acquired knowledge practically in the field. Additionally, the course allows learners to meet other managers working across the EU territory, exchange ideas or experiences, establishing a new expert and peer-to-peer network from which future collaborations opportunities might emerge across Europe.

The course is designed to meet the needs underlined by managers, such as ensuring learner-provider interactions, proposing replicable and scalable solutions, fostering a proactive role by local actors, sustaining collaborations across Europe, and ultimately supporting an effective implementation of biodiversity-oriented policies.

Social spontaneity as a mediator of associations between naturalistic settings visit frequency with caregivers and children's problem-solving ability

T5.18 Initiatives and Equity for Forest Education in a New Era

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Abstract: Children's exposure to naturalistic settings is declining, despite the positive link between play in naturalistic settings, learning, and development. Alternative educational initiatives such as visiting forests or implementing nature-based learning opportunities are increasing in popularity in Korea and internationally, yet little is understood about their impact on children's development. In this study, we examine the mediating role of social spontaneity (a positive social relationship with peers, and the ability to easily get involved in peer groups) on the relationship between naturalistic setting visit frequency with caregivers and children's problem-solving ability. A total of 862 Korean mothers with preschool-age children (3 to 5) were recruited for survey administration. The result of mediation model with PROCESS macro supported the partial mediating role of social spontaneity, indicating that naturalistic settings visit frequency with caregivers leads to better problem-solving ability both directly and indirectly through enhancing social spontaneity.

key words: forest, naturalistic settings, problem-solving, social spontaneity, forest visit with caregiver

T5.19 Innovating advisory systems to cope with complex forest governance

Agroforestry advisory services at the intersection of agriculture and forestry in Finland

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: Agroforestry is a land use system at the intersection of agricultural and forestry land uses. In Finland agricultural and forestry advisory services are in their own silos with agricultural advisory services being targeted to farmers and forestry advisory services targeted to forest owners. Whereas navigating purely agricultural and forestry advisory services is rather straightforward, the case is not the same for those who need advisory services in agroforestry. However, as agroforestry is a new, yet previously common land use practice in Finland, there is a need to have more targeted advisory services on it as opposed to having advisory services on conventional agriculture and forestry only. The Agroforestry Business Model Innovation Network (AF4EU) aims at promoting agroforestry in Europe through innovation driven interactive regional agroforestry innovation networks involving stakeholders from across the value chain in a multi-actor manner with Finland being one target country for it. In this study we explore perceptions of different stakeholders, namely farmers and advisors, on agroforestry advisory services in Finland focusing especially on advisory services on agroforestry related business models. Opportunities, barriers, and challenges that farmers associate with agroforestry and agroforestry related business models are explored. The data is collected through interviews and surveys targeted to stakeholders participating in the regional agroforestry innovation network in Finland. Besides farmers' and advisors' perceptions, we explore the regulatory framework for agroforestry in Finland in relation to developing agroforestry advisory services suited for local conditions. The results of this study bring new insights to policy makers, researchers, and advisors to develop advisory services on agroforestry in Finland and beyond, particularly in those regions where agroforestry is not among the mainstream land use practices.

Alternatives and openings for forest pluralism: Participatory research for democratic advisory and decision-making in Swedish forestry

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: The demand for diversified forestry in Sweden has been widely acknowledged for a long period, but its realization is lagging, highlighting the need for substantive changes in implementation. Previous studies have underlined the dominant and hegemonic position of present regime of the "Swedish forestry model"; focused on e.g. even-aged and clear-cut forestry, timber production, a high degree of Norwegian spruce or Scots pine monocultures and an advisory system that is dominated by timber purchasing organizations, that hampers innovations of forest management. By scrutinizing and challenging present procedures and knowledge production for forest advisory services and planning, this study aims at exploring behavioral, organizational, technological, socio-ecological challenges and openings for transformative, as well as incremental, changes towards a more diversified forest management, as well as the condition of agonism and pluralism in forest-related knowledge production, participatory processes, management, service provision and planning. To facilitate the demand for more diversified management that better matches forest family owners' needs and societal goals, we undertake a number of participatory processes that combines an organizational understanding of advisory, through private and public advisory organizations, with a poststructuralist approach to knowledge production on advisory and forest management within women forest owner's networks. The focus is on challenging hegemonic positions, knowledge, practices and understandings by investigating equivalence and differentiating logics as basis for alternatives, collective identities, subjectivities, resistance and discursive spaces to improve the understanding of advisory, relations, agency and democratic decision-making processes in private forest ownership beyond normative rationales.

Forest advisors' values and attitudes impacting on the outcome of the advisory process

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: Forest advisory processes are typically facilitating forest policy goals to the practical level. Thus, no wonder that several studies have analyzed the factors affecting the outcomes of forest advisory processes. Some of them have considered the role of the forest owners as a target group, while others have concentrated on the importance of tailoring the advising processes and methods for different kinds of forest owner types. However, significantly less focus has been put on the forest advisors' role, even though their impact on the advising process is equally important.

The forest advisors' personality, values, attitudes towards forest management, and behavior influence how and what information is brought to the discussion with forest owners, which in turn impacts on the success of the advising process and further achievement of forest policy goals. Through understanding the effect of these issues, service providers can consciously change their advising methods to improve their performance.

This study aims to understand how the forest advisors' personal opinions, attitudes and values influence the advising processes. For this, an e-questionnaire was sent out to the Finnish Forest Centre advisors (n=50). In addition, the characteristics of the advised forest owners, outcome of the advising process in a form of implemented forest management activities, the used contact method as well as the general customer feedback were collected from the Forest Centre's database. The data was analysed by using statistical methods. The results revealed that the more positive opinion the advisers had on the forest owners' own skills and knowledge regarding forest related issues, the better was their success rate in the advising process. In addition, for example the advisor's age and sex compared to the ones of advised forest owner had an impact on the success rate.

Forest certification and extension service as tools for efficient transfer of knowledge for forest smallholders

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: Sustainable Forest Management certification is a recognised tool to support sustainable development in forest management, and it is developed in all Continents since the early 90s. The role of extension, advice, and knowledge systems for the growth of this important tool has been crucial in several Countries, but in specific cultural contexts it was more successful than in other. In this contribution, we wish to describe and explore the different approaches in bringing forest certification (and the related chain of custody certification) in several Country contexts with different advisory systems, describing positive or negative results in implementation.

Forest-related Advisory Service Providers in Japan: From Extension System to Networking

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: The Japanese forestry extension system was introduced to Japan after World War II under the direction of the United States. The extension system operated in the 1950s and 1960s as a primary policy instrument for small-scale forest owners but was later relatively neglected, as the government focused on public investment. However, interest in advisory services in Japanese forest policy has increased recently, enhancing and encouraging knowledge interchanges through diverse means.

This study aimed to understand (1) the development of the forestry extension system in Japan with a focus on knowledge generation and power balance, (2) recent changes in forest-related advisory services and their contexts, and (3) the characteristics of advisory service providers in Japan.

Instead of a top–down approach, voluntary self-learning was emphasized for forest owners in the early stage of the forestry extension system during the 1950s. However, the extension system was gradually transformed into a means of directing responses to occasional government priorities. In the latter part of the first decade of the 21st century, the government again began to focus on personnel training to deliver forestry advisory services. However, this did not necessarily mean that it unfolded within the forestry extension system. Conversely, discrete actors exhibited a growing move to form networks through which they could share forest-related information and learn from each other. Such networking endeavors were characterized by the diversity of forms and participating members. Essentially, these networking initiatives comprise voluntary activities undertaken by forest owners and other actors. However, forest administrations often provide networking opportunities and contribute to the gathering of a wide-ranging group of actors. Forest-related service providers now seem to exist in a variety of forms and are engaged in seemingly chaotic relationships instead of functioning within an organized system.

How does a systems approach guide our understanding of forest advisory services?

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: Forest advisory services can be understood as a system, which consists of the stakeholders (e.g. the various service providers and forest owners) and linkages between them (modes of communication, tools and methods) in service to objectives (management and policy goals). Our conceptualisation of this as the FOrest Knowledge and Information System (FOKIS) in 2020 was modelled on parallel analysis of the AKIS in agriculture. Most users of this paper focus on its description of patterns and trends in ownership, advisory service provision and methods. The systems element of the approach has received less attention. This paper revisits the value of such an approach (a) as an guiding concept to who is participating, in what, why, and how, in different contexts; (b) to understand the multiple values and goals of different actors; (c) to understand innovation, as a complex non-linear phenomenon; (d) to focus on credibility, trust and usefulness of information. It reviews progress in the light of current policy, forest management and research developments to help identify areas for useful comparative analysis. It considers the implications of the European focus, and looks more widely to consider the effects of context, connection and consequences. Themes include the following. 1. If functioning as a system, does the FOKIS serve an overarching purpose (such as sustainability or adaptability)? 2. The fit of a country's FOKIS to historical, social and ecological conditions may appear to lock in a particular approach; what is the scope for learning and flexibility (e.g. through networking)? 3. What are the impacts and outcomes of different FOKIS and their components? Some of the greatest impacts of forest management result from the activities of institutional (e.g. commercial and investment) forest owners; this component of FOKIS is under-researched. 4. Comparisons with studies of AKIS highlight the value of research into communication between components of the system (e.g. between different services, or between different types of owners) and in focusing on innovation as well as knowledge. 5. How do 'soft' aspects of the system including personal values and cultural or professional norms affect the evolution of the FOKIS, and its impact?

Nudging forest professionals to give forest management alternatives for climate change mitigation

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: The demand for different forest ecosystem services is increasing. In certain countries, forest management decisions often rest with non-industrial private forest owners, who have diverse objectives for their forests. This diversity provides a promising context for the production of different forest ecosystem services through incentives and persuasion rather than strict regulatory control. Additionally, drivers such as urbanization and aging population will increase the need for advisory and forest management services. However, there is limited knowledge about attitudes and actions of forest professionals who provide these services, despite their significant role in forest owners' decision-making.

Our study focuses on the behavior of forest professionals and the alternatives they provide to forest owners with a particular focus on climate change mitigation. Our research questions are: i) what owner- and professional-specific factors affect the management alternatives forest professionals offer to forest owners, ii) how well do professionals consider the preferences of the owners when giving advice, and iii) can professionals be nudged to provide alternatives that support both the owner’s individual objectives and climate change mitigation?

We take reference of the literature on financial advisors and implement a choice experiment (CE) survey targeted at forest professionals. The CE is designed for a forest management activity that is relevant for climate change mitigation: continuous cover forestry. We execute key informant interviews to deepen the understanding of the interaction during the advisory service and to identify and validate the attributes of the CE. Continuous cover forestry is currently not a mainstream practice and involves uncertainties compared to traditional even-aged forest management. However, some owners may be willing to accept these uncertainties if they believe that this will bring other potential benefits. Based on these findings, we will explore if and how a nudge can influence the alternatives offered by professionals to forest owners.

The results of this study will give stakeholders insight into the complexity of different factors influencing forest professionals’ decisions when guiding forest owners. This knowledge can be used to develop and diversify advisory services towards tailored solutions to forest owners with different forest management objectives, including those related to climate change mitigation.

Services for forest owners at the Swedish Forest Agency: scrutinizing the shift from advice to information

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: Local forestry advisors at the Swedish Forest Agency (SFA) have traditionally played a very important role in influencing forest management across the country. However, in recent years SFA's ability to provide individualized advice has been in decline, while private advisors have taken over much of the contact with forest owners. This study explores the range of services provided by SFA today, revealing that SFA does indeed still provide services to owners, though in new constellations and nontraditional forms. Different kinds of services are provided by the local forestry consultants versus the specialized personnel at the headquarters. These two groups of service providers have contrasting competence areas, tools, target groups, and rationales. Informed by analyses of written SFA documents and interviews with service provides at SFA, we scrutinize the effectiveness of SFA's tools for meeting forest owner goals and broader policy objectives.

FOKIS is the key point of departure for this study, providing an overall analytical frame. Drawing from the theories of knowledge management and service-dominant logic, this study develops a framework for examining advisory services on the spectrum from information to advice. Information services are typically unidirectional and more general in scope. Advice, in contrast, requires a specific context (e.g. a particular forest stand) as well as interaction between the advisor and receiver. The extremes of the spectrum are associated with the ability to transfer different forms of knowledge, and their effectiveness varies widely depending on the policy goal and target group. These services can be synergistic, however, when opportunities arise to combine them over time. We problematize the tension between information and advice in relation to the ongoing trends of digitalization and the diminishing personal interaction between advisor and forest owner. In similar vein, we examine the effectiveness of advisory services in the context of the sharpening organizational struggle between providing advice versus the legal enforcement. We hypothesize that these core tensions create fundamental challenges for effective innovations of advisory services at SFA.

Strong sustainability forest services – Decision support for a more sustainable forest use in private forests

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: Our society is currently transitioning towards the concept of strong sustainability in which the planetary boundaries set the main criteria for evaluating human activities. Due to the various expectations for the utilisation of forests, this transition has proven to be challenging for the forest sector. Such transition to strong sustainability is also called for in the decision-support services for private forest owners. So far private forest owners have not been supported in considering forest use from the foundations of strong sustainability. Prior research has already configured the central reasons why such services have not been developed: the difficulty of detecting demand for these services under the current regime and the difficulty to move away from prevailing value creation logics. Hence, this research project focuses on solving the lack of strong sustainability-oriented decision-support services for private forest owners.

The research aims at creating an innovative strong sustainability business model for forest services and developing education for forestry experts to respond to the needs of the sustainability transition. By reviewing literature and interviewing forestry experts and forest service companies we will investigate the development of a strong sustainability forest service business model. Then we will analyse the practicality of the developed business model by introducing it to forest service companies. In addition, we will investigate what kind of expertise forestry experts and service companies need to provide such forest service. Thus, the issue is studied on three levels: the forest ecosystem level, the forest management planning level and the operational level.

We hypothesise that through the strong sustainability business model, sustainability challenges could be solved while providing new business opportunities for forest service companies. The value creation logic of these forest services should promote the well-being of nature and people beyond economic gains from wood production but also fulfil the forest owners' other objectives. These new business models could for instance relate to restoring ecosystems or producing non-timber forest products and services. In addition, we hypothesise that the future expertise of forestry experts is two-fold, forest planning and operations should be seen through both ecological and traditional forestry lenses.

Updating policies and strategies to achieve sustainable growth and job creation through wide target groups participation

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: This study focuses on the need for an updated policies and strategies in Finland and the EU that aim to achieve sustainable growth and job creation through wide stakeholder, advisor, policy maker and private forest owners (PFO) cooperation and comprehensive analysis of forestry and the bioeconomy trough showcasing all Finnish regions. The Sustainable Growth and Jobs 2021–2027, Finland's ERDF Structural Funds Programme, is one of fourteen regional forest programmes in Finland based on regional divisions. This program integrates economic, ecological, and social objectives, serving as a development plan and work programme for the entire forest sector in all regions. The polices and strategies has the potential to create significant opportunities for the advancement of forest-based livelihoods for the above mentioned target groups. A key objective of the strategy would be to fully harness the sustainable wood potential and promote local wood processing and the multifaceted use of forests through prioritized actions. It emphasizes the need for developing diverse forest utilization, including ecosystem services, bioenergy, and tourism. This study aims to identify these prioritized actions through participatory policy maker, stakeholder involvement, by including private forest owners and advisors. The goal is to optimize the vast potential of private forests, thereby enhancing forest policy instruments and facilitating their implementation by fostering exchange of experiences and policy learning among FOREXT (European Forest Advisory Organisations Network).

Utilising gamification in forest advisory systems to support forest owners' learning self-efficacy.

T5.19 Innovating advisory systems to cope with complex forest governance

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Abstract: Forest owners are increasingly being asked to adopt online and mobile-enabled forest advisory systems which have been created by forestry service providers to aid forest owners in their decision-making. Oftentimes, artificial intelligence (AI) is employed to assess the need for various operations and forest owners then have to decide whether to agree with these AI-generated recommendations or not. While these technological innovations aim to aid problem-solving and help decision-making, they do not necessarily consider the varied levels of knowledge about forestry concepts and individual motivations that forest owners have. Therefore, forest owners may have little confidence in using these tools and their uptake and acceptance may be affected negatively. New or inexperienced forest owners may not fully understand what they are being asked to make decisions about and current forest advisory systems do not acknowledge this or address the motivation of forest owners to learn about their forests. Therefore, applying gamification design to forest owners' information systems could be one innovative option to address this.

Gamification refers to the use of game-like or playful elements in non-game settings. These may be applied to information systems to motivate users to better understand the data they see, increase engagement with that data, and encourage user enjoyment of using the system. Gamified, or motivational information systems, are often encountered in daily life e.g., fitness tracking and language learning applications. These applications utilise gamification affordances, the most common being badges, levels, and leaderboards.

In this study, gamified and non-gamified versions of an online learning platform module are used to test the effects of learning self-efficacy in forest owners in Finland. The gamification elements in the module design are assessed to see how they affect participants' motivations and confidence in decision-making as they relate to self-efficacy and educational attainment.

In this presentation, the preliminary results of this study are presented and the effects of utilising gamification and motivational information systems in forest owner education applications and forestry advisory services are examined.

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

A classification and interpretation of approaches to natural capital valuation to pursue more sustainable and multifunctional forest management

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: This paper reviews existing Natural Capital valuation (NCV) approaches in the context of woodland, forest, and riparian ecosystems. To classify these approaches, it adopts a methodology proposed by the UK ENCA, an initiative that helps researchers and practitioners to better understand the values of nature and takes these values into account in the decision-making processes. In addition, the perspectives of policy and decision makers operating in the Scottish forest context on valuing nature have been integrated into this research.

The findings indicate that 'traditional' economic analyses (e.g., monetary valuation) of forest management options (through welfare valuation methods) currently receive reduced attention in the scientific literature. Landscape scale initiatives addressing the relationships between people and places tend to more frequently inform the values associated with woodlands. Methods that are being increasingly employed to capture stakeholder non-utilitarian values include participatory GIS mapping, scenario planning, and multi-criteria analysis. These methods could help identify, explore, and quantify even less tangible (e.g., cultural) ecosystem services (ES). Mixed methods are developing to elicit changes in stakeholders' decisions concerning forestry and on forest ES (e.g., timber production, carbon sequestration, tourism) under changing climate scenarios, (e.g., valuing losses from the increased drought and wildfires) and for different climate policy options. In addition, many studies address place-based NCV working towards the integration of contextual and relational values into forest/woodland relevant decisions and considerations derived from the workshop suggest implementing NCV by integrating a range of transcendental and shared values (arising from an eco-centric perspective of valuation) into the classical, instrumental value lens. This would help informing broader aspects of woodland development and sustainable forest management that may foster more effective nature conservation and the use of forest for multiple purposes (including timber) and support the management of conflicts.

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Addressing spatial, temporal and social challenges in nature contributions to people assessments for improved decision-making in forestry

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Forests are one of the most relevant terrestrial ecosystems in terms of their geographical extent, biodiversity and nature's contributions to people (NCP). Decision-making about forest adaptation to climate change is particularly important, as forest dynamics are determined by long-lasting management decisions. Therefore, assessments of forest ecosystem services and NCP have been increasingly used for policy-making from local to global scales. However, there are still important challenges to improve decision-making by better understanding the spatial, temporal and social dimensions of NCP - and their interactions. Here we aim to assess the main current challenges regarding these three dimensions, also indicating potential ways forward in order to better inform policy and decision-making. The main identified challenges are: (1) for the spatial dimension, identifying the relevant spatial scales and drivers of NCP supply and demand and their spatial mismatch; (2) for the temporal dimension, improving the predictive understanding of the temporal dynamics in NCP, accounting for the fact that service supply and demand are both dynamic and

frequently uncoupled; and (3) for the social dimension, considering the diversity in NCP social perceptions and the social mismatches and legacy effects arising from NCP management decisions. We describe these challenges and their interactions and suggest potential solutions and recommendations for policy-makers and forest managers. The main solutions we identify include methodologies to integrate the spatial scales at which a given NCP is supplied and demanded, measuring and anticipating spatial and temporal mismatches, and incorporating temporal and spatial variability of social perceptions of NCP. Finding solutions to these challenges is essential to increase the accuracy to estimate how NCPs contribute to human well-being, considering the complexity and heterogeneity at the spatial, temporal and social levels.

Appraising participatory natural capital valuation in research and governance for supporting improved forest resilience & pathways to societal impact.

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Recognising the values associated with Natural Capital (NC) is increasingly considered important in research and governance that aims to strengthen forest resilience. Recently, researchers have adopted more holistic, transdisciplinary and participatory methodologies for NC valuation, in attempts to account for people's diverse relationships with and values for the natural environment. This is often done with an expectation that incorporating input from stakeholders can improve the efficacy of research findings for policy and practice, and identify pathways to societal impact. However, it is not clear to what extent such approaches and information regarding valuation of NC are being operationalised. In this paper we combine findings from: i) a thematic synthesis of academic publications on research pertaining to use participatory approaches for NC valuation; and ii) a review of policy documents regarding the incorporation of participatory NC approaches into forest policy in the UK and Scotland, with the aim of identifying current synergies, as well as exploring how forest governance can benefit from NC valuation. We find that, although the adoption of participatory methods has served research interests well, in the sense of increasing the richness and granularity of understanding around NC, this has rarely seemed to directly influence practice. Adjacent to this, whilst secondary Scottish policy increasingly includes participatory consultations in attempts to operationalise concepts related to NC and its valuation, such approaches appear to falter after the testing phase. This raises questions about how to embed the results of both research and policy consultations in practice within various spheres of decision-making that shape Scottish forest governance. We argue that many of the outputs of participatory NC approaches may have limited useability or influence in national-level decisions, as currently framed. However, more locally-situated and site-specific decision-making would benefit from moving towards full co-production of research and local agency in governance. We conclude by suggesting ways in which NC can learn from other fields with a strong focus on integrated and end-user-oriented methodologies, to help appraise the credibility, salience and legitimacy of knowledge outputs and production processes, which may help ensure future valuation initiatives improve the management of forest ecosystems.

Are fancy decision support tools sufficient to convince a pessimistic forest decision-maker?

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: The use of decision support tools to assess, facilitate, promote, and enhance forest management practices is a common approach in modern forestry. These tools often incorporate features to account for climate change and its impact on forest growth, global timber demands and prices. They also simulate future trends in forest ecosystem services, as well as the behaviour of forest owners or managers. However, computer-based decision support systems have never gained popularity among forestry decision-makers in Lithuania. One possible explanation for this is that the forest sector in Lithuania still struggles to adapt a command-and-control approach in forest governance, which is a remnant of the totalitarian socialism era. This approach involves strict adherence to guidelines set by central authorities and heavy reliance on the opinions of established experts. This study aims to demonstrate how different forest management scenarios are interpreted and accepted by various forestry stakeholders with different professional and ideological backgrounds. The simulation of forest development and the delivery of diverse ecosystem services within a relatively large state forest estate were carried out under three alternative scenarios: production-oriented management, multifunctional management, and set-asides, each emphasizing the maximization of specific groups of ecosystem services. However, the delivery of ecosystem services belonging to the three most important groups—timber supply, biodiversity protection, and carbon sequestration—were predicted to remain at least non-decreasing over time. Subsequently, we conducted interviews with two groups of professionals actively engaged in the forest sector but with different educational backgrounds and professional experiences: traditional foresters and modern environmentalists. The aim was to evaluate the impact of alternative forest management approaches on the delivery of ecosystem services. The interpretations based on the modelled data showed less variation between the groups compared to a quick assessment of scenarios based solely on their identification, highlighting the significance of forest decision-makers' preconceived notions and biases.

Assessing and comparing the multi-service potential of different forest types: methodological challenges and perspectives for forest management

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: People expect forests to provide many ecosystem services (ES) simultaneously and in a sustainable way. Potential of forest ecosystems to provide multiple ES should be the basis for sustainable forest governance and use. However, estimating multi-service forest potential is a complex process. Even minor modifications at any stage of the assessment (formulating assumptions, selecting and defining services, constructing indicators, selecting source data) may affect the results. The aim of this study was to propose pathways to assess and compare multi-service potential of various forest types and discuss methodological challenges and opportunities for implementation in forest management.

Our case study was State Forests in Poland, covering 7.16 million hectares. We selected 17 key forest ES for the assessment, including timber, forest fruits, mushrooms, global and local climate regulation, air purification, pollination, habitat maintenance, and providing environmental settings for recreation, health regeneration and education. Due to the lack of standard ES assessment procedures, knowledge gaps, as well as the need to match indicators to existing data, a significant part of indicators are original proposals. We used data from the Polish Forest Data Bank, as well as satellite data, literature and expert assessment to calculate the proposed indicators. To capture the diversity of forest ecosystems, the national classification comprising 36 forest habitats was applied. The ES potential of these habitats was estimated based on the characteristics of sites with stands over 80 years old.

We showed that forests in Poland have the capacity to provide many important ES for people, and that their potential varies substantially depending on the type of forest and region. Only certain forest types can be considered multi-service hotspots, e.g. mountain forests on fertile soil with moderate moisture content. The main challenge for us was the weighting of services. Although being aware that ES are not equally important, due to lack of sufficient premises and appropriate source data, we treated each service the same (weight=1). Still, the developed analytical pathways can be used as a reference point and framework for a standard procedure for monitoring the forest ES potential.

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Can forest carbon offsets contribute to the net zero commitment? Pathways and barriers to develop sustainable and credible carbon offset in Spain.

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Using nature to capture and store carbon in soils and vegetation as a way of offsetting greenhouse gas (GHG) emissions is gaining a renewed interest for many organizations to support their net zero commitments. In Spain, the National Office for Climate Change launched in 2014 a Carbon Footprint Registry where organizations can document on their carbon footprints, their efforts to reduce GHG emissions or offset them through domestic afforestation/reforestation actions, including interventions to restore forested areas impacted by wildfires. The number of organizations participating in the Registry is limited, although it is growing quickly along with the number of forestry-carbon-sink projects promoted, posing challenges concerning the quality and sustainability of the resulting offsets. In this study, we investigate the potential and feasibility for generating forest carbon offsets that are truly additional, long-lasting, and are aligned with sustainability principles. To address our research question, we used in-depth-interviews and a participatory workshop to investigate the perceptions and priorities of stakeholders taking part directly or indirectly in the Registry around the performance and future perspectives of forest carbon offsets in Spain. This analysis was complemented by public data analysis on registered forestry-carbon-sink projects and offsets. Participants identified key barriers, risks, and opportunities around four main topics affecting forest carbon offsetting in Spain. Those include carbon and co-benefits accounting and valuation, long-term maintenance of forestry-carbon-sink projects, transparency in carbon markets, and management of risk. Key barriers included lack of consideration of ecosystem services or of the role of soils in carbon offsetting in the online tools used by the Registry, lack of diversity of types of carbon removal projects, or lack of resources in the National Office for Climate Change. Participants proposed and prioritized pathways towards a future transition such as increasing resources to grow the technical rigor and coverage of the types of projects that can be registered, including projects of forest management and habitat enhancement in the actions considered for carbon offsetting, incentivizing communications between key actors in forestry sector and organizations offsetting their carbon footprints, or the creation of a carbon price observatory to offer reference values to the registered members.

Co-creation of governance innovations for sustainable forest ecosystem services: behavioural approach

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: The high complexity of forest ecosystem services (FES) calls for novel governance arrangements for their sustainable provision. To understand the potential for FES governance innovations, it is essential to determine key influences of their emergence and development. This requires constant reflection and reconfiguration of governance arrangements to varying contextual conditions and actors. The paper is concerned with co-creation of FES governance innovations, contexts and actors that influence their development using behavioural approach. We use a newly designed role board game (RBG) – an interactive agent-based model for co-creation of novel governance demonstrated on six governance innovation cases in Europe. We aim to determine: *(i) How can governance innovation be co-created for long-term sustainability transformation in diverse forestry contexts? (ii) What motivates actors' behaviour towards sustainable provision of forest ecosystem services? (iii) What are the lessons learned to foster FES governance innovation co-creation?* The results indicate institutional robustness, biophysical conditions and actors' dynamics as key contextual conditions for sustainable FES provision. The RBG as an innovative method for simulation of real-world processes, assessing natural and social values interconnection and co-creating novel social practice while learning about ecosystem dynamics and potentially changing human behaviour.

COMMUNITY FOREST MANAGEMENT IN HIMALAYAS: STRENGTHENING RESILIENCE OF ECOSYSTEM SERVICES AND SOCIETAL UPLIFTMENT OF COMMUNITY- MANAGED FORESTS

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: The community forest management (CFM) is an integral component of sustainable forest management scenario across the globe. The rural poor community relies on the local forest ecosystems for their sustenance and livelihood generation. This direct link between community and forest has significant implications for societal upliftment and have various umbrella impacts on the forest dependent communities.

In the global context, forest management is currently challenged by the need to address an increasing demand for a wide range of ecosystem services. The study aims to enhance understanding by acknowledging ecosystem services that can strengthen local communities and align stakeholders to define priorities and objectives for the sustainable forest resource management, employing a scalable local-to-landscape approach.

To address this, we have conducted a study to identify the Forest Ecosystem Services (FES) under Community managed forest (CFs) as one of the notable examples of management of forest resources by active participatory approach of local communities in Himalayan region. We have investigated the stakeholder's perceptions and awareness towards these FES and their influence on local community's livelihood and resources.

The study was conducted in six CFs (referred as Van Panchayats – VPs) and data on the perception of community was collected from households through focus group discussions and semi structured interviews using participatory rural appraisal techniques like ranking and listing.

Our findings have revealed that local communities perceived reducing trends in the accessibility of various FES (mostly provisioning) particularly fuelwood and freshwater. However, study identified that local communities helps in managing forest fire, used to worship local deities inside CFs, protects the aesthetical value and perform eco-restoration activities at degraded sites by planting indigenous species.

In light of these findings, there is an immediate need to prioritise the socio- cultural conservation based incentives of local communities in policy formulation. This approach could assist in addressing difficulties within the forest ecosystem, contribute to the societal implications of ecosystem services at the local level, gradually improve forest management, and provide a foundation for future studies.

Keywords: Ecosystem services, Community perception, ecological restoration, Van Panchayat, Socio- cultural values

Conceptualizing Organizational Models for Sustainable Forest Management: Embracing Innovation and Complexity

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: In recent decades, epochal changes and challenges (i.e., climate change, fragmentation and abandonment of forest properties, changes in the ownership structure), together with disturbing environmental, social, and economic events (i.e., wildfires, wars, economic crises) are pushing the forestry sector to increase efforts in finding innovative solutions to foster sustainable forest management enabling the transition towards climate neutral, resilient, and green society. Traditionally, the research in the forestry domain has focused on product and process innovation, and more recently on innovations in business systems, non-wood forest products, and social and institutional innovations. Although organizational innovation was recognized and documented in scientific literature, the focus is mostly on northern countries. Additionally, consistent conceptualization works have been conducted separately for traditional business models and social innovation, somehow failing to capture all innovative forms of organizations working in forestry (e.g., networks, associations, partnerships, social entrepreneurship, etc.). Thus, the organizational domain in forestry seems less clear, as no recent frameworks cover the intersection of organizational and social innovation in forestry. In literature, concepts relevant to innovation in organizational models in forestry are either overlapping or discriminating against innovative networked models being characterized by multiple actors. The paper proposes a conceptualization of the organizational model as a concept embracing different approaches that capture the existing variety of organizations in European forestry. We present an analytical framework used to describe and characterize organizations in the forestry sector according to multiple criteria. The framework was drafted referring to existing theories in forest governance, organizational studies, and social innovation; then it was tested (and further refined) through a semi-systematic literature review on organizations operating in forest management in Europe. Various forms of organizational models were identified, and organizations were categorized and characterized according to selected criteria. This exercise confirms that forest management organizations are complex entities that can be described with several diverse arrangements. The framework can be used by policy and decision-makers for planning business and innovation strategies, as well as for cross-sectoral policy integration necessary for the improvement of sustainable forest management.

ECOFOREST and RIVERTOOL: Empowering Stakeholders for Sustainable Forest Expansion through Spatial Analysis and Decision Support

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Forests and woodlands offer a multitude of benefits to humanity. They serve as a valuable source of timber and food, while also playing a crucial role in carbon storage to mitigate the impacts of climate change. Additionally, they contribute to the reduction of flooding and soil erosion, as well as providing recreational opportunities for people and serving as habitats for various species that we strive to conserve. Nevertheless, forests can also encroach upon important habitats and, if planted on carbon-rich soils, may result in a net loss of carbon from the landscape.

In Scotland, forests cover approximately 19% of the country. The Scottish Government has set an ambitious goal to expand forest coverage by several thousand hectares per year in the coming decades, with the aim of supporting rural economies, safeguarding the environment, and benefiting local communities. To achieve this expansion in a manner that effectively protects and promotes ecosystem services and biodiversity, it is imperative to identify and prioritise suitable areas for planting while avoiding counterproductive locations.

To address this challenge, decision-makers must consider multiple, spatially explicit factors and their interactions within the landscape. Given the complex nature of this problem, which necessitates interdisciplinary knowledge and modelling, there is a critical need for tools that facilitate the exploration of different options.

In response to this need, we present two web-based interactive tools: ECOFOREST (Ecosystem services-based Criteria for Optimal Forest Expansion and Restoration) and RIVERTOOL (Riparian Vegetation Ecosystem Services-based Ranking Tool). These tools synthesise over thirty geographic data sets and several modelling results for the benefit of the user. They employ spatial multi-criteria analysis, a highly flexible approach that enables the generation of priority zonations for new planting. Users can customise the importance assigned to a selected set of spatial criteria and constraints, allowing for tailored decision-making processes.

ECOFOREST and RIVERTOOL significantly enhance the ability to explore various options for forest expansion. By utilising spatial multi-criteria analysis, these tools empower decision-makers to

make informed choices that prioritise ecosystem services and biodiversity conservation, while supporting sustainable landscape management.

Economic valuation of forest ecosystem services in Kisangani and its implications for sustainable forest management

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: A study was conducted to evaluate the economic value of ecosystem services provided by the Kisangani forest in the Democratic Republic of Congo. The study found that the Kisangani forest provides crucial ecosystem services such as climate regulation, biodiversity, timber production, and water filtration, with an estimated annual economic value of USD 97.5 million. However, the study revealed that illegal logging and conversion of the forest into agricultural land has led to a loss of ecosystem services and a decrease in their economic value, impacting the quality of life of local communities and the country's economy.

The discussion highlights the importance of economic valuation of ecosystem services as a tool to make informed decisions regarding sustainable forest management, but it must be used alongside other approaches such as community participation and logging regulations. It is also crucial to recognize the cultural and social significance of the Kisangani forest for local communities and ensure their needs and values are considered in forest management.

This study underlines the necessity of protecting the Kisangani forest for the benefit of local communities and the wider economy, emphasizing the importance of a holistic approach to forest management that takes into account both economic and cultural factors.

Estimating proximity effects to wildfire fuels treatments on house prices in Cibola National Forest, New Mexico, USA

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Forested landscapes in the Western US are subject to growing size and severity of wildfires, in part due to historical management strategies focusing on wildfire suppression. Forest restoration treatments and fuels reductions, including thinning and prescribed burning, can reduce the frequency and intensity of wildfires. Extensive restoration and fuels treatment efforts are underway across many areas in the Southwestern US, including New Mexico. The tradeoff between amenity values provided by forested landscapes and the wildfire risk associated with forested landscapes is becoming increasingly important to understand as development in the wildland-urban interface increases. Understanding how house proximity, relative to forest restoration or fuels treatments, is capitalized into home sale prices can provide useful information into how individuals value forested landscapes that have been altered to reduce wildfire risk or severity. We use a Hedonic Property Model to estimate the average treatment effect of proximity to forest restoration or fuel treatments in New Mexico, US. We use matching methods to estimate the average treatment effect of proximity to forest restoration. We find that proximity to the forest has a positive amenity value; however, proximity to recent forest restoration or fuel treatments results in a decrease in house sale prices. We combine the results of our two models and calculate that homes not within one kilometer of a treated forest and within one kilometer of Cibola National Forest sell for an average $73,626 premium. The average premium drops to $22,996 for homes within one kilometer of a forest that has been recently treated and within one kilometer of Cibola National Forest.

Exploring Forest Stakeholders' Perspectives on Payment for Ecosystem Services in the European Union

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Forests and biodiversity play a vital role in sustaining human life. The intricate relationship between forests and the everyday products and services we rely on has prompted the need for sustainable development processes that ensure the responsible use of natural resources while preserving them for future generations. Despite such efforts, forest ecosystems face alarming declines due to deforestation, resource overexploitation, and the impacts of climate change. This research aims to investigate the perspectives of forestry actors within the European Union regarding available financing mechanisms, mainly focusing on payment for ecosystem services. In-depth interviews were conducted with experienced forestry professionals from twelve member countries, employing a semi-structured approach to explore their knowledge, experiences, and utilization of payment for ecosystem services. Preliminary findings indicate significant variations in the implementation and utilization of compensation payment schemes, despite regulatory frameworks. Most interviewees (over 70%) demonstrate awareness of compensation payments; however, they perceive limited practical implementation primarily due to alternative incentives that align more closely with their interests. Conversely, some interviewees highlight the underdevelopment or mere proposal status of payment mechanisms in their respective countries.

Moreover, personal interest and private capital investment were identified as the primary drivers of conservation efforts for forests or ecosystems of interest. Furthermore, existing payment programs were found to be highly specific, limiting alternative forest management approaches. At the same time, access requirements and lengthy application processes posed barriers to their socio-economic and environmental benefits. Insights from forest stakeholders provide valuable suggestions to policymakers for improving the dissemination and accessibility of ecosystem service payment mechanisms, aiming to promote diversified and sustainable forest management within the European Union.

Forest Digital Twin to Support Sustainable Woodland Management and Planning

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Forests and woodlands offer many benefits, including timber, food, carbon storage, mitigation of flood and soil erosion, biodiversity habitats, water quality and flow regulation, shelter for livestock and recreation. Forest Digital twin potentially offers a much richer capability to monitor, analyze and simulate current and future forest state and support woodland management and planning.

In this work, using a case study from Scotland (Glensaugh Climate Positive Farm), we explored scenarios of woodland change and consider the multiple environmental and socio-economic benefits in terms of natural capital asset index, carbon storage, ecosystem services and biodiversity.

This approach combines Spatial Multi-criteria Analysis (sMCA) with interactive 3D GIS-VR platform and immersive forest and climate data visualisation, to showcase scenario models of different tree species and planting densities in Glensaugh which provides an innovative framework to integrate spatial data modelling, analytical capabilities and visualisation. It also allows the planner to incorporate high level of information and interaction into the development process, to get immersive experiences of the proposed scenarios and to capture user/stakeholder comments efficiently.

The Digital twin prototype for Glensaugh Climate-Positive Farming was used at the GISRUK 2022, 2022 Royal Highland Show and EGU 2023. Audience feedback suggested that the virtual environment was very effective in providing a more realistic impression of the different land-use and woodland expansion scenarios and environmental characteristics. This suggests considerable added value from using digital twin technology to better deal with complexity of data analysis, scenarios simulation and enable rapid interpretation of solutions.

Findings show this method has a potential impact on future woodland planning and enables rapid interpretation of forest and climate data which increases the effectiveness of their use and contribution to wider sustainable environment.

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Forest ecosystem services Web map as innovative tool for society

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: The paper describes the use of an integrated approach to assess the provision of ecosystem services in the forests of Slovakia with an orientation towards the end-user. Methodologically and analytically, it is based on the current state of the forest, using the dependence between the characteristics of the forest ecosystem, the applied management, the condition of technical equipment and the provision of ecosystem services.
New element is an application of an original system based on various spatial and attribute data. The proposed assessment model is based on publicly available forestry data from related sectors, verified by field surveys in the areas characterised by the different main forest functions (e.g. wood production, carbon sequestration, water regulation, hunting and recreation) in the sense of a citizen science approach. The assessment of forest ecosystem services enables the interactive mobile application, in which it is possible to identify valuable locations in terrain and store them in the geospatial layer.
The goal is to create a new interactive web-map application displaying the forest ecosystem services assessment results using spatial and attribute data on forest ecosystem services for forest owners/managers and the public. Its use consists in raising public awareness on the importance of forest ecosystem services, designing possible support instruments to forest managers (payments for ecosystem services), and in building consensus among different stakeholders on priorities in the use of ecosystem services.

Governance Innovations for forest ecosystem service provision – Insights from an EU-wide survey

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: In this talk, we analyse the occurrence of governance innovations for forest ecosystem service (FES) provision in the forestry sector in Europe and the factors that influence innovation development. Based on a European-wide online survey, public and private forest owners and managers representing different property sizes indicate what type of governance innovation activities they engage in, and why. To investigate forestry innovations as systems, the analysis focuses on biophysical, social and technical factors influencing innovation development. Our results show that most innovation activities are largely oriented towards biomass production. Accordingly, most forest owners implement efficiency-driven optimisation strategies for forest management and technological improvement for provisioning of services supply, to generate income and create pathways to societal impacts. In contrast to income generation, the provisioning of regulating and cultural services is not yet a prominent part of forestry innovation activities. Reasons are rooted in a market-oriented economic rationale focusing on timber production, which is related to a lack of financial resources to compensate for other FES provision or institutions to provide backup and security to forest owners and managers for engaging in innovation development outside wood production. If other FES beyond timber provision shall be provided, new forms of communication and cooperation, and innovation in FES valuation and financing are needed. Given that the provision of a wide range of FES is a politically well-established objective for forest management in Europe, a strategy is needed that helps to align actors and sectors for supporting related forest management approaches and business models. The current revision of the forest related policy framework on EU level under the EU Green Deal poses a window of opportunity for better fostering of novel governance approaches for a more sustainable provision of FES.

Healing interiors: in search of yet non-quantitative dimensions of social sustainability in building with wood concepts

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Buildings and built environment affect human wellbeing in many ways, creating an opportunity to develop sustainable, restorative buildings and materials. This ongoing research project studies human behavior and chosen psychophysiological parameters to create a holistic view on humans' wellbeing related to different living environments. The aim is to use a multidisciplinary approach to create better understanding on how novel material choices in built environments and interiors affect human's stress levels in longer term, and how psychophysiological load can be relieved by introducing different novel engineered wood and nature-based materials into housing. The study utilizes the Living Lab of Wood Construction at the University of Helsinki – a unique test bed for holistic wellbeing research. The research applies ambulatory health metrics technologies to obtain anonymous data from the voluntary study subjects randomized into cross-over trial. The study subjects live in both wooden and non-wooden housing for six weeks, and their heart rate, heart rate variability, skin electrodermal activity, and sleep metrics are monitored together with the self-assessments and targeted focus group interviews of perceived wellbeing. The study provides new knowledge on longer-term impacts of interior materials in built environments for human wellbeing. The results help design building materials that may provide stress-relieving, healthy and restorative environments for users in home or work environments. Moreover, the study aims to connect principles of sustainability assessment as part of the assessment of human psychophysiological wellbeing. Suitability of selected wellbeing assessment methods and biomarker measurement technologies are evaluated as part of a more comprehensive assessment of sustainability in the building with wood concepts. The results achieved will be discussed in the presentation.

How much does it cost to preserve Madagascar‘s humid forests through a conservation basic income

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

Herizo Andriambololona

Abstract: The northeastern region of Madagascar houses some of the world's most diverse forests, which are currently facing significant threats due to shifting cultivation practices employed by smallholder farmers. Although protected areas have made progress in curbing deforestation over the past decade, they have inadvertently caused severe injustices for the local population. These include the loss of land for future agricultural expansion and restricted access to timber and other forest resources, resulting in a decline in people's well-being. To ensure long-term support for protected areas, it is crucial to explore alternative conservation approaches that balance conservation success with the welfare of local communities.

One such approach gaining momentum in global conservation discourse is the concept of a conservation basic income. Our study aims to gather empirical evidence on the viability of implementing a conservation basic income to mitigate deforestation in northeastern Madagascar. We have conducted interviews with households residing in various villages within the buffer zone of Masoala National Park. Through these interviews, we have assessed the opportunity cost for the lost access to ecosystem services by communities. We have then investigated community's preferences regarding different forms of conditions and levels of compensation associated with a conservation basic income. In this presentation, we will share our preliminary findings and discuss their implications for designing an effective conservation basic income.

It is evident that the current situation calls for urgent action to safeguard the ecological integrity of these forests while addressing the socio-economic needs of the local population. By embracing innovative approaches like the conservation basic income, we can strike a balance that not only protects the rich biodiversity of northeastern Madagascar but also ensures the well-being of its inhabitants. Our research aims to contribute valuable insights towards achieving this delicate equilibrium, and we look forward to sharing our progress and engaging in discussions on the practical implementation of a conservation basic income.

How Natural Capital Accounts can support forest governance in an innovative way. Applications from INCA and LISBETH on woodland and forests in Europe

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: The System of integrated Environmental and Economic Accounting- Ecosystem Accounts (SEEA EA) was adopted as a standard by the United Nations Statistical Commission in 2021. Based on UN SEEA EA, regulation proposals on ecosystem accounts are being advanced in the Europe and in the United States, and a vast implementation program is being applied by the UN together with the Word Bank all around the world. The accounting of Ecosystem services is reported through Supply and Use tables that allocate the transaction of flows of services from ecosystem types to economic units, in physical and monetary terms. The "Woodland and forests" ecosystem type provides a vast range of services that support human activities in many ways: from the provision of ecological inputs, to the removal of pollutants, to the protection against physical and biological threats, to the contribution to global challenges (such as climate change and biodiversity loss). Ecosystem service satellite accounts can show that "Woodland and forests" provide much more than the timber provision service to the forestry sector; the majority of flows are indirect use values and also non-use values of which economy and the whole society greatly benefit. Such quantitative measurements can be used in a variety of ways: from the time series analysis, to the computation of composite indicators and sustainability scoreboards; they can also be used as input variables in conventional economic tools to assess the economic impacts of changes that affect forest ecosystems. This presentation illustrates each of these cases with concrete applications processed through the Integrated system for Natural Capital Accounting (INCA) project, founded by the European Commission, and further developed through the LInking ecosystem Services and Benefits to Economy THrough bridging (LISBETH) initiative.

Incorporating participatory assessment methods into natural capital valuation

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Keywords: ecosystem services, forest, stakeholders

The objective of this trans-disciplinary research is to analyse and advance existing methods of valuing nature. The specific objectives are:

- What are the gaps in natral capital (NC) valuation?
- Which of the dimensions of value would it be helpful to consider?
- How could these values be captured, measured, and valued to support more robust and end-user friendly knowledge transfer and decision-making systems?

We analysed a range of methods to value NC and ecosystem services (ES), and based on the review of literature (3,415 papers) and empirical examples examined main opportunities and challenges of valuation, to answer the question: can the augmented use of participatory and digital techniques offer new perspectives to enhance the basis for decision-making? We question when/where certain valuation methods are most pertinent, and how to integrate participatory, analytical, and digital tools for outputs to be most useful for end-users.

The team has adopted a mix-methods' approach and a participatory environment, in which stakeholder engagement and advanced science are being brought together. Preliminary findings suggest that monetary valuation alone can be insufficient and/or inappropriate because NC and ES are complex; there are inter-dependencies and uncertainties; components of NC may be unique or 'critical'; and as robust primary valuations are lacking. A proper combination of methods could enable more meaningful values to be placed on nature, while active involvement of stakeholders can offer a means for learning, and the co-development of capabilities to enhance the use of valuation knowledge in forest-related decision-making.

We anticipate that this research (the first of its kind in the UK) can underpin design of the framework and content of a toolkit of importance for stakeholders and a more participatory NC valuation could better inform policy decisions as to resource allocation, management, and use. Further research is required on best approaches for incorporating stakeholder perspectives into new strategies targeting the green recovery, and for translating the social capital created through participation into more effective actions on the ground.

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Integrating ecosystem service supply-demand into social innovation: spatial distribution and area identification

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Mismatch of ecosystem service supply-demand has been considered as the main driving forces of ecological degradation. Places with high human pressure could be distinguished by analyzing spatial distribution of ecosystem service supply-demand. Here, taking Wolong Natural Reserve in southwestern China as case study, we evaluated ecosystem service supply-demand ratio from the perspective of local community. The results found spatial heterogeneity of ecosystem service supply-demand in the study area. The area and proportion of areas with high supply and demand for ecosystem services are relatively low and concentrated, mainly concentrated in the central residential areas and areas with concentrated cultivated land resources. Regions with surplus, equilibrium and deficit of ecosystem service supply-demand were identified by comparing ecosystem service supply-demand ratio. Totally, 96.25% of the total study area exhibited a surplus of ecosystem service and 3.52% exhibited equilibrium of ecosystem service. Only 0.23% of the total study area exhibited deficit of ecosystem service. But relating to specific ecosystem service, deficit area of freshwater supply and soil conservation reached 7.08% and 8.97% respectively. Also difference of supply-demand existed among local stakeholders. Conservative stakeholder confronted with the most deficit area of traditional crops, soil conservation and maintaining soil fertility. Aggressive stakeholder confronted with the most deficit area of freshwater. Combing local ecological and socio-economic status, we found that spatial distribution of deficit area resulted from local physical conditions, local livelihood dependence and ecosystem services accessibility. Finally, ecological risk zone and ecological conservation zone were put forward and divided in the study area by synthesizing local ecosystem services supply and demand.

Mapping Citizens' perceptions of cultural ecosystem services provided by urban green spaces and comparative analyses between Germany and South Korea

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Cultural ecosystem services are non-material benefits people obtain from nature, including recreation, aesthetic enjoyment, physical and mental health benefits, and spiritual experiences. While those benefits directly influence human well-being and are distinguishable from other ecosystem services, they are challenging to measure due to their subjectivity and complexity. Thus, there needs to be more research on cultural ecosystem services and approaches in comparing perspectives on cultural ecosystem services across the countries. With the case study on German and Korean cities, this research examines public perceptions of cultural ecosystem services from green spaces, especially urban forests. A map-based online questionnaire was conducted via the Maptionnaire software to allow accurate and detailed assessments of cultural ecosystem services with spatial data, and involve residents in assessment and management. The questionnaire results showed that the perceptions of cultural ecosystem services vary not only between countries but also based on their social, behavioral, and economic background. Based on the participatory mapping, the spatial distribution of cultural ecosystem services in each city was visualized, which can contribute to a better appreciation and easier understanding of the social and cultural values from urban forests for end users. The result of this study will provide insights into maximizing co-benefits in nature-based solutions, improve forest policy and governance, and support decision-making by incorporating public perception and values of cultural ecosystem services in two countries.

Monetary estimates to justify investments in forest restoration. Applications in Europe

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Ecosystems provide services to economy and society. Ecological processes become services when an ecosystem potential supply interacts with a socio-economic demand. On the one hand, the match between these two sides generates a service flow; on the other hand, a mis-match may occur when a potential flow is not used, or when there are no ecosystems able to provide the needed services. Thanks to the INCA approach, it is possible to locate spatially and measure mis-matches in terms of ecosystem services in physical terms. Such mis-matches can be eventually translated in monetary terms. This valuation estimates the flows of the services that are yearly lost because ecosystems are not able to provide them to human activities. When computing a cost-benefit analysis, this kind of assessment can support and justify the need for restoration actions. Woodland and forests are the ecosystems that provide most of services for a variety of uses (ecological inputs, pollution removal, protection and global target compliance) to many users (economic sectors, households, government). The Nature Restoration Law in Europe and the Kunming-Montreal Global Biodiversity Framework advocate for restoration actions in both terrestrial and marine ecosystems. This presentation illustrates a concrete application on matches and mis-matches of forest ecosystem services. They are assessed in physical and monetary terms. The monetary valuation of lost flows is eventually discussed in terms of advantages of carrying out and implementing restoration actions where ecosystem services mis-matches occur.

Natural capital in the Dutch building sector: local and global impacts

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: There is a great need for housing in the Netherlands. The nationwide goal is to construct 900,000 new homes until 2030. This will put pressure on local natural capital (e.g. land, drinking water and recreational activities) and on global natural capital (e.g. construction materials). Taking care of natural capital can be pursued through a nature-inclusive approach to the urbanization task facing the Netherlands. Mass timber products are, potentially, a sustainable alternative to traditional building materials but the environmental benefits and circular economy aspects need to be evaluated (Ahn et al., 2022). However, where demand for timber increases, the maximum supply is limited by sustainability constraints and the willingness and ability of suppliers to increase supply (Lerink et al., 2023).

The need to include natural capital in integrated policy-making is gaining traction nationally and internationally, as recognition of the central role of nature in a future-proof and sustainable society grows. In ecosystem accounting literature, a new phase started revolving around the testing, engagement and adoption of ecosystem accounting (Comte et al., 2022). A key step is the link between ecosystem accounts and users, in view of the need for more integrated forms of policy-making.

In this paper we focus on the natural capital required in the form of building materials. We focus on the impact of timber construction through changes in the value of the world's forests directly and indirectly affected by Dutch construction. To provide this global context, we use meta-analytic value functions to include the value of forests in all regions relevant to the Dutch Building Challenge. The use of timber is analyzed using the MAGNET macroeconomic model, which includes the value of ecosystem services at the country level. The aim of this paper report is to map the policy playing field and understand what knowledge on natural capital accounting and forestry is needed to further develop the guidance and implementation structure for integrated policy making.

Pareto in the landscape: analyzing the potential supply of ecosystem services on a landscape level through efficiency analysis

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: In this study, we utilized the concept of Pareto efficiency to develop a framework for analyzing multiple ecosystem services (ESs) on a broader scale than individual ecosystems. Within this framework, ESs are considered as outcomes of functioning landscapes that require inputs to operate. These inputs represent the costs associated with managing various land uses or the average cost of producing products and supplying ESs linked to specific ecosystems. Given limited resources and the provision of ESs, the problem can be formulated as a mathematical linear program, enabling the use of operational research methods. We employed Data Envelopment Analysis (DEA) to examine the efficiency of different Units of Assessment (UAs) in producing ESs with given inputs and regression analysis to assess the factors influencing UAs efficiencies. To validate the framework, we selected a region in Southwest Slovenia and divided it into 627 UAs, each measuring 1 x 1 km. We modeled 17 ESs that had been previously identified as important and utilized freely available spatial data sources. The software tools used for organizing, producing, and visualizing the results were ArcGIS PRO 3.0, InVEST 3.10.1, and MS Excel. We employed Win4DEAP 2.1 software to conduct the DEA analysis and Gretl 2022c to run a Tobit regression analysis to identify the key factors influencing efficiency. The most efficient UAs are characterized by a larger share of forests and a smaller share of urban or other agricultural land uses. These UAs supply the most ESs for lower inputs, thus serving as benchmarks for inefficient UAs. Importantly, considering the costs of management as inputs in the presented framework adds an economic component, which is often overlooked in ESs analyses on a landscape level. The framework provides the foundation upon which more sophisticated models, such as dynamic models, can be built.

Spatial patterns of supply and demand for forest ecosystem services in Europe

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Forest ecosystems provide multitude services to the society. Indicator-based assessments focus on their supply and valuation studies look at their demand. Basic economics states that equilibrium is where supply meets the demand. Does it exist for Europe's forests? In this study we aim to answer this question. Data for eleven forest ecosystem services is drawn from two Europe-wide surveys, where supply is provided by forestry practitioners and demand is provided by general population. Supply and demand data is then further extrapolated on a 1-kilometer spatial resolution for almost all of Europe's forests through application of machine learning, which combines survey-data with Europe-wide geospatial data. Results show patterns of supply and demand across Europe, describe how forests could be clustered based on these patterns and also link supply and demand data to forest descriptors (e.g. growing stock, tree species composition, protection status, distance to the city, etc.). Aside these direct results, the study also advocates for the notion that some methodologically sound and comparable data on both supply of and demand for forest ecosystem services is needed to sustainably govern forest ecosystem services provision.

The role of the innovation system in local payments for forest-water-related ecosystem services provision

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Almost all drinking water from surface sources in Slovakia is tied to forest ecosystems. Most water reservoirs (nine in Slovakia) for drinking water "production" and abstraction points are in forested areas. Providing such services relates to the forest management practices that forest owners and managers apply. To secure the provision of water-related services, innovative local payment schemes can be implemented. A functioning innovation system is needed to fulfil this task. The paper identifies the innovation system prerequisites to support local payment schemes for ecosystem services (PES) adoption in Slovakia. We analysed the three basic functions provided by the innovation system: information, coordination, and incentives. Data were collected using a standardised questionnaire sent out to stakeholders from forestry, nature protection, water management and civil society. The service valuation was carried out using the alternative cost method, where the positive impact of forest stands was alternated with water treatment costs. Results show that the state should communicate information on payment implementation possibilities and provide a regulatory framework. Respondents identified priority areas, mainly around water reservoirs, favouring local schemes. State authorities play a key role in designing and implementing PES schemes and should introduce innovative governance models to finance ecosystem services. The forest owners near the water reservoirs represent the supply side. Water companies, municipalities, and residents represent users. The innovation system should provide monetary and non-monetary incentives to motivate interested actors to provide water quality and quantity services. Monetary incentives should be either regulatory or public-private. Based on these findings, we proposed a PES scheme that would cover the costs of forest management changes to increase the water protection service. The experimental assessment confirmed that dependence on water treatment costs increases with the decrease in the forest cover of the water reservoir basin. The value of the water protection ecosystem service of the forest was quantified in the range of 1.67 - 8.90 € per hectare per year. The stakeholders consider such local payments an innovative mechanism for financing forest ecosystem services in Slovakia.

Valuation and governance of ecosystem services of nature protection areas in Slovenia

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Protected areas are key elements of landscapes that are to facilitate conservation of either ecosystems and ecological hotspots or artefacts of past human interaction with nature. Different types of parks (national, regional and landscape) are an important part of nature protection system in Slovenia and are complementary to stricter nature conservation aspirations, such as nature reserves, natural monuments, Natura 2000 sites, etc. Their management usually focuses on above mentioned aspects of nature protection, however parks can contribute to wellbeing in other, perhaps previously ignored, ways as well.

The aim of the study is to identify and assess ecosystem services in five parks throughout Slovenia (Logarska dolina, Škocjanske jame, Kozjanski park, Goričko, Triglavski park) but in a highly participatory format and to investigate whether or not these protected areas provide more diverse and more abundant ecosystem services that surrounding non-protected areas. This is important in a wider context of empowering protected areas as in theirs, to some extent neglected, role in the society. We designed and implemented a series of workshops where we identified relevant ecosystem services in each park, then we made a link between ecosystem services and types of ecosystems that provide them, and in the last stage are evaluating their potential provision. We also addressed possible conflicts of interest in use of ecosystem services. Among all identified ecosystem services, we picked three, which are being spatially represented (mapped); grassland productivity in relation to grazing and grass fodder, recreational landscape attractiveness, and pollination potential.

The entire approach outlined above is also being implemented in a format of guidelines that are to be used by parks (and perhaps other protected areas in Slovenia) in future management. It lays down a participatory and innovative process of valuation and governance of ecosystem services in protected areas in Slovenia, that had not been implemented up to this moment, but it also serves as a platform for connecting managers of protected areas with local communities and decision-makers. Something which is not always in place, but is imperative to successful management.

Valuing Ecosystem Services of Trees and Woodlands in the United Kingdom in improving Mental Health: an Avoided Costs approach

T5.20 Innovation in valuation and governing of forest ecosystem services to strengthen forest resilience and create pathways to societal impacts

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Abstract: Trees and woodlands can impact mental health through a variety of pathways. However, few monetary estimates currently exist of the value of the associated forest ecosystem services.

We estimate the direct cost savings – including those to the National Health Service, considering four pathways through which trees and forests can impact mental health, based upon relationships identified in the wider literature. The pathways considered are (i) the impact of visits to UK woodlands on improving mental health; (ii) the impact of physical activity in woodlands in improving mental health; (iii) the impact of street trees in reducing anti-depressant prescriptions; and (iv) the impact of a greater proportion of greenspace in a neighbourhood on improving mental health. Dose-response relationships are used to estimate improved health outcomes. Indicative economic values are based on avoided treatment costs and reduced work absences.

To minimise potential risks of double counting, estimates are given separately for each pathway. Cost savings associated with street trees reducing antidepressant use are estimated at £16 million per year, those due to physical exercise in forests at £18 million per year, those associated with visits to UK woodlands are estimated at £185 million per year, and trees' contribution via neighbourhood greenspace at £394m per year at 2020 prices.

Drawing upon population projections for the UK, the natural capital value over 100 years (from 2020) is estimated to be just over £11 billion for the mental health benefits of visits to woodlands. The aggregate value for woodland visits and street trees of mental health benefits is estimated at just over £12 billion.

This paper provides a first estimate of the value of the natural capital benefits of trees and woodlands for mental health in the United Kingdom and can be compared to other natural capital values to help support further development of UK natural capital accounts and policy.

Potential areas for future research include additional work to quantify the impact of woodland visits on reducing the prevalence of mental health conditions such as anxiety, the long-term benefits of exercise in woodlands, and the extent to which associated benefits vary between woodland types.

T5.21 Modelling forest scenarios as if people, climate and biodiversity mattered.

T5.22 Modelling forest trajectories under climate stress and changing management

A Pan-European Perspective on Past Disturbance Effects on Vertical Forest Structure

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: This study investigates the relationship between vertical forest complexity and past disturbance regimes across Europe. Forests are essential components of the global carbon cycle, serving as vital carbon sinks and regulators of climate. Understanding forest structure is crucial for accurate carbon storage quantification and predicting future ecosystem dynamics. Disturbances, both natural and human-induced, can have significant impacts on forest structure and alter the carbon balance of ecosystems. These alterations affect vegetation composition, forest density, and vertical structure, ultimately influencing ecosystem processes such as carbon sequestration, biodiversity, and habitat suitability. Therefore, comprehending the linkages between past disturbance regimes and vertical forest complexity is fundamental for assessing forest responses to disturbances.

We use Level 1B product waveform data from the Global Ecosystem Dynamics Investigation (GEDI) to characterize vertical forest complexity. The GEDI waveform data provide detailed information on the vertical distribution of vegetation, enabling us to assess the degree of forest structure complexity at a pan-European scale. We derive a vertical complexity index by extracting features from each waveform, such as waveform height, width, skewness, kurtosis, and the number of peaks, and combining them in a single index using dimensional reduction techniques (e.g., Principal Component Analysis). We also introduce and utilize the EUForest4ModelCube, a comprehensive pan-European Earth Observation forest data cube. We leverage the EUForest4ModelCube to extract Landsat-based temporal dynamics of disturbances to identify and classify events from 2000 to 2020. Additionally, we use the EUForest4ModelCube to estimate the biomass gap due to disturbance regimes, defined as the difference between potential maximum and actual biomass, as a complementary disturbance metric, using the ESA-CCI biomass product at 100m for 2010, 2017-2020. The integration of the EUForest4ModelCube, GEDI waveform data and the derived disturbance metrics allows for a thorough exploration of the influence of past disturbances on vertical forest complexity across European forests.

Through this analysis, we aim to investigate the widespread pan-European coupling between past disturbance regimes and vertical forest complexity. The findings of this study will contribute to a better understanding of the relationship between disturbance and vertical forest structure, providing valuable insights for forest management and conservation strategies in Europe.

Applying deep neural networks to develop high-resolution future forest and disturbance scenarios

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Climate change challenges forest ecosystems and amplifies forest disturbances and their wide-ranging impacts on ecosystem services, biodiversity, and carbon storage. The ability to predict detailed vegetation dynamics and disturbance scenarios on large geographical scales is therefore gaining in relevance. To inform decision-makers, it is essential to incorporate both the direct effect of climate change as well as the interaction between forest development and disturbances into such scenarios. Here, we used the scaling vegetation dynamics (SVD) framework to upscale forest dynamics from stand and landscape scale to the continental scale to simulate high-resolution (100 x 100m) forest development trajectories. We couple those trajectories with process-informed statistical disturbance modules calibrated on remote sensing-based map products to further produce future disturbance scenarios under climate change.

SVD is a framework to simulate vegetation transition in response to environmental conditions. The predictions for these vegetation transitions are driven by a deep neural network (DNN), which is trained on forest simulations from process-based models. We established a database of local climate change simulations covering 10 million simulation-years across 13’500 locations in Europe. Coupling those simulations with auxiliary information of climate and environmental conditions, we created a training dataset for the DNN. The trained DNN predicts vegetation state transitions in response to environmental conditions, allowing to upscale forest dynamics efficiently. To initiate SVD on the continental scale, we compiled remote sensing products to establish a pan-European dataset on the current state of Europe’s forests (i.e., species composition, leaf area index and canopy height). Furthermore, we developed disturbance modules for wind, fire and bark beetles. These modules were built as process-informed statistical models based on historical disturbance and capture the relationship between environmental conditions and the occurrence of disturbances. These statistical models are integrated into the dynamic forest simulations in SVD, creating a feedback loop where the effect and extent of disturbances are contingent upon forest development states and, conversely, where disturbances can abruptly alter forest states. Our study is the first continental scale application of SVD and provides valuable insights into the potential impacts of climate change on European forests.

Assessing climate change impacts on Japanese cedar plantations: Mitigation and adaptation measures in shrinking scenarios

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Achieving a balance between mitigation and adaptation to climate change in forestry has gained increasing significance in forested countries worldwide. Numerous studies have assessed the impacts of climate change on planted forests, analyzing the effectiveness of both mitigation and adaptation strategies by comparing present and projected future conditions within the same geographical area. However, the extent of planted forest can vary over time. In the case of Japan, the ratio of planted forest to the total forested area showed a rapid increase after World War II; however, it is currently anticipated to decline due to the challenges posed by an aging society with a diminishing number of children. In this study, our objective is to investigate the interaction between the shrinking area of planted forest and the effectiveness of mitigation and adaptation measures in addressing climate change on a nationwide scale. The process-based carbon cycle model for Japanese cedar (*Cryptomeria japonica*, Toriyama et al., 2021, PLOS ONE) plantations, based on Biome-BGC model, is updated in two ways: 1) by extending the tree age to encompass higher age classes, and 2) by incorporating the growth patterns of the two major genetic types of Japanese cedar. We utilize climate scenarios (GCMs of MRI-ESM2.0 and MIROC6) and spatial scenarios of Japanese cedar plantations at a 1-km resolution. These scenarios cover a historical trend spanning from 1960 to 2010, as well as future projections extending to 2090. Future trends are generated by considering different rates of harvesting (high/low) and re-planting of Japanese cedar (high/low). This approach results in four different future scenarios: baseline, active regeneration, passive regeneration, and transition to broad-leaved forests. These scenarios exhibited 87%, 76%, 72%, and 41% respectively of the remaining area of Japanese cedar plantations in 2090, relative to the area observed in 2000. The projected increase in net primary production in future scenarios generally exhibited lower values in the southwestern region of Japan compared to the northeastern area. We further investigate the impacts of regional zoning, based on the four scenario types, on the outcomes of climate change mitigation and adaptation.

Assessing European forest trajectories under climate change with a high resolution forest resource model, EFISCEN-space

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: European forest are rapidly changing: pressures from climate change and disturbances are increasing, as well as demands for goods and services. Analysing these future trends and where they clash has always been a huge challenge because of limited access to national forest inventory data (NFI). Over the past 10 years, we have been gathering detailed NFI plot data and its individual tree measurements. Now the database comprises > 300,000 NFI plots and > 4 million remeasured trees, thanks to 17 NFIs. For the demand side, we compiled the European Forest Industry Database (EUFID), which encompasses the location and capacity of 6,000 forest industry facilities, categorized into three value-chains: sawmills, pulp and paper, and bioenergy.

We developed the EFISCEN-space model, which now has spatially explicit distribution of timber resources at national forest inventory plot level, including details about the species and diameter composition. We fitted climate dependent tree growth functions, mortality functions and ingrowth functions, as well as litterfall rates and soil carbon models. High resolution (1x1 km) projections of the future carbon balance European forests, soils and harvested wood products will be presented, under trajectories of forest management changes (restoration needs) and changing societal demands with an industry accommodating and following these changes.

Assessing healthy forest regions and their ecosystem functions in Europe

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Unsustainable forest management practices and escalating impacts of climate change on forests significantly affect the forest health and the provision of forest ecosystem services crucial for human well-being. The project "Healthy Forest Regions" aims to address this challenge by engaging policy- and decision-makers and empowering key actors to safeguard forest ecosystem functionality, enhance biodiversity conservation, and ensure the provision of forest-based ecosystem services for sustainable regional development. It is a European project, implemented in 6 countries (Germany, Slovenia, Slovakia, Croatia, Austria, Czech Republic). We employ remote sensing and leverage the capabilities of the Google Earth Engine to define healthy forests by assessing forest ecosystem functions and their regulating services such as the temperature regulating effect and the buffering capacity. The cooling function of healthy forests is based on the land surface temperature at Landsat resolution. Trends over time and the relation to adjacent forest regions gives insights into the current functionality of these regions. The product is an accessible website that informs about the developments over time in each Healthy Forest Region. Additionally, users can select their own region and can assess information about their forests. Another key output of the project includes strategies for effectively communicating the value of healthy, functional forests and their ecosystem functions in promoting human health and well-being. This is implemented by workshops for actors in the regions. Ideally, our findings will assist actors in adopting sustainable forest management practices and formulating effective climate-change mitigation strategies.

Climate-Driven Shifts in Tree Recruitment: Implications for the Adaptation Potential of European Forests

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Climate change has emerged as a significant threat to forest ecosystems worldwide, impacting their dynamics and compromising the provision of essential ecosystem services. This study focuses on European forests, aiming to understand the effects of climate change on tree recruitment. While stand and landscape-scale projections have shed light on the importance of tree regeneration in forest dynamics, large-scale models often lack realistic representation of climate change impacts on forest regeneration. This research addresses the knowledge gap regarding the current state of forest regeneration and actual changes occurring at a European scale, thereby

enhancing our understanding of the adaptive capacity of European forests under climate change. By incorporating a dynamic tree recruitment model into the empirical forest growth model EFISCEN-SPACE, we utilise a comprehensive dataset of national forest inventories from 17 European countries to accurately represent the current forest state and investigate recruitment dynamics under the climate change scenario RCP 6.0. The study examines the density and compositional changes of tree recruitment, as well as their spatial patterns across Europe. Tree recruitment densities decrease with rising temperatures and water limitations, following a north-to-south gradient. Compositional shifts occur across all forest types due to a combination of climate change impacts and changing forest management paradigms. By applying a uniform concept to investigate shifts in tree recruitment at a pan-European level, this research identifies potential limitations to the adaptive capacity of European forests and contributes to our understanding of how these forests will respond to climate change. The findings of this study have implications for forest management strategies aimed at maintaining the health and sustainable provision of ecosystem services in European forests.

Climatic turning points in productivity of four main tree species in Central Europe

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Local environmental conditions determine tree species productivity that can be further modulated by forest management. However, the ongoing climate change modifies forest productivity patterns, which may affect ecosystem sustainability. Here we aim to identify climatic turning points in species productivity in Central Europe identified by the shifts in local species ranking due to the changes in climatic conditions, manifested by the replacement of the productive superiority of one species by another one. We focus on four main tree species in Central Europe: European beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* (L.) H. Karst), Scots pine (*Pinus sylvestris* L.), and oak (*Quercus* spp.) and their response to climate change defined by 14 climate models driven by two RCP scenarios.

We examined the productivity response of the four tree species to changed climatic conditions by predicting forest development at 86 research sites distributed along a large environmental gradient with a process-based model Biome-BGCMuSo that simulates cycling of carbon, nitrogen, and water in terrestrial plant ecosystems with a daily time step. The data come from long-term experiments and cover five European countries including Croatia, Hungary, Slovakia, the Czech Republic, and Poland, at latitudes from N 43.889° to 54.559°, longitudes from E 12.62 to 23.72°, and elevations from 20 to 1,325 m a.s.l. Their mean annual precipitation total varied from 450 to 1,720 mm, the mean annual temperature range from 2.56 to 14.9°C, and soil depth fluctuates between 0.4 and 2 m.

The experimental design allowed us to compare the simulated performance of individual tree species and to identify the turning points in their productivity under local environmental conditions. The results revealed the pattern of winner and loser tree species across Central Europe, and indicated the site-specific potentials to compensate the decline in the productivity of one species by the increased productivity of another species. These findings provide valuable information about possible changes in tree species composition that can mitigate adverse effects of climate change and sustain future forest productivity.

Closing the DAta gap to develop Land Surface MOdels for COngo Basin forests (DAMOCO)

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Ground-based data suggest tropical forest carbon sinks might soon become less effective at slowing the accumulation of CO_2 in the atmosphere. However, Earth System Models fail to reproduce the observed trends of forest carbon sink saturation/decline, partly due to important gaps in the existing data underlying these models. The DAMOCO project intends to fill one of those most important data gaps concerning a tropical region of paramount importance: the Congo Basin.

In this project, we are first collecting and/or valorizing data covering all the successional gradients (pioneer, regenerating and mature forest) of the most dominant forest types of the Congo Basin. By combining different but complementary scientific approaches, we produce multi-temporal records of forest dynamics: (i) sub-daily estimates of carbon and water fluxes collected with eddy covariance equipment on the first flux tower in central Africa, (ii, iii) decadal-scale changes in carbon balance and biodiversity through repeated tree and tree trait measurements from a network of permanent forest inventory plots, and finally, (iv) millennial-scale changes in biodiversity through the analysis of ancient charcoal from soil profiles located next to the plots.

Secondly, we will combine this data to parametrize a state-of-the-art process-based Land Surface Model (ED2) for the central Congo Basin. Once the model is optimized, we will use it to upscale carbon and biodiversity dynamics for the entire central Congo Basin, apply it to test forest resilience to climate and land-use change in the region and simulate future carbon and biodiversity dynamics under climate and land-use change scenarios.

Here, we present the early progress and results of the project. In particular, we focus on our first ancient charcoal data which suggest a gradual change in species composition throughout the Holocene, related to past long- and short-term droughts and fluctuations in population density. Furthermore, we provide an outline of how this paleodata will be integrated and combined with the other data sources in the ED2 Land Surface Model.

Development of geospatial afforestation options and estimation of carbon storage under climate change in North Korea

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: North Korea, located in the Mid-Latitude Ecotone, faces significant forest degradation caused by climate change and deforestation. However, the country lacks an efficient long-term and spatial restoration plan. To address this gap, this research aims to develop an optimal forest restoration plan for North Korea, aligned with the national restoration target, through the use of biophysical modeling. We focus on modeling afforestation targets and evaluating future management options. In order to identify suitable areas for afforestation, we identified degraded and deforested regions and determined appropriate forest species. Given the limited availability of forest resource information in North Korea, we utilized time-series satellite data, land cover maps, and South Korea's yield tables to evaluate the potential impact of afforestation under climate change. Based on the identified afforestation options, we simulated simple management scenarios that align with North Korea's national restoration target. The findings of our study offer valuable insights to policymakers and technical officials tasked with formulating regulations and action plans for forest management in North Korea. The geospatial analysis and afforestation modeling conducted in this study contributes to the development of effective strategies and guidelines for the restoration and sustainable management of forests in the country.

Disentangling land management and global change drivers of historical shifts in California forests

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Our ability to confidently predict future forest structure and dynamics at landscape to regional scales requires capturing interactions among increasing atmospheric CO2 (iCO2), climate changes, and land management. In the Sierra Nevada Mountains of California, forest biomass and tree density have increased alongside shifts in species composition since European settlement. Observations and experiments suggest that iCO2 has promoted a positive global carbon sink through increased water use efficiency. There is also evidence that over the 20th century, tree harvest, fire suppression and climate changes have influenced these forests. However, no study has yet quantified the relative importance of these multiple drivers of forest change and how they may vary across the region. We used the vegetation demographic model, CLM-FATES, to simulate transient forest change over the 20th c. in the mixed conifer forest – the most widespread forest type in the Sierra Nevada. By implementing factorial scenarios with single and combined drivers, we determined that fire suppression increased biomass by 27 ± 12% and iCO2 increased biomass by 12 ± 2% over the 20th c. Fire suppression decreased light demanding pine density and relative abundance, while iCO2 increased shade tolerant functional types. Fire suppression effects on biomass were more pronounced in relatively cooler, wetter portions of the domain, while iCO2 most increased biomass in warmer, drier areas. Harvest slightly increased pine density, but reduced pine size because it was only applied to large diameter trees. The results, which reproduce observed changes in water use efficiency and are consistent with empirical studies of fire suppression and harvest effects, suggest that capturing these interacting drivers is both possible and necessary to predicting ongoing forest change.

Do models of forest dynamics correctly capture tree regeneration?

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Under the pressure of climate change, increasing disturbance impacts, and changing societal demands on forest ecosystem services, it is becoming ever more important to understand future forest trajectories. Models of forest dynamics are pivotal for assessing long-term forest dynamics considering the impacts of climate, and tree regeneration is a key process in forest dynamics, particularly in the context of forest resilience and climate change. However, an assessment of the ability of models to accurately represent tree regeneration is lacking. We used 15 models that were built to capture long-term forest dynamics at the stand, landscape, and global

levels. They comprise both empirical as well as process-based approaches. With these models, we simulated tree regeneration at 200 unmanaged sites in European forest reserves, representing large environmental gradients across Central Europe. The results were evaluated against comprehensive observed data from these forests. Most of the models overestimated regeneration levels, which is compensated in some models by high simulated mortality rates. Simulated species diversity of regeneration matched observed ranges. Models simulating higher species diversity at the stand level did not feature higher regeneration diversity. The effect of light availability on regeneration levels was captured better than the effect of temperature and soil moisture, but patterns were not consistent across models. Increasing complexity in the tree regeneration modules of the models was not related to higher accuracy of simulated tree regeneration. Overall, individual model design was more important than scale (stand, landscape, global) and approach (empirical, process-based) for accurately capturing tree regeneration. Despite considerable mismatches between simulation results and data, it is remarkable that most models captured the essential features of the highly complex process of tree regeneration reasonably well while not having been parameterized with such data. We conclude that much can be gained by evaluating and refining models of tree regeneration, and we provide a set of research recommendations. The representation of forest dynamics in these models would become much more robust, particularly in the face of climate change and post-disturbance dynamics, thus strongly reducing the uncertainty in long-term projections of future forest dynamics.

Drought response of rear edge bottomland forests in the largest green corridor of the the Po Plain

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Climate change poses significant challenges to forest ecosystems worldwide, particularly in vulnerable regions such as rear edge forests and bottomland hardwoods. Understanding the resilience of these forests to climate-related stressors, specifically drought, is crucial for effective conservation and management strategies. This study aimed to assess the temporal and spatial variability of resistance and resilience to drought in the forests of Ticino Park, witha specific focus on natural formations of Scots pine in plain and hilly environments.

To evaluate the temporal variability of drought response, dendrochronological analyses were conducted on three populations of Scots pine. These analyses examined the growth response of the trees to climatic conditions over both long-term and short-term periods, providing insights into their resistance, resilience, and recovery following drought events. By examining the growth patterns and incorporating climate data, a comprehensive understanding of the forests' adaptive capacity was obtained.

Furthermore, the spatial variability of resistance and resilience to drought assessed using multi-temporal analysis of remote sensing imagery, specifically the Enhanced Vegetation Index, derived from Landsat data. This analysis allowed for the detection of changes in vegetation dynamics in response to extreme climate events. Descriptive statistical models were developed, incorporating topographic, climatic, seasonal, and structural variables, to elucidate the factors influencing the forests' resistance and resilience to climatic extremes.

Finally, we simulated carbon sink in different forest formations of Ticino Park under various climate change scenarios. Utilizing the Carbon Budget Model simulator, the growth of the forests and their carbon sequestration potential were predicted based on available data from the park's forest management plan. These simulations provided valuable insights into the future carbon dynamics of the forests under different climatic and management scenarios.

Overall, this research contributes to our understanding of the resilience of rear edge forests and bottomland hardwoods to drought in the context of climate change. The findings can inform adaptive management strategies, aiding in the conservation and sustainable management of these important forest ecosystems.

Early management decisions after natural disturbances and their long-lasting legacies

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Forest ecosystems are projected to experience disturbances in greater intensity and severity due to further rapid change of climatic conditions. The early management of disturbed forest sites often includes salvage logging and the planting of tree species. To understand the influence of this early management decisions on the forest trajectories, it is essential to aggregate the current empirical findings regarding their effects on ecosystem services and biodiversity. In a first step the study systematically reviews existing empirical studies and meta-analyses addressing the effects of early management after disturbances on forest trajectories. In a second step the individual-based process model iLand is parameterized and applied to the Harz mountains in central Germany. The outcome is used to evaluate if the projected trajectories based on empirical findings can be reproduced by the model. The modelled scenarios include the management of salvage logging, tree planting and a non-intervention natural regeneration scenario. A scenario analysis will be conducted with the iLand model to compare different early-stage forest managements and investigate their long-term legacies for future forest ecosystems beyond the scope of available empirical data.

The negative effects of management decisions like salvage logging have been demonstrated for several species taxa and ecosystem services. Removing biological legacies on large-scales has the potential to reduce ecosystem resilience on the long-term even if measures of preventing further insect outbreaks and mitigating subsequent disturbances may seem appropriate on the short term. The decision of which tree species is planted often targets a specific outcome (e.g., timber volume). The paradox situation of persisting clear singular management targets in parts of the forestry sector in a rapidly changing world is addressed by discussing the anticipated uncertainty encountered on projected forest development on a landscape scale by the iLand model. We address uncertainty by multiple simulation runs for the same scenario and evaluate the difference in variance of outcomes between management scenarios. To understand the consequences of post-disturbance management for forest trajectories it is important to minimise negative consequences of current management decisions for future forests under further enhanced environmental change.

Eco2Adapt - Maintaining ecosystem services in a changing climate: a case study from the Swiss Alps

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: The European project Eco2Adapt aims to support stakeholders, forest owners and practitioners to manage forests and optimise social and environmental resilience using the concept of nature-based solutions. The project combines interdisciplinary knowledge from scientists and stakeholders in Europe to understand perceptions and provide incentives for adaptive management and policy. The project is based on Living Labs (LLs). These consist of a network of case studies located at regional scale in climate hotspots across Europe. Data from the LLs will be used to refine models to determine temporal socio-economic pathways, to calculate alternative adaptation strategies for multiple risk analysis, and to consider interactions between large bundles of ecosystem services in a spatial setting. One of the models that will be used in the LLs is LandClim, a spatially explicit forest landscape model developed to assess climate and management impacts on forest dynamics. In addition, LandClim has several modules to simulate the effects of natural disturbances, such as storms or bark beetle outbreaks. One of the Living Labs is located in the Swiss Alps, in the canton of Grisons in the Surselva valley. The case study represents the alpine environment with a wide range of species and altitudes. Special attention is given to the forest's protective function against natural hazards (e.g. rockfall and avalanches), as this is the most distinctive feature of this Living Lab. Sustainable wood production is a key ecosystem service that would also need to be investigated, especially under different climate change scenarios. The ultimate goal for the Swiss Living Lab is to assess how different management practices affect the sustainable provision of wood and the protective function of forests in the future.

Ecological range and spread of selected Kenyan forest species in changing climate

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: The impacts of climate change on forest ecosystems are of growing concern, particularly in regions characterized by high biodiversity such as Kenya. Understanding the ecological range and spread of tree species under changing climatic conditions is essential for effective conservation and management. This study investigates the ecological range and spread of five selected Kenyan forest species, namely Liquidambar stracyflua, Alnus junguiana, Cynometra webberi, Brachistagia spiciformis, and Cestrum aurantiacum, in the context of a changing climate. Using species distribution modeling techniques, historical occurrence data, environmental variables, and climate projections were integrated to assess the potential shifts in the distribution of these tree species. MaxEnt, a widely used modeling tool, was employed to generate current and future distribution maps of the selected species.

Preliminary findings indicate distinct responses among the studied species to projected climate scenarios. Liquidambar stracyflua and Alnus junguiana demonstrate a potential expansion of their ecological ranges towards higher elevations, reflecting their preference for cooler and more humid conditions. Cynometra webberi and Brachistagia spiciformis exhibit a contraction in their suitable habitats, indicating their vulnerability to increasing temperature and altered precipitation patterns. Cestrum aurantiacum, on the other hand, demonstrates a relatively stable distribution range, with minimal projected shifts under the changing climate.

Furthermore, the study explores the ecological factors influencing the range dynamics of these tree species. Elevation, and biotic interactions were considered as important determinants of species distribution. The findings from this research provide valuable insights into the potential impacts of climate change on the distribution and spread of selected Kenyan forest species. The projected shifts in species ranges can inform conservation efforts, such as identifying suitable areas for assisted migration or reforestation programs. Moreover, understanding the ecological factors driving range dynamics contributes to a better understanding of species' responses to a changing climate. Considering other factors such as land-use changes and human activities is crucial for comprehensive conservation planning and adaptive management in the face of climate change.

Keywords: climate change, ecological range, species distribution modeling, Kenyan forest species, conservation, management strategies.

Ecosystem model projections on the impact of climate change and forest management on the provisioning of forest ecosystem services in Sweden

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Ecosystem models provide useful tools for assessing the influence of changing climate conditions and of forest management on ecosystem structure and functioning. This work provides insight into potential outcomes for forest ecosystems in Sweden at the end of the 21st century, as projected by the dynamic vegetation model LPJ-GUESS for two climate change trajectories, RCP 2.6 and RCP 8.5.

Outcomes for multiple forest ecosystem services are assessed, comparing three future alternatives for forest management: (i) Business-as-usual (BAU) when the current Swedish management paradigm continues, (ii) Adaptation & Resilience (AR) where species mixtures and deciduous stands increase and monocultures decrease, and (iii) EU-policy (EUPOL) where the area managed as continuous cover and set-aside forest land increases.

End-of-century model projections reveal higher rates of carbon sequestration in forests managed as BAU when compared to AR or EUPOL, but also increased risks of storm damage and nitrogen leakage. In the EUPOL scenario, forests provide higher levels of deadwood and improved carbon storage, whereas the AR scenario offers a middle ground with moderate provisioning of multiple ecosystem services.

Our findings indicate that a climate trajectory representative of RCP 2.6 will have a relatively limited influence on the functioning of forests at the end of the century. For all three management scenarios, the model indicates a consistent increase in the carbon stored in woody biomass within the ecosystems, whereas the carbon stored in soil show small but steady decreases.

The implications of RCP 8.5 are larger changes in the rates of ecosystem carbon uptake and emissions, regardless of the given scenario of forest management, with an increase in net primary productivity in the range of 19-26% at the end of the century. Although overall woody growth is stimulated in RCP 8.5, the expected increased frequency and intensity of natural disturbances contribute to uncertainty regarding the extent of potential ecosystem carbon gains and losses.

Futures of European forests and forestry

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: The future of forests and forestry in Europe is determined by multiple factors, different actors, and variating expectations. The forest policies at different spatial scales ranging from global to regional level, set targets and limits for the sustainable forest management and use, to the whole forest-based sector. At the same time, climate change impacts e.g., growing condition and damage risks in the forests. Further, a need for biomass is increasing for various purposes. At the end, the forest management decisions are made by forest owners which as a group is heterogenic (e.g., state, investment companies and private owners) each having different and sometimes contradicting priorities for their forests. Consequently, modeling the future of forest resources is not a simple task.

In the Horizon Europe project EUFORE we aim at identifying the anticipated future trends on the supply side of forest resources in Europe. We consider future changes in 1) forest resources, 2) forest management (e.g., close-to-nature forestry, introduction of new tree species), 3) wood mobilization, 4) societal developments (e.g., evolving forest ownership structure, demographics, urbanization and emerging counter-urbanization), 5) climate-change impacts (e.g., changes in productivity, changes in species ranges, natural disturbances and extreme events), and 6) demands for ecosystem services and sustainability (e.g., biodiversity, non-wood forest products, recreation, protective functions of forests).

First, we make a literature review covering existing forest modelling studies and forest statistics. Starting from the current state and observed trends in the past derived from forest statistics and utilizing the results of previous studies we formulate future trends for chosen forest and forest related indicators and forest scenarios. The literature-based scenarios are modified, future developed and validated with a participatory method in workshops targeted at experts and stakeholders of different interests, sectors, and regions of Europe. The result will provide a Europe-wide outlook on the wood supply and forest state in 2040, which we are willing to present in the seminar.

Implications of climate change, CO2 fertilization and disturbance impacts on GHG emission projections in the large-scale forest model G4M

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Climate change alters forest dynamics and is expected to increase forest damage due to windfalls, insect outbreaks, forest fires, and other disturbances. Climate change impacts involve complex interactions and forest processes, making changes in forest productivity context-dependent, with regional variations. Depending on the RCP scenario, the climate, atmospheric CO2 concentration, and the damage caused by amplified disturbances may change considerably by 2100, compared to the current levels, making accounting for the respective impacts on GHG essential. Typically, large-scale models do not account for climate change effects on the forest sink. Here, we address this issue and employ the large-scale Global Forest Model G4M to assess GHG emissions under different wood demand and CO2 mitigation policies in Europe. To account for the climate change and CO2 fertilization impacts, we apply a process-based 3PGmix model for deriving geographically explicit change in growing stock that is used in G4M for modifying forest increment. To consider the forest damage due to windfalls, insect outbreaks, and forest fires we use projections by Seidl et al. (2014) and downscale them to a 0.5x0.5° grid, taking into account the vulnerability index in each cell based on Forzieri et al. (2021) and the disturbance activity in each country given by Patacca et al. (2023). The damage data is implemented in G4M to force salvage logging of a specified amount of wood in the case of windfalls or reduced amounts in the cases of insect outbreaks or a forest fire, based on relevant forest attributes (e.g. age or tree height). The resulting forest productivity, in the case of acclimation to elevated CO2, remains stable under the RCP2.6 scenario. In the Mediterranean region, forest productivity is reduced due to the hotter and drier conditions. In montane forests of the temperate bioclimatic zone and boreal zone, forest productivity responds positively to increased temperatures. However, under RCP8.5 the forest growth decreases also in the boreal zone. The persistent CO2 fertilization counterbalances the negative effect of the decrease in precipitations in intensive climate change scenarios, while forest damage increases over 3 times by 2100, with higher values under more intense climate change scenarios.

Lowland forest structure and composition approach a turning point under increasing climatic stress

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Climate change-induced decreases in forest vitality combined with an increase in natural disturbances may fundamentally shift future forest composition and structure. Recent studies have revealed irreversible shifts in mountain forest ecosystems under continued climate change. It remains an open question whether and when such shifts occur in lowland forests which might be more tolerant to climate change, but lack topographic buffering mechanisms. In this study, we investigate the future of temperate lowland forest ecosystem using the Meerdaalforest complex in central Belgium (Western Europe) as case study. Potential shifts in composition and structure were simulated using the mechanistic individual-based forest landscape model "iLand", incorporating a variety of climate projections and disturbance regimes. Finally, we analysed whether ecosystems might return to their initial state if temperature and precipitation revert to historic conditions.

Our findings show that natural disturbances currently have a limited effect on lowland forest composition and structure, although projections indicate that their impact (disturbed volume) could increase by up to 193% under the hottest and driest climate projections. Furthermore, lowland forests are susceptible to tipping points in forest composition and turning points in forest structure if temperature increases exceed 2°C. These shifts are particularly pronounced on fine-textured, well-drained soils, as soils with a high sand content are typically already dominated by more drought-tolerant species. As a result, the sandier sites can often revert more closely to their initial state, experiencing turning points rather than tipping points in their composition. We found that soil diversity may serve as a refuge for drought-sensitive species in lowland forests, similar to the role of topographic microrefugia in mountain forests.

Our study highlights the vulnerability of lowland forest composition and structure to climate change, if society fails to keep warming well below 2°C. However, our results also suggest that soil diversity may act as refugia in lowland forests, indicating that lowland forest resilience could benefit greatly from improved forest connectivity.

MEDFATE 3.0.0: A trait-enabled model to simulate Mediterranean forest function and dynamics at regional scales

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Several dynamic vegetation models exist that combine a detailed mechanistic approach to energy, water and carbon balances with the ability to represent vegetation structure and simulate demographic processes. However, examples of such models specifically designed for Mediterranean forest ecosystems are less common. Here we report the design, parametrization and evaluation of MEDFATE (v. 3.0.0), a cohort-based and trait-enabled model of forest dynamics, for its application over a region in the Western Mediterranean Basin. The model allows performing forest energy, water and carbon balances coupled to demographic processes, and can be used to simulate both fire and drought impacts on forest function and dynamics. 217 taxonomic entities are represented in the model, defined according to woody species codes of the Spanish National Forest Inventory. While forest inventory records were used to obtain some empirical parameter estimates, a large proportion of physiological, morphological, and anatomical parameters were matched to measured plant traits, with estimates extracted from multiple databases and averaged at the required taxonomic level. Estimates for non-observable key parameters were obtained using meta-modeling and calibration exercises. Missing values were addressed using imputation procedures based on trait covariation, taxonomic averages or both. The model properly simulated observed historical changes in basal area, with a performance similar to an empirical model trained for the same region. While strong efforts are still required to parameterize trait-enabled models for multiple taxa, and to incorporate intra-specific trait variability, we advocate for the adoption of trait-enabled and population-structured models for regional-level projections of forest function and dynamics.

Modeling Douglas-fir and Western Hemlock Seedling Mortality Using Competing Vegetation Abundance, Climate, and Soil and Plant Water Relations

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: The Pacific Northwest of the United States (PNW) is expected to experience substantial climate change impacts, including increased temperatures and drought. Understanding the physiological responses of planted seedlings to water deficit is essential for their adaptation and survival. Analyzing the xylem's vulnerability to cavitation is a promising way to understand the limitations to water transport experienced by seedlings in the context of reforestation. This method has been used on a variety of tree species, including Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*), but specific thresholds triggering mortality are not well understood. The Competition and Site Interactions Experiment (CoSInE), developed by Oregon State University's Vegetation Management Research Cooperative, began in 2016 with the aim to understand the effects of forest vegetation management (VM) regimes on seedling physiology, growth and survival, as well as early-seral vegetation community characteristics across the diverse landscapes of the PNW. CoSInE includes 11 sites installed in Oregon and Washington States. We developed models to estimate early-seral vegetation abundance and water use dynamics as a function of climate and soil characteristics. Models to estimate seedling pre-dawn and midday water potential were also determined for both, Douglas-fir and western hemlock. Laboratory determination of vulnerability to cavitation curves were validated with *in situ* measurements of seedling midday water potential and native hydraulic conductivity. The effect of water stress on seedling's xylem loss of hydraulic conductivity and its relationship with mortality were also determined for each species using laboratory and field assessments. The models developed are a useful tool for addressing the impact of VM treatments and genotype selection on seedling survival under changing climate and site conditions.

Modelling and Predicting Global-scale Suitable Areas for Sclerocarya birrea, (A. Rich.) Horchst, subspecies Under the Current and Future Climates

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Marula, *Sclerocarya birrea* (*S. birrea*) (A. Rich.) Horchst, is a drought-tolerant and multipurpose tree native to Africa whose population is currently declining. The *S. birrea* subspecies have been used to restore drylands and introduced outside Africa as a pilot towards commercial cultivation. However, there is a global paucity of information regarding where its subspecies can successfully establish themselves beyond Africa with changing climates. We aimed to model and document environmental variables which define the global-scale suitable areas for *S. birrea* and its subspecies, and predict and quantify global-scale suitable areas for *S. birrea* and its subspecies beyond their native ranges under the current and future warming climates. We modeled and predicted areas by using MaxEnt algorithm using occurrence data from Africa and, climatic and topographical environmental variables, and the Max Planck Institute for Meteorology and Hadley Climate Center's global Earth Systems Models climate data under shared socio-economic pathways (SSPs) greenhouse gas concentrations, SSP3-7.0, for the year 2050 and 2080. The results show that the models' predictive power was robust, with Receiver Operating Characteristics (ROC)'s Areas under the Curves (AUCs) ranging from 0.90 to 0.98. Suitable areas for *S. birrea* are mainly defined by potential evapotranspiration of the coldest quarter and potential evapotranspiration seasonality; subsp. *birrea* by continentality and potential evapotranspiration of the coldest quarter; subsp. *caffra* by isothermality and potential evapotranspiration of the wettest quarter and subsp. *multifoliata* by temperature seasonality and precipitation of the driest quarter. Currently, suitable areas for *S. birrea* and its subspecies exist in all continents except Europe and Antarctica and, occupy 3,751,057 km^2 to 24,632,452 km^2 of earth's terrestrial area scattered in 54 to 107 countries predominantly in global biomes with climatic conditions ranging from desert tropical to temperate humid. Under future climates, the areas will retract by 64 to 100%, shifting to high latitudes and being limited to tropical desert-to-desert temperate, Mediterranean warm global biomes, and some regions of Eastern Europe will become suitable. Suitable areas for *S. birrea* and its subspecies exist beyond Africa, and they will retract and migrate to high latitudes under future warming climates.

Modelling forest ecosystem services resilience to drought and assessing its drivers in Mediterranean forests

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Forests cover ca. 30% of the land surface, host a significant amount of Earth's biodiversity, and provide a multitude of material and non-material benefits to humans. While global environmental change is rapidly altering ecosystems, we still have a limited understanding of how forests and their ecosystem services may endure and recover from anthropogenic and natural disturbances. The resilience framework represents a powerful approach for assessing forest ability to withstand pressure and its drivers and, ultimately, understand how to preserve biodiversity and human well-being. Here we used a process-based forest model (MEDFATE) together with several sources of empirical data to estimate five forest ecosystem services (timber provision, water supply, carbon sequestration, erosion control, potential recreation value) and their resilience to the severe drought that hit Catalonia in 1994. The model was initialized and evaluated using data from ca. 3,400 plots of the Spanish National Forest Inventory. Our modelling exercise spans the period 1990-2016 and uses (i) actual weather (disturbed scenario), (ii) simulated, non-drought weather (undisturbed scenario), and (iii) simulated, extreme drought weather (extreme scenario). We estimated forest ecosystem services for each of these scenarios and calculated the resilience using the log response ratio between the disturbed/extreme scenario and the undisturbed scenario (counterfactual approach). Initial results based on leaf area index (LAI) dynamics for trees (DBH > 7.5 cm) showed the lowest resilience in the extreme scenario. Further, plots with low resilience values were observed at sites characterized by warmer and dryer climates (southern Catalonia). We expect similar results for the five forest ecosystem services. This work is part of the EU-funded project RESONATE (https://resonateforest.org/).

Modelling resilience to wind disturbances in production forests: a case study and its implications for management

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: In Europe, the frequency and intensity of disturbances has been increasing in recent decades. In the light of expanding demand for a variety of ecosystem services provided by forests, the resilience of these ecosystems is of growing interest.

The first part of this study focuses on the resilience of forest ecosystem services in a region dominated by even-aged production forests, examining the effects of a single disturbance event. In a 60.000 km^2 region in south-western Finland, we model the impacts of a severe wind disturbance that occurred in 2001.The process-based forest model PREBAS is initialised with national forest inventory (NFI) data acquired prior to the storm, and plot-level disturbance impacts are based on a special post-disturbance inventory. We analyse the effect of the storm event and the ensuing management on a range of forest variables and ecosystem services: growth, age structure, C storage in biomass and soils, available and harvested timber assortments, deadwood, biodiversity, and the supply of non-wood products. Resilience is quantified by the measures of perturbation and recovery rates. We apply a range of scenarios, considering multiple levels of disturbance intensity, the extent of salvage logging, and different post-disturbance management approaches. The results of the study support the formulation of post-disturbance management measures which increase forest resilience and maintain the long-term provision of ecosystem services.

In the second part of the study, an empirical wind disturbance model based on NFI data and a comprehensive dataset of salvage loggings is implemented in PREBAS. The modelling framework is applied in the same study area and initialised with 16x16m resolution multi-source NFI data. The occurrence and severity of wind disturbances are dynamically and spatially explicitly modelled based on stand structure, wind speed, topography, and management. Simulations cover a range of management and climate scenarios, and the long-term impact of wind disturbances on the ecosystem services mentioned above are analysed, as well as the efficiency of adapted management approaches to support these.

In addition, the two studies allow for a comparison of wind throws as pulse vs pressure disturbances on large scales, with implications for future wind disturbance modelling.

Modelling Swedish Forest Transpiration under future enhanced summer extremes

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: The escalating occurrence of droughts and heatwaves on a global scale poses a significant threat to ecosystems worldwide, including those in Sweden. The severe drought experienced in Sweden during the summer of 2018 had a profound impact on the country's forests, causing disruptions in their functioning and productivity. This situation presents a crucial challenge to the resilience of Sweden's forests in the face of future climate change. Uncertainty persists regarding the ability of these forests to adapt to rapidly changing climatic conditions while maintaining crucial ecological functioning, such as transpiration and carbon uptake capacity, as well as ecosystem services like biomass production. The maintenance of these functions and services is of great value to both Swedish society and the regional climate system. To assess the resilience of Sweden's forests to changing climate extremes, we conducted a study utilising recently available in-situ forest measurements, including comprehensive sap-flow measurements from research stations in the ICOS Sweden and SITES networks. We establish the ecosystem response based on observations from recent extreme droughts, which we thereafter use in LPJ-GUESS together with climate change scenarios to assess future changes in Swedish forest resilience. Our analyses revealed a significant decrease in whole-tree transpiration during the drought of 2018. Furthermore, we observed a distinct relationship between surface conductance and Bowen ratio at the ecosystem level, indicating strong vegetation feedback during drought compared to non-drought years. These findings suggest that the changes in forest functioning observed during the drought were substantial enough to affect the efficiency of land-atmosphere interactions, particularly in terms of water and carbon exchanges through the soil-plant-atmosphere continuum. Consequently, these changes are likely to have long-lasting effects on ecosystem productivity in subsequent years and increase the overall vulnerability of the forest to climate variations over an extended period.

Modelling the potential distribution of major plant species under climate change scenarios along an aridity gradient in Namibia

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Climate change is expected to have major impacts on plant species distribution worldwide. These changes will affect plant species in one of three ways: the timing of seasonal activities, physiology and distribution. This study aims to predict the effect of shifting climatic conditions on the major vegetation units and their dominant species along an aridity gradient through Namibia. Namibia's vegetation is characterized by open woodland in the northeast to low open shrubland in the southern part of the country. These differences are a result of increasing aridity from north to south with a rainfall gradient from 600 mm to 100mm. A classification of vegetation was done for 1986 relevés using cluster analysis, a multi-response permutation procedure and indicator species analysis. Future projections for the most important climate variables were used to model potential future distribution of the presently dominant vegetation units. This modelling approach used two scenarios of Representative Concentration Pathways (4.5 and 8.5) from two Global Climate Models - the IPSL-CM5A-LR and HAdGEM2-ES for 2080. The predicted distribution shows a high expansion potential of *Eragrostis rigidior—Peltophorum africanum* mesic thornbush savannas, *Combretum africanum—Terminalia sericea* broad-leafed savannas and *Combretum apiculatum* savannas under both scenarios. For other vegetation types Climate scenarios of the IPSL-CM5A-LR, and the RCP4.5 of the HAdGEM2-ES predicts a north-to-south shift, whilst a south-to-north shift of the vegetation units is likely under the RCP8.5 of the HAdGEM2-ES. *Combretum apiculatum* savannas are predicted to become dominant over other vegetation units for both scenarios, with a percentage gain between 10% for the intermediate scenario, and 31% for the RCP8.5. Knowing the future distribution of these vegetation units is important to establish adaptive management strategies.

Modelling tree mortality from forest inventory data: which approach for which purpose?

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: In recent years, increasing background tree mortality has been observed across many European forests. Numerous studies investigate how forests are responding to global changes to foresee how these forests will develop in the future, and to generate management recommendations accordingly. Forest inventory data are often used in such studies as they can provide representative data at regional to national scales. Modelling approaches based on such empirical data can help identifying and understanding the drivers of tree mortality, as well as predicting current and future forest development trajectories. However, forest inventory data are complex and their statistical handling presents some methodological challenges. In addition, tree mortality data are highly unbalanced (higher proportion of living trees compared to dead trees), which further complicates the modelling process and performance assessment. For these reasons, while the drivers of tree mortality are increasingly well understood, we are still lacking concrete and practical guidelines on how to develop well-performing empirical tree mortality models that account for the complexity of forest inventory data.

We used Swiss National Forest Inventory data (~4300 plots, up to 5 times remeasured over the last 40 years) to identify the characteristics of forest inventory data that should be accounted for when modelling tree mortality. We determined if and how these characteristics could be implemented in various modelling approaches such as generalised mixed models, a survey approach, random forest and convolutional neural networks. We compared the performance of these approaches when inferring the effect of environmental factors on tree mortality as well as when predicting tree mortality. We conclude that the best-suited modelling approach depends on the goal of the model, i.e., inferring or predicting. We stress that metrics used to evaluate the performance of a modelling approach must be adapted to unbalanced data, and provide recommendations on best practices for modelling tree mortality from forest inventory data. Our results can help future tree mortality studies to choose, based on their goal, which modelling approach would be most suitable as well as the appropriate metrics to evaluate the model's performance.

Predisposing and inciting stress factors leading to drought-induced mortality

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: The increase in both frequency and magnitude of drought-induced mortality events in low-elevation forests in Europe represents a puzzling phenomenon to investigate. Indeed, both empirical and dynamic models fail to capture and reproduce mortality caused by the combined effects of climatic extremes and biotic stressors.

We examined the drivers and processes leading to mortality during the drought years of 2018-2019 in even-aged beech stands in Switzerland in two steps: by means of empirical models (e.g., drought indices) linked to tree-ring indices and through the dynamic forest gap model ForClim.

In the first step, we assessed the suitability of drought indices of different complexities to capture stand-level growth responses to extreme drought events based on the assumption of direct feedback linking growth decline to mortality. We found that even the best-performing index cannot capture mortality patterns as it is associated with carbon starvation alone.

We developed a novel modeling framework that accounts for a combination of predisposing and inciting factors, according to the Decline-Disease theory, in the ForClim model. In this context, we included a drought memory term as a predisposing factor and a drought duration term that accounts for soil water deficit in spring and autumn as an inciting factor.

In addition, we enhanced the response of both growth and mortality dynamics to environmental extremes (e.g., temperature) and soil water dynamics. Finally, we applied a pattern-oriented modeling approach to this new model version to account for the uncertainty arising from alternative process formulations.

The proposed phenomenological stress approach for drought-induced mortality modeling can reproduce mortality events induced by drought extremes in managed stands in Switzerland. We tested the scheme on sites along a climatic gradient from cold–wet to warm–dry conditions in Central Europe, where we simulated potential natural vegetation. Towards the dry range of the selected sites, our results indicate the progressive dominance of drought-tolerant species as an increase in the frequency of mortality events. We argue that under changing climate conditions, site conditions (e.g., soil water availability) will play a crucial role in stand level dynamics, particularly in terms of species response to drought events.

Simulating Central-European forests in the 21st century – Effects of climate change and management.

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Large-scale scenario analysis to project development of European forest resources and explore the effect of climate change and forest use scenarios is a key requirement for policy making and has attracted much attention recently.

In a recent study we harness the individual-tree based ecosystem model PICUS v1.5 to simulate 20 mill ha forests in five Central European (CE) countries (Germany, Czechia, Slovakia, Austria, Slovenia). In a quasi-spatial frame work we assigned 46 mixture types which had been defined based on the national forest inventory (NFI) data to 8x8 km grid-cells and distribute these mixture types over 1x1km sub-cells considering CORINE landcover types and regional age-class distributions. A gap-filling algorithm had been used to complete the information base for all 5 countries. PICUS includes disturbance modules for spruce bark beetles and wind storms. Current climate and three transient climate change scenarios were prepared for each 1x1km cell. Currently applied management regimes (BAU) had been operationally defined for the mixture types based on reports and interviews with experts from the five countries. BAU includes also a share of not actively managed forests. Five management response options from owner´s perspective were defined, including a no management option. BAU and the response options were then combined in six adaptive management scenarios for the entire CE forest area.

Under conditions of moderate climate change volume stocks can be retained under BAU management. If precipitation decreases, a drastic reduction of growth at lower elevations results, in parallel with a sharp increase of salvage harvests. Stocks decrease due to reduced increment and high tree mortality. Adaptive management is replacing productive coniferous and broad-leaved species by more drought and heat tolerant broadleaves which overall are less productive. The more extreme future climate develops the sooner adaptive management approaches reduce potential losses and stabilize production and stocks and perform better than the currently practiced management would. Non-native species such as Douglas fir improve the net effect of adaptation strategies further.

Beyond selected results we scrutinize currently available means and conclude on useful improvements.

Spatial vulnerability assessment of silver fir and Norway spruce dieback driven by climate warming

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: A significant forest decline has been noticed these last years in Europe, mainly for coniferous species. Managers need tools to better anticipate these massive events. We evaluated the efficiency of easily available data about environmental conditions and stand characteristics to determine different levels of vulnerability. We combined remote sensing images, photo-interpretation, and digital models describing environmental conditions within a modelling approach to achieve spatial vulnerability assessment of the stands. We focused on silver fir and Norway spruce stands in the Vosges mountains (8,900 km², north-eastern France), where severe symptoms of decline are visible.

Silver fir were predicted highly vulnerable on 7% of their area *versus* 33% for Norway spruce. Using an independent dataset, we observed ten-times (silver fir) and two-times (Norway spruce) higher mortality rates in the units with a high level of vulnerability than in the others. About half of the model deviance was directly or indirectly explained by variables related to water stress (soils displaying low water availability, having suffered severe drying events these last years). Furthermore, the stands acclimatised to drought conditions were more resilient. Stand characteristics also influenced dieback spread, suggesting that an evolution of silvicultural practices toward mixed stands with broadleaved species and uneven-aged trees can contribute to better adapt to future climate conditions. We conclude that vulnerability maps based on easily available geographic information describing climate, soil, and topography can efficiently discriminate canopy mortality patterns over broad areas. They can be useful tools for managers to mitigate the effects of climate change on forests.

The value of a terrestrial ecosystem model for evaluating forest policies

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Reflecting the importance of forests in some of the Nordic countries, national policies and private governance initiatives have affected forest management for a long time in these countries. In recent decades, there has been a shift from a highly regulated and rationalized forest management regime towards softer forms of governance and strengthened principles of freedom and responsibility but also wider considerations of the forests' multifunctionality. Forests are expected to play a crucial role for mitigating climate change by, in addition to timber, supplying resources for wood products, bioenergy or biofuels in accordance with international and national climate targets. At the same time, forests provide important ecosystem services, e.g., carbon sequestration or biodiversity conservation. The muti-faceted use of forests will lead to trade-offs and synergies of the national policies governing the use of forests.

In this study, we use the LPJ-GUESS terrestrial ecosystem model to assess the effects of important changes in forest policies on forest ecosystems that have been identified in recent decades in the case of Sweden. To this end, the changes in forest management and/or in land use that are associated with the selected policy changes are prescribed to the model. The focus of the analysis is on the effects on the carbon stocks and fluxes of the forest ecosystems (relevant for climate mitigation) and the structure of the forests that affect biodiversity. As part of the study, we evaluate the model's ability to simulate the state of Swedish forests against data from the Swedish National Forest Inventory. This allows for evaluating the robustness of the simulated effects of the recent policy changes on Swedish forest ecosystems and, thus, gives an understanding of the value of a comprehensive ecosystem model such as LPJ-GUESS for evaluating forest policies.

Transformation paths towards biodiversity-enhancing landscape structures for temperate multiple-use forests

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: To enhance biodiversity, the retention of old forest structures and deadwood (Retention Forestry), has been integrated in the management of multiple-use forests of Europe's temperate zone since over a decade. Balancing the provisioning of multiple ecosystem services (ES), however, poses a challenge for the development of biodiversity-oriented management strategies. This is additionally complicated through the impacts of climate change and increasing disturbances on forest ecosystems. We investigate optimal management portfolios and landscape structures for the enhancement of biodiversity while guaranteeing the flow of ES in the southern Black Forest area, by coupling ecological-economic models in a simulation-optimization framework.

We will present preliminary results of our study following three objectives:

- Forest landscape simulations will be carried out using the individual-based forest landscape and disturbance model (iLand model) with scenarios varying in climate, disturbance intensity and management.
- Based on the simulation results, we will analyse the responses of multiple taxonomic groups using empirical models parametrized for the study area.
- Finally, we will identify optimal landscape structures for promoting biodiversity and providing ES. Using optimisation techniques, we will derive a transformation path from the current state of the study landscape to the optimal landscape.

With our study we expect to provide a robust decision support for biodiversity-oriented management of temperate multiple-use forest under climate change and increased disturbance risk.

Tree level growth responses to climate evaluated at the stand level: Expected growth reductions for Scots Pine and Oak on dry sites in Europe .

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Oak and Scots Pine, two of the most commonly managed xeric-/acidophilic species in Europe are being pushed out of their climatic niches. Using high spatiotemporal resolution climatic data from four non-correlated global circulation models (ACCESS1-3, CESM1-BGC, MIROC5, CMCC-CM) depicting the RCP 4.5 and RCP 8.5 emissions scenarios and retrieved historical data from the CHELSA high-resolution climate dataset repository, we could model the development of 72 in detail measured and previously described unmanaged stands at 15 sites from southern Sweden through northern Spain.

Tree-level growth simulations (no management) from 2017 to 2100 were run using a modified version of the PrognAus individual tree-based model which was outfitted with a newly published climate-sensitive diameter growth model (Vospernik et al. 2021). Results were post-processed to yield yearly stand-level summaries which could be used for extrapolation of the results.

Using only easily accessible variables we successfully manage to generalise our results to a prediction-oriented model (Linear Mixed-Model) of standing live volume year 2100, and contrast growth for unmanaged stands of 3 different species mixtures (Oak, Oak-Pine, Pine) at 3 separate latitudes (58°N, 50°N and 42°N) under the historical climate with 2 future possible scenarios (RCP 4.5, RCP 8.5). Our results indicate that stand-level growth will be hampered under both RCP 4.5 and 8.5. Growth losses relative historical scenario increase in severity from the Nordic countries to the Mediterranean (For Pine, 58°N:-8%, 42°N:-12%; For Oak, 58°N:-2%, 42°N:-7%;). In both percentual and absolute terms, growth decreases are larger moving from the historical scenario to the RCP 4.5 scenario than moving from the RCP 4.5 scenario to the RCP 8.5 scenario for all species mixtures. Oak shows the greatest resilience to change between RCP 4.5 to 8.5 – decreasing only for the lowest latitude, whereas Scots Pine is sensitive to the changes associated with the future climatic scenarios – the magnitude of percentual change between RCP 4.5 and 8.5 being c. 80% of that between the historical scenario and RCP 4.5.

Our study, with no climate-sensitive mortality, is likely optimistic in terms of the decreases that can be expected, with strong implications for dry-land forestry in Europe.

Uncertainty of water balance simulations related to soil parameterization in Alpine forests under climate change conditions

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Climate-change-induced stress in forest ecosystems will have consequences for society worldwide. A decent understanding of future ecological conditions is required to identify suitable actions for dampening these stresses. A major impact of climate change is the gradual shift in water balance which can lead to drought stress in forest stands in many parts of the world. Soil-vegetation-atmosphere transport (SVAT) models are useful tools for investigating the water balance under current and future climate conditions. However, using such models in Alpine environments with spatially heterogeneous edaphic conditions strongly depends on the parameterization of soil properties. The present study investigates the sensitivity of water balance simulations and their uncertainty towards soil characteristics under current and future climate conditions. A lumped, physically-based SVAT model (LWF-Brook90R) was used to reproduce the water balance at 1823 mapped forest sites in Tyrol (Austria). For the soil parameterization, detailed laboratory analyses based on samples taken at multiple depths were available for 102 locations. At all other locations soil texture classes and bulk density in each soil horizon had been assessed with field methods. Based on interpolated meteorological observations and bias-corrected climate projections, the water balance was derived under current (1991-2020) and future conditions (2036-2065, 2071-2100). Using generic parameterizations of forest stands of native tree species (European beech, Norway spruce, European black pine), the uncertainty of the modelling results and derived drought stress indicators towards soil input parameters was evaluated. To do so, the soil parameters (texture, bulk density, organic content) were systematically sampled at each site to represent the respective texture class mapped in the field and the variability indicated by the laboratory results. The results suggest that soil parameterization has a strong influence on the resulting water balance components (e.g., evaporation, transpiration). Depending on the considered representative concentration pathway scenario, the soil-related uncertainty can be in the same order as projected changes due to climate change. This highlights the importance of reliable soil parameterizations for assessing climate change impacts on the water balance in Alpine forests. This work was carried out within the WINALP21 project, funded by the INTERREG VI-A program (grant number BA0100020).

Understanding forest resilience through simulation modelling

T5.22 Modelling forest trajectories under climate stress and changing management
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Abstract: Forests are facing an increasingly uncertain future due to climate change, shifting disturbance regimes, and changing societal demands. Hence, we need a better understanding of how forests will develop, recover after disturbances, and adapt to new conditions. In addition, it is not well known if such an adaptation is even fully possible and how forest management can actively support it. The concept of forest resilience, in its various definitions, has become a popular framework to approach these questions. Resilience can help us to understand the limits of forest recovery and adaptation and find potential tipping points. Methodologically, simulation models provide the capacity to explore a wide array of environmental and human drivers as well as forest responses over the large areas and long durations, which are necessary to approach forest resilience.

We explored the role of simulation modelling in understanding forest resilience, showing the breadth of existing applications as well as focus areas for further model development based on a literature review. Through several examples from Europe using landscape simulation modelling, we went deeper into the opportunities and limitations of using simulation modelling to understand the future development of forests through the resilience lens. These simulation studies explored potential tipping points of forest structure, composition and functioning under climate change and increasing disturbances as well as investigating how resilience can be fostered proactively through forest management.

Simulations from different European landscapes showed that, from an ecological viewpoint, forests are remarkably resilient, able to recover from substantial changes in climate and sustain ecosystem functioning even under increasing disturbances. However, once tipping points are reached, the simulated forests underwent drastic changes in composition, structure, and ecosystem functioning. Management had the potential to support forests in adapting to rapidly changing environmental conditions but could not fully avoid the impact of climate change and increasing disturbances.

These results show the potential of simulation modelling as a powerful tool in exploring the responses of forests to extreme environmental changes. However, there are several areas where further model development is urgently needed to understand forest resilience to these changes.

Using LANDIS-II to model potential outcomes of an experimental management system in coastal forests under climate change, windstorms, and wildfire.

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Our project supports management planning for the newly designated Elliott State Research Forest (ESRF), now the largest research forest in North America, which extends over 33,000 hectares of the Southern Oregon Coast Range. Oregon State University plans to implement an experimental Triad system of management that incorporates silvicultural treatments of varying intensities. Their goal is to take a sharing-sparing approach to determine how to produce timber at least cost to biodiversity. To answer this question, managers plan to divide the forest into subwatershed-level research units. Each unit will be allocated to one of four treatments comprising different proportional combinations of the following three stand-scale silvicultural strategies: 1) reserves, where the focus is on conservation of habitat and species with minimal active management; 2) intensive management, where maximizing timber production is the primary objective; or 3) extensive management (or ecological forestry), which attempts to balance timber production with broader ecological objectives, such as development of structural complexity. However, it is unknown how this management regime, interacting with wind and fire disturbances, will affect key ecosystem services. To answer this question and help refine the preliminary forest management strategy, we estimated changes in long-term forest and carbon dynamics under the proposed harvest design, windstorms, wildfire, and climate change using LANDIS-II, a spatially explicit, process-based forest simulation model. Our study landscape, modeled at a high spatial resolution (30m x 30m), includes the entire ESRF and a surrounding buffer to allow fires to spread into the forest. Our initial results indicate the importance of wind as a driver of mortality in mid- to late-successional Coast Range forests, a shift towards higher species complexity, the need for forest managers to consider how management practices interact with natural disturbances, and the potential inability of a shorter 70-year harvest rotation to produce more timber than the original 100-year rotation over in the long term. This project presents a novel opportunity to explore the ecological and economic impacts of different management scenarios on a newly developed research forest under windstorms, wildfire, and climate change.

Using provenance trials across a climate gradient in Europe to understand acclimation of Norway spruce photosynthesis under future climate scenarios

T5.22 Modelling forest trajectories under climate stress and changing management

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Abstract: Four young Norway Spruce sites between France and mid-Sweden were compared, to see possible adaptions to a temperature difference akin to increases predicted under climate change. The use of clones between sites – cancelling out confounded acclimation -, temperature gradient, and the difference between wet and dry sites, has isolated some of the main limitations for future photosynthesis. These young sites' climate and shoot data over 6 years, were contrasted to mature Norway Spruce ecosystem data from the Integrated Carbon Observation System over as similar conditions as data allowed. Then, the northernmost site was modelled with climate predictions. These simulations were compared against current and future modelled data for the other sites. Acclimation was tested by running the model with climate, site and photosynthesis parameters interchanged to isolate individual effects. The Shared Socioeconomic Pathways (2 4.5, 5 8.5) generated by Coupled Model Intercomparison Project 6 were used for climate predictions. Ecosystem models: Stand Photosynthesis Program (SPP) and PREdict Light-use efficiency, Evapotranspiration and Soil water (PRELES) were respectively used to, upscale local measurements to a stand level, and then to apply the future climate projections.

After Bayesian calibration the models fit together well, allowing us to use tree level measurements to extrapolate to a landscape level. According to current results from PRELES, the future CO2 effect overshadows any other environmental parameters. However, when the CO2 effect is discounted; temperature, specifically its effect on the growing season rather than daily increases, has the second largest consistently important effect. In years with a significant drought effect, PRELES shows that the low soil water content restricted the potential photosynthesis. In the original data drought is seen in the mortality rate, rather than a change in photosynthesis potential; as we cannot measure the photosynthesis parameters when the tree cannot photosynthesise. Although CO2 and temperature have a more consistent effect, possible photosynthesis increases will not be fulfilled unless other environmental conditions allow, the soil water content being the limiting factor in this case. Acclimation to environmental conditions also limited potential increases, as seen by the reduction in predicted photosynthesis when applying the southernmost parameters to northernmost sites.

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

A cross-site model-data integration approach for tracking carbon and water fluxes dynamics under drought conditions in montane forests

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Under climate change, the frequency and intensity of summer drought and hot spells are predicted to be more extreme in the future. Contrasting impacts of climate change are particularly expected in montane forests, which are generally energy limited ecosystems and adapted to short growing seasons. Thus, it is crucial to understand how extreme events might impact forest ecophysiology and in turn shape the carbon and water cycle in such a particular bioclimatic area. Since the carbon and water cycles are tightly coupled through the process of plant photosynthesis, and because forests can respond on both short and long temporal scales to meteorological variability, with instantaneous and lagged effects, linking observations of carbon and water fluxes is of first importance to assess the forest contribution to climate-change mitigation.

In this study, we focus on two mountain ICOS monitoring sites:Torgnon (IT-Trf, Fluxnet) and Renon (IT-Ren, ICOS). The first is a European larch, and the second a Norway spruce dominated stand, two common forest species in the Alps While the European larch has been often considered to have an anisohydric behavior (i.e. weak stomatal regulation under drought conditions), the Norway spruce can be assumed isohydric. The undisturbed forests stands were monitored with the eddy covariance technique for long periods (Torgnon 2012-2023, Renon 1997-2023) and the areas were characterized by drought spells of different types, intensity and duration in the years 2017 and 2022. However, to understand how extremes might modulate the interaction between carbon assimilation, evapotranspiration and growth, a cross-site model-data integration approach is crucial. Here, we used modeling simulations by means of the process-based forest model 3D-CMCC-FEM in combination with fluxes estimates and complemented with ancillary records, i.e. satellite-based observations, dendrometric and sapflow measurements. We found that the parametrized model is suitable for tracking carbon and water fluxes dynamics and the resulting response to drought is quantitatively contrasting across the two experimental sites. Finally, we highlight the challenges in monitoring complex ecosystems and provide a framework of analyses of drought induced direct and legacy effects on montane forests and their potential consequences on carbon and water fluxes exchange in the alpine region.

Applied monitoring of forest dynamics for climate action planning in the United States

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Maintaining and expanding forests and urban tree cover are critical components of a multi-pronged climate strategy. In the United States, many local governments and land managers are developing Climate Action Plans (CAPs) which outline goals for reducing GHG emissions and bolstering resilience. However, due to a lack of clear guidance and accessible data, many land managers do not account for their forests and trees or for the potential enhanced role they could play within CAPs. To fill this gap, the Land Emissions and Removals Navigator (LEARN) tool provides open-source, automated analysis and calculation of GHG impacts associated with forests and trees within any area in the Continental U.S. The web tool analyzes national datasets from the U.S. Forest Service and U.S. Geological Survey to derive spatially explicit estimates of carbon emissions and removals from land cover change, forest disturbances, and changes to tree canopy on non-forest lands within an area of interest over a specified period. Ongoing research and development are underway to improve the accuracy, breadth, and disaggregation of geospatial data on forest dynamics. Wall-to-wall, 30-meter datasets of forest characteristics (e.g., stand age, stand height, stand origin) produced using plot data from the USFS Forest Inventory Analysis (FIA) database in a machine learning environment are priorities for integration into carbon calculations. Another key improvement may involve working with the USFS to integrate directly with the FIA database to improve accuracy of carbon calculations. This innovation would not only improve historical monitoring capabilities but will allow for dynamic carbon estimations based on ground measurements under a changing climate. The LEARN tool builds on this growing body of research by bringing together state of the art data and methods to provide tangible insights to land managers in a user-friendly, accessible environment. In doing so, LEARN is easing the burden on land managers and accelerating the transition from monitoring and planning to implementation of forest-based climate mitigation.

Are leaf and stem trait interactions good predictors of individual tree growth in a Tropical Dry Forests?

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Trait-based ecology is built on the notion that traits impact individual performance. However, trait-growth relationships are rarely tested, particularly in tropical dry forests. This scarcity of investigation can partially be attributed to the challenges of accurately measuring growth rates and anatomical stem traits related to hydraulic properties across many individuals and species. Compounding these issues, many studies overlook intraspecific variation or use simple models that do not account for trait interactions or non-linear trait-growth relationships.

Here, we examined trait-growth relationships in woody species of Colombian dry forests, including traits and growth information measured in the same individuals. We analyzed stem and leaf traits related to growth and hydraulic safety efficiency in 967 individuals (263 species) in seven permanent plots (1ha). We assessed trait-growth relationships using random forest models for each plot with different trait resolutions (individual, plot, area) and complexity of trait interactions (low, medium, high).

Trait-growth relationships were generally weak without significant differences among trait resolutions or levels of interactions between traits. However, when accounting for leaf phenology, we detected a higher growth variation explained in deciduous species than in evergreen species. Finally, we also found that the effect of traits on growth was consistent across plots and phenological strategies, with both stem (vessel area and pit diameter aperture) and leaf (leaf area and specific leaf area) traits being ranked as the most important predictors.

Our results suggest that other factors not included in the analysis such as microenvironmental variability might influence trait-growth relationships in tropical dry forests. Indeed, this is an ecosystem with markedly seasonal climatic conditions that might have filtered species coordinated and adapted to this environment, which could be the reason behind the lack of importance of trait complexity interactions to explain growth variation. Furthermore, the importance of the traits depends on the group of leaf phenology considered, which indicates that growth is probably limited by different factors depending on the species' physiology. Therefore, a trait coordination approach at the whole-plant level is needed to understand better plants´ fitness and demographic rates in this particular ecosystem.

Assessing dead wood by integrating Full Area Sampling and Line Intersect Sampling: combing the best of both worlds

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Effective and comprehensive monitoring of quantity and quality of the dead wood component has become an important aspect of forest inventories. It's an indicator for structural and demographic dynamics of trees, but it is also an important variable for biodiversity assessments and carbon stocks. Assessing dead wood is however challenging due to its structural complexity and associated characteristics such as size, tree species and decay stage. Commonly applied survey methods for lying woody debris (LWD) are Full Area Sampling (FAS) and Line Intersect Sampling (LIS). In FAS , all LWD fragments above a specific size threshold are measured and positioned. This method provides a good estimate of the local volume of LWD, and also allows identification of each specific logs for remeasurement. This can, however, be extremely time consuming, especially in forests with accumulating amounts of LWD. LIS is based on incidence of LWD intersecting of a line. It has proven to be reliable and robust and takes much less time, but requires sufficient sampling to level out randomness, especially of rare but large elements. In general, LIS is inadequate for assessment of deadwood on a local (plot) scale, reliable figures need to be based multiple-plot scale. As a new approach, we propose a combined protocol by using FAS to position and measure all larger diameter trees and branches and LIS for smaller dimensions. This combines fast and easy sampling with good local estimates of dead wood at plot level and still allows larger logs to be linked to previous and future measurements to study its dynamics. We will present how to correct for double counts, asses the reliability of this method and time saved compared to FAS. Based on our results we propose a cut off level of 20cm diameter for the FAS.

Assessing forest ecosystem functions in Biosphere Reserves worldwide

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: The establishment of protected areas is a prevalent measure to mitigate the loss of biodiversity and effects of climate change. Within the global network of protected areas, the World Network of Biosphere Reserves (WNBR) is aimed at "conserving biodiversity, restoring and enhancing ecosystem services, […] and empowering people to mitigate and adapt to climate change and other aspects of global environmental change." Although substantial resources have gone into establishing, promoting, and monitoring the WNBR and many studies have examined these issues, the ecological effectiveness or ecosystem functioning of forests within Biosphere Reserves is less well understood. By assessing forest ecosystem functions in Biosphere Reserves worldwide, we investigate the potential of these forests to contribute to sustainable development and assess the effectiveness of the biosphere reserves framework in supporting the development of resilient forests globally. This study develops a remote-sensing based method on a global scale with the Google Earth Engine using various ecosystem functioning indicators, such as the relative cooling and buffering capacity of forests. The main aim is to investigate possible differences of ecosystem functions in relation to their surroundings and thereby derive a quantification of the ecological effectiveness of forests in Biosphere Reserves globally. The main expected result is a ratio of ecosystem functioning inside and outside globally, which is a proposed proxy value for the ecological conditions. This will be derived by model estimations of 1) the behavior of different indicators globally, 2) each indicator related to different biomes. By using this approach, we hope to address certain challenges when conducting global ecological analyses, such as the integration of diverse regional parameters, biome-specific variables, or anthropogenic factors. Methodology and results should be applicable to other global forest monitoring approaches and could contribute to the evaluation of measures considered as ecosystem-based adaptations to climate change. If proven effective, the biosphere reserves framework could serve as a valuable model for managing forests in various regions.

Assessing role of forest by estimating potential soil erosion in a Himalayan watershed using empirical modelling

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: In Mountain regions, soil erosion causes severe hazards, such as heavy rainfall, surface water flow on bare lands that contribute to land degradation. In Himalayan region, erosion leads to loss of forests, productivity and changes the hydrological behaviour of the lotic system. The relationship between ecological processes such as soil erosion and landscape spatial patterns is elucidated well by assessing spatial heterogeneity. Forest land use plays a significant role in controlling the loss caused due to soil erosion. However, it is important to understand the relationship between soil erosion and various land use to the importance of forests and also identify the erosion vulnerable zones to understand the role of a landscape. The study was carried out in the Himalayan subwatershed located between 30º 40' 30" N to 77º 43' 30" E and 30º 28' 30" N to 77º 51' 0" E. The elevation range varied from 431 to 1803 m above mean sea level (amsl) covering an area of 91.91 km^2. To estimate potential soil loss the Revised Universal Soil Loss Equation (RUSLE) was used on ArcGIS 10.3. Rainfall erosivity, soil erodibility were obtained by kriging data interpolation using remote sensing tools, and further analysis was performed to calculate potential soil loss under each land use. Soil sampling was conducted to assess soil quality and to compute the soil erodibility in the watershed. The results indicated that the estimated potential soil loss was maximum in settlement land use (19.42 tons/yr/ha) and minimum in forest land use (1.73 tons/yr/ha). The results showed that the estimated soil loss under each land use was significantly different. Dunn's post hoc comparison based on adjusted Bonferroni p-values suggested significant differences between the groups i.e., land use. Potential soil erosion in forest land use was significantly different from agriculture, barren, settlement and scrub land uses. The study indicated the importance of forests in the conservation of soil as well as water resources. It also suggested that the inclusion of land use criteria is crucial in the decision process for formulation of management strategies for conservation in a watershed.

Assessing the impact of climate change on natural forest regeneration dynamics across Italy.

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Natural regeneration is critical for forests climate change adaptation, ecosystem restoration, and the preservation of biodiversity. Many forest models can robustly simulate the growth, development and mortality of adult tree species compared to the regeneration process. Indeed, how environmental conditions and management practices affect the success of seeds production, germination requirements, seedling establishment and saplings ingrowth remains the most uncertain processes to model. In order to tackle this challenging task, we implemented into the process-based forest model 3D-CMCC-FEM a new module to simulate the natural regeneration. This module includes key drivers such as temperature, light, and water availability, aiming to understand each factor's contribution to regeneration success. Since young saplings are more sensitive to changes in climatic conditions than adult trees, it is pivotal to investigate their plasticity and adaptation capacity at the stand scale. Because of these reasons, we selected three beech-dominated experimental forest sites and permanent monitoring plots along a latitudinal gradient on the Italian peninsula, as European beech thrives in diverse conditions. We systematically analyze model behavior by conducting a comprehensive assessment of parameter sensitivity. Our aim is to identify the key parameters and processes that contribute to the greatest variability in model output, particularly in relation to saplings recruitment. We performed short-term simulations, using observed climatic data, stands and soil data collected as input starting from the first year of available data to initialize the model. Model performances are shown, including the ability of the model to simulate carbon fluxes, specifically gross primary productivity (GPP) and structural variable such as basal area increment and height of trees. Furthermore, seeds production, density of newly saplings recruited simulated by the model will be compared with observed data in the permanent-sample plots applying a 'space x time' substitution. Subsequent long-term simulations will be conducted (at least 100 years) forcing the model in the same plots with climate scenarios data considering the factors such as, CO^2 fertilization effect, increasing mean temperature and water resource to investigate how these factors could affect growth and mortality of seedling and sapling under future climate change scenario.

Carbon Accumulation in European Forests: insights from old-growth beech forests in different environments within the UNESCO World Heritage Site 1133

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Natural forests can remove significant amounts of carbon (C) from the atmosphere annually and stock it for the long-term in living aboveground and belowground tree biomass and soil organic matter.
We used a network of representative old-growth beech forests from the UNESCO World Heritage Site "Ancient and Primeval Beech Forests of the Carpathians and Other Regions of Europe" to quantify Cstocks in living and dead biomass and soil. Old-growth forests covering biogeographic regions in Europe (Mediterranean, Alps, Carpathian Mountains, Atlantic Region) were compared to nearby mature managed forests in similar environmental conditions.
In each forest, we measured living and dead tree biomass in dendrometric sample plots, and calculated species-specific volumes converted to C stocks using available allometries and wood densities. Trees from different size classes were cored with increment borers to determine wood density variability according to size and naturalness (old-growth vs. managed) along environmental gradients. In each forest, soil organic C content was determined at different depths (maximum until 1 m) using a sample of cores or pits.
C density data from old-growth beech forests served to build a reference framework in different environments, necessary to assess the potential of forest restoration for climate-change mitigation.

Comparing drought effects on vegetation of natural forest reserves and adjacent managed forests in Southern Germany

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Increased frequency of drought years with alarming forest decline is challenging forestry and society in Central Europe. The longevity of forest ecosystems as well as the extent and ecological diversity of forest areas hinder the attribution of causes and effects of the decline. Foresters, forest owners, conservation organisations and public are struggling for adequate responses to the crisis. While strict forest reserves (SFR) have often been perceived in terms of biodiversity conservation, climate change calls for reconsidering their role as a reference for forest management. In Central Europe, SFRs are the only forests, where mortality of trees and stands and their effect on vegetation can be observed without interference of timber harvesting. Further, they are indispensable for deciding whether managed or natural forests exhibit higher resistance and resilience towards climate change and to what degree silvicultural adaptation measures can be replaced by self-organised forest dynamics. An integrated analysis of the development of 16 SFRs in conjunction with adjacent managed forests along a climatic gradient in Southern Germany, ranging from subalpine spruce forest to colline mixed oak woodlands promises answers to these questions.
Our contribution reports on preliminary results of the work packages on the reaction of radial growth and water use efficiency of trees and on the dynamics of ground vegetation and tree regeneration.

Coupling functional and structural data to improve estimates of forest carbon fluxes and ecosystem responses to climate change

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Forest ecosystems contribute to mitigating climate change through the process of photosynthesis. However, the increasing occurrence of climate extreme events has the potential to alter forest ability to sequester CO_2 from the atmosphere and to store it as plant biomass, with an increased risk of ecosystem transition from carbon sinks to carbon sources. The detailed effect of climate change on the timing and the functioning of different forest processes and its impacts at the tree vs. ecosystem level show high spatial and temporal variability. In this context, forest structure and the spatial heterogeneity of vegetation may represent a form of biological insurance against environmental changes. Further efforts are therefore needed to assess the resistance and resilience of forest ecosystems to climate change as mediated by forest structure.

The main objective of this study is to establish a quantitative link between the functional and structural properties of a European larch forest (*Larix decidua* Mill., IT-Trf, LTER site: LTER_EU_IT_078) in the Alps, located in the Aosta Valley (Italy) at about 2100 m asl. The eddy covariance method was used to measure carbon fluxes between the ecosystem and the atmosphere at two levels: the whole forest ecosystem, and the understory vegetation. Biometric measurements of tree growth were carried out in 2020 to quantify the carbon allocated to the wood biomass pool. Finally, satellite and UAV-based LiDAR observations were used to derive the composition and the structure of the various vegetation layers.

Results showed that only a small fraction of the total CO_2 absorbed by the ecosystem is allocated to stem growth and that due to the openness of the larch forest stand, the understory vegetation has around a 30% share of the total ecosystem gross primary productivity. The results are discussed by exploring the link between forest structure and the functioning of the whole ecosystem and the specific vegetation components.

Dynamics and relationships of belowground processes and aboveground growth and their impact on carbon burial in a mangrove forest

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Mangrove forests are extraordinary ecosystems, providing a wide range of benefits to humans, including exceptional carbon sequestration and protection against climate change impacts. They are globally threatened; finding new and more effective approaches to mangrove conservation is a conservation and climate mitigation priority. Different management approaches have been adopted, including the Payment for Ecosystem Services (PES) approach in mangroves of south coast of Kenya. The Vanga Blue Forest (VBF) project, designed to protect and restore 455 ha of degraded mangrove forest over 20 years, uses an incentive-based management approach where communities are compensated for their mangrove conservation efforts through a carbon credits scheme. Estimation of baseline levels of carbon, along with projections of forest growth, that are key components of this and similar projects (Bento, Kanbur and Leard, 2016), often need to use approximations and extrapolations from other sites, due to a scarcity of site-specific data and methods. Existing models that could be applied to predict mangrove forest productivity, and carbon capture and storage, are highly complex and data intensive, making it impossible to apply them at small-scales and with limited resources and capacity (Saatchi *et al.*, 2011; Baccini *et al.*, 2012; Willcock *et al.*, 2012; Langner, Achard and Grassi, 2014). It is in this context that experimental and theoretical techniques adopted from Lang'at et al., (2014) and Lynch et al., (2015) were applied to explore belowground processes and soil organic carbon build up dynamics in the study area. Modified sediment elevation tables and marker horizons (SET-MH) and root ingrowth were deployed across the study area within the permanent monitoring plots established under the Vanga Blue Forest (VBF) project and measured over time to assess sediment elevation/subsidence and surface accretion/erosion under different conditions. The findings will improve knowledge on forest productivity and carbon stocks and flows for local and global applications. They will also contribute towards tools, such as biomass and C storage models and sustainable extraction models, essential for the current management conservation efforts at VBF project.

Exploring the Carbon Dynamics of natural forests: Insights for Climate Change Mitigation and Sustainable Forest Management

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Forests play a crucial role in the global carbon cycle by effectively sequestering and storing carbon, while its wood also serves as a substitute for carbon-emitting products and energy sources. However, deforestation, such as for agricultural purposes, contributes to the exacerbation of climate change.

The multifaceted role of forests, encompassing carbon storage in biomass and soils and the provision of sustainable resources for the green transition, has prompted an intensive scientific discourse on optimal forest management strategies to combat climate change. The natural forest serves as the reference in these investigations, representing the maximum potential carbon storage achievable over extended periods. These references are crucial for guiding discussions on forest management that plays an important role in global carbon management.

While natural forests are pivotal to understanding forest ecosystems and form a cornerstone of European forest and climate policies, they are not widely prevalent and are often under-researched. The beech dominated Suserup Skov in Denmark stands as a noteworthy exception, having been subject to repeated inventories and systematic studies during the past 30 years.

In this study we provide analyses of the long-term carbon dynamics of natural forests, focusing on Suserup Skov and other unmanaged forest areas, to understand their potential and limitations in mitigating climate change through carbon storage in biomass and soil. The study provides valuable insights for future forest management strategies, supporting the development of sustainable practices that maximize carbon sequestration and storage potential and contribute to global climate change mitigation efforts.

Forest structure, deadwood and tree-related microhabitats in high beech forest stands under different management regimes in southern Europe

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Beech (*Fagus sylvatica* L.) is one of the most important forest species in Europe from an ecological and socio-economical perspective, and the present structure of beech forests in Europe is the result of their long management history and other interacting factors. The aim of this study was to compare the complexity of forest structure, including deadwood and tree-related microhabitats as relevant biodiversity components, in high beech forest stands under different management regimes in southern Europe, ranging from actively managed stands to unmanaged old-growth forest stands. Fieldworks were carried out in 14 plots of 2500 m^2 (50 x 50 m) distributed in Italy, Croatia and Slovenia, seven plots with even-aged structure dominated by beech and 7 plots with uneven-aged structure, the latter mostly dominated by beech and silver fir (*Abies alba* Mill.). In each plot, all living trees with diameter at breast height (DBH) $\geq$ 3 cm were measured and the following data were collected: x,y coordinates, DBH, total tree height, height-to-base of the live crown, and crown's projections. Coarse woody debries, stumps, standing (including snags) and downed dead trees with diameter $\geq$ 10 cm were also measured (x,y coordinates, diameter, height or lenght, and decay level). Tree-related microhabitats were inventoried both for living and standing dead trees according to the classification system by Kraus et al. In each plot, the forest complexity was characterized by species composition, forest structural variables (e.g., stand denstity, basal area, and volume), spatial indices for vertical and horizontal (point pattern analysis) structure, amount and types of deadwood components and microhabitats. The results were discussed to compare the forest complexity and biodiversity features among the examined sites in relation to forest management activities carried out in the past in order to outline possible strategies for sustainable management practices oriented towards more structurally and compositional diverse beech forest stands. The study was carried out within the LIFE SySTEMiC project - LIFE18ENV/IT/000124.

Gas exchange of sun and shade-developed leaves is differently affected by drought: implications to scaling up models and silvicultural recommendations

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Droughts are becoming a recurrent event worldwide, which reduce carbon uptake and increase tree mortality risk threatening several ecosystem functions and services. Furthermore, global change is increasing the intensity, duration, and frequency of droughts due to a combined effect of scatter precipitations, atmosphere warming and soil erosion. However, droughts do not affect equally to all the species of a forest due to species-specific differences in shade tolerance, growth rate and functional traits related with drought resilience. In fact, within a forest there are many microclimates and tree species adapt their leaf physiology and anatomy mainly to changes in light intensity and quality. However not many studies consider adult trees and drought responses within the tree canopy. Here we provide novel measurements and concepts on how gas exchange responds to drought within tree canopies of four contrasted species in shade and drought tolerance. The study was carried on at the Natural World Heritage Site of “Hayedo de Montejo”, a relict and old European forest in Central Spain growing under Mediterranean conditions in a very dry and wet years. We performed photosynthesis-CO2 curves, photosynthesis-light response curves and changes in leaf hydraulic conductance in shade and sun developed leaves of the studied species growing in transects of less to more soil depth, and at the early summer in both years to avoid the seasonal and ontogenetic effects associated with leaf age. We show that shaded leaves are more susceptible to water stress than sun-developed leaves and that decreased photosynthesis is due to the combined effect of reduced stomatal and mesophyll conductances and higher biochemical constrains, while top canopy leaves are mainly limited by the stomatal closure. This results in lower carbon balance of the more shaded leaves within the canopy and earlier leaf shedding. We also found close coordination between decreased water supply and stomatal closure. More shade tolerant species were more affected by drought along the canopy, while more drought tolerant ones were able to maintain modest gas exchange rates but only in sun-exposed leaves. Climate change may promote open forests which may benefit the more drought albeit less shade tolerant species.

Integrated approach for monitoring the vulnerability of Mediterranean oak forests affected by drought-induced dieback: evidences and research avenues

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Rising aridity, mostly driven by higher temperatures and reduced water availability, will undermine the health status of many forest ecosystems. If climate warming proceeds at its current rate, the resilience of many seasonally dry Mediterranean forests will be threatened by altering their structure and impairing their functions. However, our understanding of vegetation-climate couplings is still partial, as we need data on responses at multiple temporal and spatial scales. In this context, we aimed to forecast oak forest responses to climate stressors, particularly during post-drought dieback episodes when tree vulnerability is exacerbated, through a combined, multiproxy approach. We focused on several oak species differing in drought tolerance but showing dieback events since the early 2000s. For all species, coexisting healthy and unhealthy trees were sampled, and analysed using dendrochronology, wood anatomy, stable isotope technique, non-structural carbohydrates, and pathology. We also explored how remote-sensing indices of vegetation activity and radial growth responded to drought. Our results pointed to changes in wood anatomy and growth related to major mortality mechanisms such as hydraulic failure and carbon starvation. In addition, we also modeled the probability of tree death as a function of tree size. We also pointed out that the resistance of oaks to droughts is strongly determined by the ability of their root system to extract water from the soil. We demonstrated that the effects of climate extremes such as droughts on vegetation can be detected either in terms of canopy greenness or radial growth reductions, thus hinting at the opportunity to combine remotely sensed data as a stand-level indicator of vegetation stress and to scaling up information from tree to stand levels using tree-ring data. Finally, our findings provided new insights on how trees showing ongoing dieback may keep their vital activities by changing their phenological performance, leading to potential implications on the global carbon and water balances of forest ecosystems.

Leaf phenological monitoring through IoT technology: the example of two beech forests in the Apennines

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Tree phenology refers to studying and observing the timing and sequence of recurring biological events in trees throughout their life cycle. Its study involves monitoring and documenting various seasonal changes and stages in the growth and development of trees, such as leaf emergence, flowering, fruiting, leaf senescence, and bud dormancy. To deeply comprehend the dynamics of tree phenology linked to the environment and its changes, tree physiological response parameters should be observed at high frequency in the long term. Recent technical development has made available IoT monitoring systems, comprising environmental and physiological parameters, to accomplish measurements of tree functionality with detail and large datasets. The TreeTalker is one of these instruments.

The TreeTalker technology was adopted to monitor trees in mountain beech forests at two altitudes in the Apennines (Matese, Molise). In particular, the light transmitted through the forest canopies, and its spectral components, measured by a spectrometer, were used to observe the tree's phenological activity in two growing seasons. Classical phenological observations were conducted on the same experimental sites. This study aims to assess variations in tree phenology in time (two years) and altitude (two elevations), comparing TreeTalker measurements and visual observations. We also tested the effects of environmental variables, such as temperature and precipitation, on phenological phases. According to our results, TreeTalker may help reduce the need for visual *in-situ* observations and continuously monitor leaf phenology, therefore providing new opportunities for supporting the mechanistic understanding of the processes underpinning tree growth responses to environmental changes.

Long-term monitoring of silviculture for temperate old-growth forest characteristics in eastern North America

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Many have wondered if silviculture could be used to restore characteristics of temperate old-growth forest in eastern North America, both in reserves and managed forests. After several decades of research, old-growth silviculture is employed operationally in a variety of settings, and long-term monitoring has proven pivotal for understanding lagged effects and outcomes across a range of responses. This talk will review several examples, focusing specifically on a system called *Structural Complexity Enhancement* (SCE). The hypothesis has been that SCE can accelerate rates of late-successional stand structural development faster than conventional selection systems. Response variables include financial viability, late-successional biodiversity, tree regeneration, and aboveground carbon pools. The experimental design and monitoring compares SCE against two modified selection treatments. Manipulations and controls were applied to 2 ha units and replicated four times at two research areas in the Green Mountains of Vermont, USA. The selection treatments and controls were replicated two additional times in the Adirondack Mountains of New York. Field data were collected over two years pre-treatment and 18 years post-treatment. Ten years after harvest, measured aboveground carbon in SCE units was 15.9% less than simulated no-harvest baselines, compared to 44.9% less in conventional treatments. All treatments were successful in maintaining overall richness and/or abundance of understory plants, terrestrial salamanders, and fungi. Statistical model results show that understory plant responses were strongly affected by treatment and less influenced by soil chemistry and drought stress. However, diversity for sensitive, late-successional herbaceous plants increased significantly in SCE units and decreased significantly in the semi-open canopied conditions within group selection units. Fungi and salamander responses were strongly associated with microsite characteristics, particularly coarse woody debris, and increased significantly under SCE, but showed no statistically significant decrease in silvicultural gaps. SCE is economically profitable or breaks even under the right site and market conditions. Potential applications include old-growth restoration, riparian restoration, carbon management, and low intensity commercial management. Adaptive silviculture promoting old-growth forest characteristics will contribute to biodiversity conservation and climate mitigation while providing both timber and non-timber economic opportunities.

Masting impact on leaf area index, light condition and growth of below-canopy trees in Fagus crenata forests, Japan

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Masting is synchronous intermittent production of large seed crops in perennial plant populations, which occurs for 5 to 10 years interval in *Fagus crenata* forest. Since heavy seeding requires many resources, leaf area of fruit bearing trees decreases in mast years. Therefore, masting is expected to improve light conditions on forest floor and thus growth of below-canopy trees. However, study focusing on role of masting as transient gap is generally limited. Since climate factors directly and indirectly control masting, understanding the linkage between masting, canopy structure and growth of below-canopy trees is important to predict climate change impacts on forest dynamics. We thus monitor leaf area index, fruit production and growth of below-canopy trees in *Fagus crenata* forest for more than 9 years. The objective of this study is to test the hypothesis that masting play important role for sustaining below-canopy trees as transient gap.

Study site is 200-250 years old, almost pure beech forests at 550 m and 1500 m a.s.l. on Naeba mountain in Japan. Stand LAI and fruit production were measured for 16 years (from 2003 to 2007 and from 2014 to 2022) with litter trap method. Stem diameter increment was measured for all individuals in the stands for 9 years from 2014 to 2022. Light conditions on forest floor were estimated with hemispherical photography and radiative transfer model. Synchronous masting across the sites occurred at four times during the study period; 2005, 2015, 2018 and 2022.

Stand LAI significantly decreased in masting years, but returned to pre-masting level in the year following the masting events. Stem growth of below-canopy trees was markedly improved in the masting years, but peak of the improvement occurred in the years following of masting. A masting event at the 550 m site in 2018 did not reduce LAI exceptionally, but stem growth of below-canopy trees increased as well as other occasions. Therefore, masting events and subsequent reduction in LAI improve growth of below-canopy trees, but factors other than light condition, such as nutrient supply, may also contribute to the improvement of growth.

Monitoring above-ground biomass for multiple species-rich natural forests in Japan using UAV-LiDAR

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Conventional forest biomass estimate involves time-consuming and costly ground census (e.g., measuring DBH and height). UAV-LiDAR can collect crown geometrical information (e.g., height and area) for wider areas in a short time, making it an important tool for estimating forest biomass. However, the extent to which this technique can accurately predict biomass and growth of species-rich natural forests across a wide range of environments is still unknown. To investigate this, we acquired LiDAR data in multiple (currently 11) natural forests across Japan. A combination of LiDAR data, image segmentation, and ground validation was employed for accurate estimation of height (H) and crown area (CA). Above-ground biomass (AGB) and growth rates (GR) were calculated from the most recent five-year census data. We then compared a set of linear regression -and mixed models to determine the important parameters in determining growth rates.

The drone survey detected a total of 1938 individuals from 85 species (out of 10,644 stems belonging to 153 species with DBH > 5cm). The contribution of drone-detected individuals to the total biomass varied across different sites, ranging from 64 % in deciduous forests to 84 % in evergreen conifers. Consistently, canopy trees make up *c.a.* two-thirds of the total biomass in 1 ha underscoring their reliability in monitoring biomass dynamics. A strong correlation was observed between CA and AGB, and between GR and CA, both exhibiting significant variation among different sites ($p < 0.001$). CA was a better predictor of GR ($R^2 = 0.35$) than H ($R^2 = 0.14$). Together they can explain up to 37 % of GR variation ($R^2 = 0.37$). We found that adding species information much improved the estimation of GR ($R^2 = 0.49$).

In conclusion, the study demonstrates the effective application of UAV-LiDAR for detecting crown areas of tall canopy trees. It offers an innovative and reliable method for monitoring above-ground biomass in species-rich natural forests, providing valuable insights for their management.

Monitoring natural forests in the Andes-Amazon in three dimensions with multi-satellite sensors

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: The region from the Andes to the Amazon holds diverse ecosystems due to the different environments created by the great differences in elevation. These mountain ecosystems have multifaceted functions such as biodiversity conservation and global environment conservation that mitigate global warming and stabilize the global climate system, and provide various ecosystem services for human life. On the other hand, natural forests in this region are exposed to natural disturbances caused by forest fires and anthropogenic disturbances caused by human activities, and proper conservation and management of natural forests are necessary to maintain the functions that forests possess. The data obtained from the GEDI, which is LiDAR sensor and is onboard the International Space Station (ISS) by NASA, can provide three-dimensional information at observation points. However, the data is discrete and does not cover the entire area of interest. Therefore, the objective of this study is to develop a method for monitoring the extent and condition of natural forests from the Andes to the Amazon region by combining GEDI data with data from optical satellite sensors. First, we performed region segmentation on optical satellite Sentinel-2 images into regions of high similarity. The resulting objects were then classified on the object-based classification using data on land cover type and forest carbon stocks obtained from ground-truth surveys in the field. For objects classified as natural forests, GEDI data were used to assess the state of natural forest disturbance. The results showed that the more degraded the forest, the lower the height from the ground at the peak of the intensity of reflected energy from the forest canopy. Using this feature, it was possible to evaluate the condition of natural forests. However, the observed data at sites with very steep slopes showed significant slope effects and future development of methods to reduce the effects of slopes is required. In addition, the use of satellite LiDAR is not suitable for monitoring dwarf natural forests in high-elevation zones, and other monitoring methods using other sensors, such as high-resolution satellites, are needed.

Monitoring patterns of natural dynamics and biodiversity in several mature and old-growth forests through an ecological gradient.

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Natural dynamics over a long-term perspective is a very little studied aspect in southern european forests. Monitoring the relation between structure, biodiversity, demographic processes and natural disturbances is essential for better understanding the role of forests in key issues such as climate change and nature conservation. In the last years we have established a network of reference mature and old-growth forest stands through a broad ecological gradient for the long-term monitoring of key ecological aspects. From the sea level close to the Mediterranean Sea to the timberline in the Pyrenees mountains we explored forests dominated by different tree species: *Pinus halepensis, Quercus ilex, Juniperus thurifera, Pinus pinaster, Pinus nigra salzmanii, Quercus pyrenaica, Pinus sylvestris, Fagus sylvatica – Abies alba,* and *Pinus uncinata.* We installed two permanent plots (square and size 0.25 ha) per stand. Dendrometric values vary greatly among forest types. Montane forests belonging to the Alpine Bioregion showed the highest values of volume (658 m^3/ha), basal area (58 m^2/ha), Assman dominant height (28 m), and volume of dead wood (100 m^3/ha) probably as a consequence of higher Net Primary Production. Nevertheless, forests in the Mediterranean Biogeographical *Region* had the thickest (DBH 79 cm) and oldest (364 years) trees. The abundance of tree-related microhabitats was higher in hardwood forests, however the maximum values was obtained in a coniferous forest in the high Mediterranean mountains (*Pinus uncinata* in the Iberic Range). The analysis of the phases of the silvogenetic cycle helps to understand the functioning of forests and with a dendrochronological approach we reconstructed the stand historical dynamics tending to establish the current state of the forest. New technologies as terrestrial Lidar scanning and drones help us to have a more accurate representation of the forest structure. Studying insects and epiphytic lichens and bryophytes will allow us to verify the potential effects on the most sensitive species to habitat alteration. Long-term monitoring of these stands will enable to understand the resilience and mitigation effects of different mature forests to ongoing global change.

On the utility of forecasting seed production in forest trees

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Masting, the intermittent production of synchronized bumper crops by population of plants, is a pervasive phenomenon in temperate and boreal trees. The resulting interannual variability in reproduction provides considerable challenges for foresters, land managers, and conservationists, as the resulting resources pulses affect not only natural tree recruitment, but also whole forest communities through trophic cascades built on seeds. Because our mechanistic understanding of and data foundation for seed production in forest trees has grown extensively over the last decade, anticipatory and long-term forecasts of annual seed production patterns may soon be available for many common species. Here, we discuss how such forecasts may be useful to plan the timing of forestry operations, land management decisions, and conservation actions. We present examples from ongoing forecasting efforts and their impact on the work of practitioners in forests. Furthermore, we highlight how anticipatory forecasts may also be useful to forest- and tree-related public health aspects, for example by predicting pollen density, tick abundance, or the rate of zoonotic disease transmission to people living in and near forests.

Pattern of natural dynamic of a sessile oak- European beech old-growth forest

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Old-growth forests are important sources of information. The Runcu-Grosi Reserve is one of the few remaining, good preserved sessile oak-beech old-growth forest in Europe. The 10-years dynamic of this rare old-growth forest was investigated based on the re-measurements of approximately 1880 trees with a threshold diameter of 5 cm, grown in 26 circular plots of 1000 m^2 randomly distributed. Three important processes of forest dynamics: ingrowth, mortality and increment of trees were investigated, and the effect of the main tree species on these processes. The ingrowth (the number of trees per hectare that passed the diameter threshold at the second inventory) ranged from 0 to 200 per hectare, with an average value of 63. Beech accounted for 71% of the new trees, followed by hornbeam (24%), while sessile oak accounted an insignificant percentage (0.02 %). The lowest average number of new trees was found in pure beech plots (25), three times lower than in plots dominated by beech or oak (75), but with no significant differences, due to the high variability. The average number of the tree per hectare that died, during the 10 years, was 113, which corresponding to an average volume of 107 m^3 ha^{-1} (17 % of the initial volume of living trees, ranged from 0.5 to 50%). Although, the percentage of trees that died was almost similar between plots of different composition, the oak dominated plots had the greatest volume loss trough mortality (19 % comparing to only 14% in pure beech), indicating that a greater number of larger trees died in these plots. Most of the trees that have died, are lying dead trees (more than 65% in both number and volume). While beech accounted for 67% of the number of trees that died, the Quercus species accounted for over 50% of the volume. The mean radial increment per 10 years was 2.72 cm, being similar in plots with different composition. Our results provide a valuable basis for understanding of sessile oak – European beech old-growth forest dynamic in a changing climate and will be completed with more information collected in inventory plots of 1 ha.

Shifts in wood anatomical traits after a major hurricane

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Trait variation across individuals and species influences the resistance and resilience of forest ecosystems to disturbance, as well as the ability of individuals to capitalize on post-disturbance conditions. In trees, the anatomical structure of xylem directly affects plant function and, consequently, it is a valuable lens through which to understand resistance and resilience to disturbance. In many tropical regions, disturbance regimes are historically dominated by cyclonic storms, which are predicted to occur with higher frequency and intensity under climate change. To determine how hurricanes affect wood anatomy of tropical trees, we characterized a suite of anatomical traits (vessel sizes, vessels grouping, tissue fractions) in wood produced before and after a major hurricane in Puerto Rico for 65 individuals of ten species. We quantified anatomical variation at different scales (within individuals, within species, among species), and evaluated trait shifts between the pre- and post-hurricane periods. We also assessed correlations between traits and growth rates. While most trait variation occurred among species, we also observed substantial variation within species and individuals. Within individuals, we found significant shifts for some traits that generally reflected increased hydraulic conductivity after the hurricane. We found weak evidence for an association between xylem anatomical traits and growth rates. The within-individual variation of xylem anatomical traits observed in our study may be related to post-hurricane recovery and growth. Other factors are, however, likely to decouple the direct relationship between xylem anatomy and diameter growth. While adjustments of wood anatomy may enable individual trees to capitalize on favorable post-disturbance conditions, these may also influence their future responses or vulnerability to subsequent disturbances.

Start with the forest: monitoring terrestrial carbon fluxes with geospatial data

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: The Paris Agreement goal of limiting global warming to well below 2 degrees cannot be achieved without significant reductions in human-caused emissions from land. In order to reduce terrestrial carbon emissions, as well as maintain or increase carbon removals, we need to understand historical carbon fluxes. Ideally, terrestrial carbon flux monitoring would be sufficiently spatially resolved for actionability by a range of parties, as well as transparent, complete, consistent, and accurate. Numerous approaches have been used to monitor terrestrial carbon fluxes—both emissions and removals—but usually not within a targeted geospatial framework, and often with highly divergent, potentially conflicting results.

Here we build on a global geospatial, Earth Observation-based framework for monitoring forest carbon emissions, removals, and their net flux from 2001 onwards. This framework was developed to monitor carbon emissions from forest loss and carbon removals by standing and regrowing forests according to Intergovernmental Panel on Climate Change greenhouse gas inventory methods. Agricultural commodity companies, multilateral organizations, researchers, and civil society have applied this forest carbon monitoring data to their specific needs and regions of interest. Although forests contribute the majority of terrestrial carbon fluxes, there is increasing interest in more comprehensive terrestrial carbon monitoring, as demonstrated by the shift from deforestation-free commitments to conversion-free commitments among companies. Thus, we are expanding the forest carbon monitoring framework to cover fluxes from all land uses and land-use change, as well as agricultural emissions, through a stepwise, incremental approach.

This presentation will explain how an Earth Observation-based forest carbon monitoring framework can serve as the basis for monitoring carbon changes for all land, the progress made on broadening the framework beyond forests, challenges encountered, anticipated uses, and the potential for not just forests but all land to contribute to climate change mitigation.

Structural characteristics of natural European temperate forests – how do they relate to time since management?

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: In Central Europe, strict forest reserves are an important component of forest conservation strategies, aiming at restoring natural structural properties in previously managed forests. However, by time of designation most reserves had been more or less intensively managed and vary in stand and site conditions. Although important with regard to both, carbon storage and biodiversity, it remains unclear, how different structural characteristics of these forests are related to time since management cessation, and how this relationship is modulated by site conditions, forest type and climate.

We related forest structure characteristics to time since reserve designation ("reserve– age"), using *in situ* data from 85 unmanaged forest reserves in Baden-Württemberg, Germany, ranging from one to 99 years in age. While we expected a continual increase in *old-growth attributes, tree-related microhabitats (TreMs)* and *species and structural diversity* with "reserve age", we hypothesized a temporal decrease of *open structures*.

In line with our expectations, reserve age was strongly positively related to *old growth* attributes like dead wood volume, the number of giant trees (>80 cm diameter at breast height) and the proportion of forest in decay phase. Strong relationships were also found for *TreMs,* in particular for fungi and broken tree parts, and for indicators of *structural diversity*, such as the diversity of decay stages and the variance in stem diameter of dead trees. No significant trend was found for indicators of *open structures*, except for the volume of living trees, which showed a maximum for 30-year-old reserves.

While no differences were found between broadleaved and conifer-dominated forests, climate conditions significantly modulated the responses of most structural attributes to reserve age, except for the share of late successional phases, the diversity of decay stages and for *TreM* abundance of fungi and cavities. In addition, site productivity affected the response-level of living tree volume and the variance in the stem diameter of dead trees.

Our results provide evidence, that climate change will accelerate the development of structural complexity in natural forests and thus increase their potential to support forest biodiversity.

STUDY OF THE DYNAMICS AND CARBON STORAGE IN SWAMP FORESTS IN THE UCAYALI, MARAÑÓN AND TIGRE RIVERS IN THE PERUVIAN AMAZON»

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: In Peru, Amazonian peatlands are estimated to store 3.14 (0.44–8.15) PgC, representing 40% of the country's carbon, and in 3% of the forested territory (Draper et al., 2014). In this study we expand the knowledge of these formations, in swampy forests such as hydromorphic Aguajales and Varillales in the Loreto region. Ten permanent plots of 0.5 ha were evaluated with the RAINFOR standardized methodology. In five of these plots, the carbon content of the organic soil (peat) was evaluated. Biomass was estimated using the pan-tropical equation of Chave et al. (2014). Organic soils were characterized and carbon reserves were estimated by measuring apparent density and the percentage of total carbon. In addition, diversity descriptors, floristic composition and estimators of forest dynamics were evaluated. A similar basal area was obtained in the two formations, 27.4 to 28.2 m2/ha. Only in the hydromorphic Varillales was a high tree density of 892–1074 ind/ha higher than the Aguajales and other formations of the Amazon plain. Low values of richness and diversity were obtained due to the presence of monospecific species where Mauritia flexuosa is the most ecologically important species (130–185% of the IVI) for Aguajales and Pachita nitida (58–126% of the IVI) for hydromorphic Varillal. We found that swamp forests contain between 641.74–2189.75 MgCha-1, above and below ground. Furthermore, the hydromorphic Varillal has been found to be the most carbon dense ecosystem with 2187.80–2189.75 MgCha-1, of which approximately 90% is Soil organic carbon; these present an average peat depth of 4.50m, in contrast to the Aguajales of 0.96m. Regarding forest dynamics, for seven plots with an intercensal period of 2.26-5.8 years, the mortality, recruitment and turnover rate of individuals present high values, between 1.76-5.41%; 2.31–5.65% and 2.03–5% per year respectively.

Towards a functional monitoring network in Catalan forests (FUNBOSC)

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Forests are key for Earth functioning and provide human societies with numerous ecosystem services, including nature-based solutions that aid in climate change mitigation. However, environmental stress and disturbances, frequently magnified by anthropogenic global change, threaten forests and the services they supply. Our toolbox for large-scale monitoring of forest state and functioning includes forest national inventories, periodic surveys of forest health, remote sensing tools and forest ecosystem models. While these approaches have been refined over the years and now provide highly valuable information about forests worldwide, they also show important limitations when it comes to identifying how tree water use and carbon dynamics respond to stress/disturbance across different tree species and at large geographical scales. At the same time, decades of research on tree ecophysiology have equipped us with the expertise to measure tree water and carbon use at diel to seasonal scales. Here we present the initial design of a forest functional monitoring network (FUNBOSC) aimed at providing data on tree water use, tree water status and tree radial growth across forest stations in Catalonia (NE Spain, total forest area *ca.* 12,000 km2). This network will integrate sap flow probes, automatic dendrometers and tree water content sensors in wireless sensor networks to provide near real-time data. FUNBOSC will start with 10 initial stations to be deployed in the short term and which will be located in forests with existing ecohydrological monitoring and/or sites affected by drought-related forest die-off. We will present the prototype of a tree monitoring station and the infrastructure for data transfer, storage, processing and visualisation developed during a 6-month test period in a diverse Mediterranean forest (Can Balasc Biological Station, Barcelona). The data resulting from FUNBOSC will be publicly available and will contribute to improve our understanding of the response of water and carbon fluxes to climatic variability, derive early-warning signals of forest decline, improve forest ecosystem models and refine remote sensing indicators of forest functioning. FUNBOSC is designed to be integrated into broader, regional forest monitoring networks and its principles can be applied in other regional contexts.

Towards closing the seed dispersal loop: the role of temporal variation in seed rain for tree population structure in old-growth forests

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Altered disturbance regimes in forests create unique challenges in terms of tree regeneration and carbon storage in future forests. Understanding spatiotemporal dynamics of tree seed production and dispersal is thus key to sustaining ecosystem function of old-growth forests. As the number of long-term studies and the availability of global data sets on tree seed production grow, the understanding of proximate factors driving tree seed production has strongly increased. However, to understand the effect of seed production and dispersal on long-term community dynamics and, ultimately, to evaluate the fitness consequences of different seed production strategies, it is important to link seed production and dispersal with tree population dynamics. This is particularly important because processes that act at different stages of dispersal, germination and seedling growth can be uncoupled and even have opposing effects. Here, we use a combination of empirical research on seed rain, tree regeneration, and seed predation in old-growth forests combined with the parameterization of a spatially explicit, individual based tree population model (SORTIE-ND). Specifically, we studied the consequences of temporal variation in seed production on long-term tree population dynamics including seed fate and the population dynamics of small mammals. We tested the following hypothesis: (1) through pronounced masting in species with palatable seeds, seed predators are driven into hunger cycles and reductions in populations leading to windows of opportunity for tree establishment through intermast seeding and (2) Intermast seeding creates spatial structure in trees and influences species composition and dynamics. We found that high spatial variability of seed rain for Fagus sylvatica was caused by distinct and stationary seed hotspots, seed input positively predicted the spatial structure of seedlings and saplings for this species. The signature of annual variation in seed rain fades with seedling mortality over time in all three focal species. We found that spatial variation in seed rain interacts with subsequent processes to shape the distribution of seedlings and saplings, but in ways that suggest decoupling of the processes between life history stages.

Tree growth during 50 years and stem respiration along elevation gradients in Japanese beech forests

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: *Fagus crenata* (Japanese beech), a late-successional and climax species, is ecologically the most important forest species in the cool temperature zone in Japan. Japanese beech forests are distributed widely in Japan and at 550 to 1500 m in elevations around the Naeba mountains. The elevation gradients of the beech forest distribution in this area are about 1000 m and it means that there is the maximum difference in temperature of about 5 °C. The temperature environments might be one of important environmental factors for tree growth and respiration. And temperature trends to increase in recent days under global warming. We tried to evaluate the effects of temperature environment changes on tree growth and stem respiration for the Japanese beech forests grown at different elevations in the Naeba mountains.

Eight study sites were set at different elevations of 550, 700, 900, 1100, 1300 and 1500 m in 1970. All living tree with more than 4.5 cm in DBH were numbered and their spatial locations were recorded. DBH of trees in each study site were measured after growing season intermittently during 1970 to 2021. The tree growth and NPP were calculated and compared among sites and ages.

Stem CO_2 efflux were measured in situ seasonally from May to November in 2022. The measurements were conducted in 11 to 12 trees grown at four different elevations of 550, 700, 900 and 1500 m. Diameter increments were also measured by dendrometer bands. Stem respiration were divided into growth respiration and maintenance respiration, and analyzed.

Trends in climate oscillations drive spatio-temporal changes in tree reproduction phenology

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Anthropogenic climate change is influencing the biosphere via a generalized warming trend and variation in global circulation patterns, with tremendous cascading effects on the phenology and timing of ecosystems processes and their interactions. Disentangling the mechanisms that link large-scale modes of climate variability to spatio-temporal patterns in tree reproduction can improve our understanding and prediction of forest ecosystems dynamics under the current climate crisis. In Europe, changes of the NAO have been affecting the inter-annual variability and large-scale synchrony in tree reproduction of key families such as Fagaceae, Betulaceae, Pinaceae and Cupressaceae. Our research investigates how NAO properties, seasonal patterns, cycles and trends in the last 70 years prompted large-scale reproductive pulses in beech forests, and how this mechanism and related processes (e.g., trophic cascade, human diseases) can be affected by predicted changes in climate. We expect that as the altered circulation patterns might lead to a shift in the intensity, duration, and frequency of NAO phases, it might as well impact the periodicity of the summer NAO, with tremendous implication for beech reproduction in the next decades.

Tropical forest response to climate change: advancing understanding with high-resolution and long-term data

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: Tropical forests contain the majority of Earth's biodiversity and provide immense benefits to humans at both local and global scales. To date, however, we have a surprisingly poor understanding of how specific climate stressors (e.g., drought) affect these forests and, ultimately, scale up to ecosystem-level responses. Accurately forecasting the global consequences of climate change requires stronger mechanistic links between climate variability and the dynamics of tropical forests. We established a set of long-term monitoring plots in forests across a precipitation gradient (mean annual rainfall ranging from 900 – 3500 mm year) in the Caribbean island of Puerto Rico. We collected spatially-explicit, annual data on individual tree diameter growth and survival over 6 years to better understand demographic responses of species to climate variability. We collected complementary data on numerous functional traits (e.g., wood density, SLA, hydraulic vulnerability to embolism) to understand how traits mediate demographic responses to climate variability. Finally, we used information on species broader geographic distributions to contextualize growth responses to climate variation in terms of species climatic niches. Preliminary results show highly variable growth rates among species and across species ranges, as well as trait-mediated responses to climate variability. Ongoing work is will further assess climate-growth relationships in the context of species climate niches, local topographic position, and local biotic neighborhood to determine the processes the mediate growth depend on the climatic context. Overall, our study illustrates the value of long-term monitoring across regional environmental gradients to understand the variety of processes that govern forest dynamics.

UAV-LiDAR carbon modeling for REDD+ projects in Brazilian savanna (Cerrado)

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: The Cerrado formations (Brazilian Savanna) represent a diverse and unique tropical savanna biome. Despite its ecological significance and rich biodiversity, the Cerrado remains one of the most threatened biomes globally, primarily due to agricultural expansion and land-use changes. Understanding the biomass dynamics within these formations is crucial for effective conservation. Precisely estimating carbon stocks is a crucial undertaking for both climate change mitigation and conservation initiatives, particularly in the context of REDD+ projects. Traditional approaches, relying on costly field-based carbon measurement methods, encounter constraints related to their spatial coverage, impeding comprehensive and accurate assessments across expansive forested areas. To address this challenge, remote sensing with UAV-LiDAR emerges as a valuable solution that has the potential to overcome these limitations. By harnessing remote sensing technologies, carbon stock estimates can be scaled up, fostering transparency in carbon reporting. However, achieving dependable outcomes mandates the development of precise regional models and the adoption of high-accuracy techniques to ensure reliable and robust results. In this sense, we assess the capability of high-density UAV-lidar to estimate and map the aboveground carbon density (AGCt) of live trees in the Brazilian Savanna (Cerrado) using 45 field-based sample plots (30 m × 30 m). Three generalized least square regression models were tested, and we considered the presence/absence of palm trees as variable to improve precision in biomass estimates. We hypothesize that the presence of palm trees is an indirect indicator of higher soil moisture, occurrence of trees with higher canopy cover and biomass. We found that considering the presence of palm trees as a biological index of areas with higher carbon content improves the model accuracy by 27%. Comparing the LiDAR estimates and field-based control plots, we found a global uncertainty of 2.1% and sub estimates of 1.6% when applied to 1000 iterations of the resampling procedure. The findings of this study serve as a benchmark for future research endeavors aimed at generating accurate carbon maps and providing baseline data for the efficient management of fire and predicted climate change impacts on tropical savanna ecosystems.

Understanding forest stream flow regulation and restoration in the seasonal tropics: A view from Agua Salud

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: On an area basis, forests use more water than grassland. Tropical forests also more directly regulate stream flow due to deeper rooting and longer time periods of water use. Few long-term studies of stream flow exist for tropical watersheds at the precision and accuracy necessary to understand forest stream flow regulation. Even fewer studies examine the restoration of stream flow regulation over time. The Agua Salud Project in central Panama studies the ecosystem services provided by tropical forests in a seasonal climate and how they change with land use and climate change. Catchments in Agua Salud have been monitored continuously (5 minute averages) for 15 years, where monitoring not only includes forest, pasture, and invasive grass end members but also several active and passive forest restoration treatments (natural secondary forest recovery, exotic tree species (teak) plantation, native tree species plantation, invasive grass, silvopasture treatments). In 2013 researchers showed that the mature forest catchment had enhanced dry season stream flow relative to the pasture and showed that the forests greatly reduced storm runoff peaks and volume. Multi-year studies of different compartments of the water cycle (rainfall, throughfall, infiltration, stream flow) combined with natural tracer experiments help provide a mechanistic understanding of how forest stream flow regulation works.

Concurrent with stream flow monitoring, vegetation, soil, and micrometeorology have also been recorded in experimental catchments. Here trees, lianas and seedlings have been monitored annually for growth, mortality, and recruitment. Sap flux measurements help understand the water use of trees and forests.

The 15-year monitoring in Agua Salud includes the flood of record in the Panama Canal Watershed and other extreme storms. The period also captures one of the worst droughts during the last 100 years, the period for which rainfall data are available.

In this talk we will discuss the results of over a dozen studies undertaken to monitor and understand the mechanisms of stream flow regulation by forests. We will discuss this in relation to plantation and natural forest dynamics with special attention given to vegetation response to extreme weather events, one of the best windows into the effects of global change.

What is and what is not an old-growth forest? A case study from hemiboreal Latvia.

T5.23 Monitoring patterns and processes in natural forests to assess their contribution to climate-change mitigation

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Abstract: The EU Biodiversity Strategy (2030) prioritizes the preservation of Europe's old-growth forests (OGFs). Protected areas should make up at least 30% of the EU land area, with 10% under strict protection, including all primary and old-growth forests. The mapping of OGFs, however, at EU and Member state level presents a challenge. Though knowledge on OGFs has improved, at the EU level, large uncertainty remains regarding the definition of old-growth due to both the lack of data and broad variation in OGF forest characteristics, including age.

A conceptual approach should be developed which, for each ecosystem, defines what is and what is not an OGF. This will permit an adequate mapping of OGF relevant protection areas at the EU and Member state levels. Current definitions, for example, suggest that once an old forest stand is lost, e.g., through natural disturbances, that the stand should no longer be considered an OGF.

The aim of this study is to assess the definition and presence of OGF stands across the territory of Latvia. Based on the OGF Guidance by European Commission (COM, 2023), we apply OGF criteria, select reference stands, and develop indicators and threshold values for hemiboreal forests with the goal of distinguishing, e.g., between patches of old trees which meet some OGF criteria, on the one hand, and forest stands that can be qualified as true OGF, on the other.

OGFs in hemiboreal Latvia have now been systematically studied for 8 years (since 2016) and have been assessed in the National Forest Inventory since 2004. Based on empirical data from established OG research sites, we assess the principal forest stand characteristics (H, DBH, N, M) for coniferous and broadleaved tree species growing on mineral and organic soils. Above- and below-ground carbon pools, including the deadwood pool, have likewise been assessed, making it possible to evaluate the climate change mitigation potential of hemiboreal OGFs.

We suspect that OGF cannot be defined by tree age alone and find broad variation across stands and stand structures.

T5.24 Moving towards digital forests for a sustainable future

Assessment of forest structural dynamics over a phenological cycle using mobile laser scanning

T5.24 Moving towards digital forests for a sustainable future

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Abstract: The phenological cycle is more and more affected by climatological changes. Spring activities such as the shooting and flowering of vegetation have occurred progressively earlier since the 1960s, changing structural dynamics of forest ecosystems. Changes in forest structure resulting from altered phenological patterns can impact ecosystem processes such as carbon and nutrient cycling, water availability, and biodiversity. Understanding phenological changes in forest structure is crucial for effective forest management and conservation.

Monitoring 3D structural dynamics in forest ecosystems on plot or stand scale can be labor intensive. With mobile laser scanning (MLS) becoming more prominent in forestry applications, repeated measurements of the 3D forest structure on plot scale are getting more feasible, allowing for an assessment of 3D structural dynamics over a phenological cycle.

In this contribution, we performed repeated MLS acquisitions on four sample plots in a mixed temperate forest close to Zurich, Switzerland. The sample plots have a size of 50 x 50 m2, corresponding to the sample plot size of the Swiss National Forest Inventory (NFI). MLS acquisitions were acquired on a weekly repetition cycle from March until June during the most dynamic vegetation period. Before and after that period, sporadic acquisitions have been performed to capture the entire spring phenological vegetation cycle.

From the acquired time series, the forest structural dynamics were analysed in terms of changes in vegetation density (i.e. plant area density) for various canopy strata (under-, middle-, and upper-storey), vegetation density profiles, extracted canopy height from the acquired point cloud, and the change in visibility within the canopy using an occlusion mapping approach.

Preliminary results show that repeated MLS acquisitions are well suited to assess small scale variations in 3D canopy structure, possibly giving important insights into phenological dynamics. Linking these structural dynamics with meteorological data and measurements of forest gas exchange, water- and nutrient cycles could deliver important information on the impact of climate change on forest structural dynamics and ecosystem functioning.

Augmented reality in forestry - Potentials and challenges

T5.24 Moving towards digital forests for a sustainable future

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Abstract: In the process of digitising forestry (Forest 4.0), extensive data are generated and digitally stored as a digital twin of the forest and the processes taking place in it. While the data recording has been intensely investigated so far, the efficient provision of the processed digital data to the respective user on-site in the forest continues to be challenging. In particular, the visualisation of these digital data in a suitable, application-oriented form in the forest, e.g., for forest rangers or forest workers, has not yet been sufficiently solved. Currently, this is done, for example, via printed maps or digital representations on devices such as smartphones or tabs, which can only be used to a limited extent in daily work in the forest.

The field of augmented reality (AR) offers a promising approach to visualising stored digital data in reality. In AR, a computer-assisted extension of reality perception is carried out by inserting digital data in real-time onto digital images (smartphone/tablet) or projecting them into the viewer's field of vision with the help of a projection surface (e.g., AR glasses). Ideally, digital data and reality are spatially congruent, with data enrichment of reality taking place. In this way, the quantity, quality, and safety of work in the forest can be increased, especially for forest workers, district managers, and decision-makers, by displaying digital data and/or hazard information in real-time without having to restrict/interrupt the work in question.

The presentation shows the results of a feasibility study and the potential for the operational use of AR in the forest with an iPad as well as with the currently most frequently used AR glasses HoloLense2 from Microsoft. Furthermore, the scientific questions, the current solutions and the challenges that still need to be solved, such as data preparation and transmission, available technology, insufficient positioning accuracy and orientation under shielded conditions, and a potential gain in productivity and safety, will be addressed.

Construction of 3D Data on Urban Trees Using Integrated Investigation Method

T5.24 Moving towards digital forests for a sustainable future
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Abstract: Recently, cities and countries have implemented a 3D virtual space by applying the concept of a digital twin. The level of digital twin technology is classified according to how detailed it is to implement a building. Accordingly, while modeling technologies are focused on the realization of buildings, the level of implementation of trees, which are the main components of a city, is lower than that of buildings.

This study aimed to establish 3D data on trees that can be used to implement a 3D virtual space through various methods of tree investigations. Tree information was collected using three investigating methods: literature review, field survey, and remote sensing analysis with UAVs and terrestrial LiDAR. The investigating data was implemented with GIS-based data consisting of tree information such as location, height, treewidth, and bole height. The investigation site was the Jung-gu district in Daegu Metropolitan City, South Korea. The investigation focused on streets, schools, and residential areas where trees were planted the most in the city. First of all, a literature review was conducted for areas with literature data, and a field survey was applied for areas without literature data. A remote sensing analysis was conducted by collecting point cloud data and recognizing points as an object. In this study, aerial viewpoints were collected through UAVs, and ground viewpoints were collected through terrestrial LiDAR, and the two were integrated. The method was conducted only for a neighborhood park called National Debt Redemption Movement Memorial Park. The remote sensing results were compared with the field survey to improve the establishment method of 3D data on trees by the remote sensing method.

The results of this study can be used as basic data for building 3D spatial information and realizing digital twins in Daegu Metropolitan City. In addition, it is judged that they can be used for improving environmental effect analysis by 3D spatial information of urban forests.

Enhancing Forest Tree Species Mapping in High-Resolution UAV RGB-Imagery with Pseudo-Labeling-based Semi-Supervised Learning

T5.24 Moving towards digital forests for a sustainable future

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Abstract: UAVs play a crucial role in forest inventory and forest management due to the accessibility of high-resolution RGB imagery. With the advancements in deep neural networks (DNNs), the utilization of UAV imagery for semantic segmentation has significantly enhanced the accurate mapping of tree species in diverse temperate forests. However, generating training data for semantic segmentation typically relies on a large amount of labor-intensive reference data. In this study, we propose PoLa-Net, a deep learning-based approach for classifying tree species from UAV imagery. PoLa-Net leverages pseudo-labeling techniques to train a semi-supervised semantic segmentation model by utilizing both unlabeled data and a limited amount of annotated data. We evaluate the performance of PoLa-Net on a dataset comprising very high-resolution (<2 cm) RGB imagery acquired by multi-copter UAVs over heterogeneous temperate forests in the southern Black Forest region of Germany. Our model achieves accurate classification of ten tree species, deadwood, and forest floor, with a best mean Intersection over Unit (mIoU) score of 73.9%. The experimental results demonstrate that PoLa-Net is a robust and efficient method for tree species mapping. Furthermore, the training strategy employed by PoLa-Net can be applied to analyze and process various types of air- and spaceborne remote sensing imagery data.

Estimating pan-Mediterranean reburn frequency using Earth Observation

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Fires are one of the most widespread natural disturbances and an important driver of forests ecosystem dynamics worldwide. Fire disturbance regimes have changed profoundly in recent decades as a result of climate and land use change, leading to an increase in the frequency, size and severity of forest fires. In the European context, the Mediterranean basin concentrates around 85% of the total burned area and recently suffered extreme fire seasons attributable to unprecedented dry and warm conditions (e.g. 2012, 2017, 2022). Previous research suggested that fire frequency has doubled after the 1970s due to land abandonment, with certain areas that burned in the late 20th century now burning again. This would result in fire-return intervals of 20-30 years and thus jeopardizing the time needed to reach maturity age in many species. Estimating fire frequency is, however, still challenging and it thus remains unclear if and where fire frequencies are changing in the Mediterranean.

Consistent information on fire disturbances is essential to understanding changes in forest fire regimes. We present a new approach to quantify fire disturbance regimes in Europe, building upon a newly developed pan-European forest disturbance map (Viana-Soto et al. in prep.). Disturbances are annually mapped from Landsat data for the period 1984-2022 using a machine learning approach and attributed to fire based on shape and spectral reflectance properties. Our approach further enables to detect multiple fire events per pixel and thus to estimate reburns and recovery trajectories.

Based on this new product our aim is to improve the quantitative understanding of fire disturbances in Mediterranean Europe's forests by: (1) identifying reburned areas (i.e., areas that burned multiple times over the last four decades), (2) quantifying the total forest area affected by reburn events, and (3) analysing whether reburn frequencies have changed over time and how this has impacted post-fire recovery dynamics. Results will provide insights on the fire frequency, how it changed over time and how reburns might hamper post-fire recovery, particularly in forest dominated by species that regenerate from seeds and thus need a certain fire-free interval to achieve both structurally and functionally maturity.

Exploring changes in forest structural diversity, biomass and tree species richness along a multi-species chronosequence in Denmark

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Forest structural diversity (FSD) is a key determinant of forest conditions, ecological processes, and dynamics, and is related to several ecosystem services such as biomass stock and tree species richness. Recent advancements in LiDAR remote sensing have enabled the assessment of FSD metrics at a high spatial resolution. These metrics had been described to analyses structural heterogeneity (internal and external), height, canopy and openness within an ecosystem. This study aimed to investigate changes in FSD metrics in oak, beech, and N. spruce forest chronosequences and their relationship to biomass stocks and tree species richness, using LiDAR and ground truth data. LiDAR data was extracted from 66 forest plots, spanning from 22 years to over 100 years since planting, using a density of 5.4 pulse/m^2 during leaf-off season in 2019. LiDAR metrics were calculated at point cloud and grid level ($1m^2$). Ground truth data, collected in 2022 following Danish National Forest Inventory protocols, included trees counts, species, height and diameter at breast height. We evaluated changes of FSD metrics through the years and the association with biomass, and tree species richness by employing regression and PCA analyses. Our results revealed significant age-related variations in FSD metrics. Older forests exhibited higher values in terms of height and internal heterogeneity, witch beech forests displaying grater internal heterogeneity than N. spruces forests. Canopy and external heterogeneity metrics showed significant differences among forest types, with N. spruce forests having higher canopy cover values, while oak forests displayed higher values of external heterogeneity across all ages. The relationship between FSD metrics and biomass and tree species richness varied. Biomass showed a strong relationship with age for all analyzed species, with biomass values increasing with height and internal heterogeneity. Conversely, tree species richness increased with age for oak and beech forests, and only in oak forests richness values increase with height and heterogeneity. This study contributes to our understanding of forest structure dynamics and its implications for biomass stocks and tree diversity, advancing our knowledge of forest ecosystems. Integration of LiDAR remote sensing with ground truth data enables comprehensive assessment and facilitates effective management strategies.

Exploring the dynamics in spring phenology of dominant deciduous tree species in Poland using Sentinel-2 time series

T5.24 Moving towards digital forests for a sustainable future

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Abstract: The variations in vegetation phenology observed in recent decades have large ecological impacts, particularly taking into account climate change. In this study, we leverage the capabilities of satellite imagery, specifically Sentinel-2, to develop spring phenology models for dominant deciduous tree species in Poland, such as common beech, pedunculate and sessile oak, European larch, silver birch, and black alder.
We utilized two spectral indices (MTCI and EVI) derived from the Sentinel-2 time series spanning from 2018 to 2023, combined with modeling and detection of the Start of the Season (SOS). In the next steps, we investigated multiple factors potentially influencing SOS such as topography, longitude, latitude, and meteorological conditions. In particular, we focused on evaluating the impact of air temperature conditions on the onset of spring activity among examined species. Approx. 50 thousand reference samples were used based on the Polish Forest Data Bank and a national-level map of tree species distribution.
Preliminary results indicate that Sentinel-2-derived indices can effectively track phenological patterns for the dominant deciduous tree species on a country scale. The analyzed species show interesting and distinct spatial patterns in phenology, which differ in the examined years. For example, later SOS characterizes stands in the northern part of the country located closer to the Baltic Sea. On the other hand, elevation impact on delayed spring response is important in the mountain areas – this effect in the case of common beech is observed above approx. 400 m a.s.l. The results also suggest that these patterns are different depending on the year, which results from high variability in meteorological conditions in Poland. Particularly high differences are observed between 2018 (advanced spring phenology), and 2021 (delayed spring phenology). The impact of different meteorological variables will be further studied in this research.
The results will offer valuable insights into the timing of seasonal changes in different deciduous species, contributing to a better understanding of forest ecosystems and their responses to changing environmental conditions. It can further aid in understanding the spatial and temporal dynamics of forests and supporting sustainable forest management practices.

From single trees to country-wide maps: Modeling tree mortality across Germany

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Several extremely dry years have caused dramatic increases in tree mortality since 2018 in many regions of Central Europe. In particular Norway spruce has been strongly affected, but also other species have shown signs of decreased vitality and increased mortality risk. Long term monitoring programs such as the ICP Forests Level I monitoring provide valuable information about tree loss rates at annual resolution and on a systematic sampling grid. The German Level I monitoring (crown condition survey) consists of 410 plots on a 16 km × 16 km grid with a total of ca. 10,000 trees. The loss reasons for sample trees have been recorded since 1998. In this project, the goals were 1) to model tree mortality at the survey plots as a function of environmental drivers and 2) to produce country-wide maps of predicted mortality for a number of common tree species in Germany.

All trees in the dataset that died due to a cause other than planned management or windthrow were included as mortality events in the analysis, while all other trees were labelled as survivors. A set of more than 400 candidate predictor variables were derived with the condition that the data had to be available wall-to-wall for whole Germany. These environmental predictors covered the domains of climate, soil, topography, landcover and deposition. A multiple logistic regression model with the binary response "dead or alive" was fit to the data. The most important predictors for every tree species were identified via feature selection. Prediction accuracy and model robustness were tested via leave-one-location-and-year-out cross validations (AUCs between 0.65 and 0.9). Germany-wide maps of average mortality at 1-ha resolution were derived for Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), European beech (*Fagus sylvatica*), penduculate+sessile oak (*Quercus robur+petraea*) and other conifer and broadleaf species pooled.

The maps provide insights into the spatio-temporal patterns of mortality and enable the derivation of summary statistics at regional scales. The cause-effect relationships from the regression models will be combined with climate scenarios and process-based forest models to predict trajectories of future forest development.

Harnessing artificial intelligence for high-resolution forest modeling and decision support

T5.24 Moving towards digital forests for a sustainable future

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Abstract: The rise of remote sensing and data science led to an unprecedented wealth of forest-related data, however, primarily focusing on the current state and recent history of forests. At the same time, the urgency of climate change and evolving societal demands necessitate the adaptation of forest management practices. To assess the potential long-term impacts of forest management decisions in a no-analog future, it is important to employ high-resolution model-based projections of forest development and related ecosystem service indicators. Such projections can be integrated into decision support tools designed to assist forest managers in addressing specific challenges related to forest adaptation.

This requirement presents a dual challenge. On one hand, there is a need to cover large geographical areas to ensure wide applicability of such tools. On the other hand, it is crucial to achieve high resolution down to the individual tree level in order to accurately capture the effects of local management decisions. While high-resolution models operating at the tree or stand level typically cannot cover large areas, large-scale models like dynamic global vegetation models often lack the structural details necessary for realistic predictions. To bridge this gap, we propose a novel data-driven approach that leverages artificial intelligence techniques. The approach is built upon three key components. Firstly, detailed process-based models are employed to simulate a multitude of individual forest trajectories under diverse climate, environmental, and management scenarios. Secondly, a deep neural network is utilized to learn the specific responses of forests to environmental and management drivers using these simulations. Lastly, this "meta-model" is employed to simulate forest dynamics at high resolution across large scales. This final step requires comprehensive information on the current state of forests that can be derived from state-of-the-art remote sensing products.

The output of this modeling approach comprises multiple forest development pathways, contingent upon climate and management contexts, along with associated indicators for ecosystem services. This dataset serves as a foundational resource for decision support tools. In this contribution, we introduce our AI modeling approach and present an example application that assesses climate change adaptation strategies for Germany's forests.

Hyperspectral image reconstruction from RGB image using deep learning

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Hyperspectral imaging is a remote sensing method that provides detailed insight into plant and tree biochemical composition (through the analysis of the electromagnetic spectrum). This makes it a powerful method for monitoring forest biodiversity. Indeed, the generated hyperspectral image can be used to classify tree/plant species (for forest inventory surveying), and assess tree health based on biodiversity indices (including NDVI for chlorophyll estimation, CRI550 for carotenoid estimation, and others). However, it requires highly expensive, complex cameras and long acquisition times. To mitigate this issue, one solution is to reconstruct spectrum data from RGB images that are much cheaper to acquire (e.g., using regular phone cameras). Multiple studies and computer vision competitions have investigated the possibility of such reconstruction. However, none have focused on plants specifically, and they are limited to the visible range only (400-700 nm). Our study uses different deep-learning models and trains them exclusively on plant datasets. The number of spectrum bands was increased, and the spectrum interval included the near-infrared range (up to 1200 nm), crucial for plant health analysis and species identification. Initial testing showed a mean average error comparable to state-of-the-art models. The results indicate a solution for plant/tree health assessment is feasible at a fraction of the cost while maintaining high accuracy. Moreover, through the application of species identification, this new method can be very helpful for forest inventory missions. Finally, the low cost and ease-of-use of our proposed method means it is highly scalable and can be used by non-experts to cover large forest areas in a relatively short amount of time.

Improved forest edge descriptions by fusing airborne laser scanning and close-range remote sensing data

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Forest edges represent the transition zone between the forest interior and the open countryside and provide several ecological functions. They contribute to biodiversity as habitats for plant and animal species, regulate the microclimate and the fluxes of nutrients and pollutants between surrounding agricultural areas and the forest interior.
To ensure maintenance of these edge functions, a reliable and frequent assessment of their conditions is required. Countrywide airborne laser scanning (ALS) data (15-20 points/m^2) for Switzerland, which is publicly available and will be regularly updated in the future, is ideal to monitor forest edge conservation and renaturation efforts. From the ALS data, we derive forest edge structure characteristics for entire Switzerland (total forest edge length ~187,000 km). The product comprises five metrics describing the horizontal and vertical structure of forest edges (canopy height variability, presence or absence of the shrub layer, forest edge slope, light regime information and forest façade density). These metrics are indicative for the edge structure and well interpretable.
In our ongoing study, the information content of the ALS point cloud is enhanced by combining it with mobile laser scanning (MLS) and field imagery to derive improved edge structure descriptions. The data fusion serves two goals. Since MLS provides a more detailed representation of the forest structure than ALS, particularly within lower canopy layers, we first test the feasibility to upscale highly detailed, quantitative forest edge structure attributes from MLS at the plot level to larger areas using ALS. The second goal is to evaluate the potential of the methodology for implementation in the next iteration of the Swiss National Forest Inventor (NFI), which will integrate MLS and field image acquisitions. The combined data set of ALS, MLS and field imagery allows to derive more detailed information on structure and plant diversity than ALS alone. Hence, this data fusion allows to gain valuable additional information to complement the forest edge assessment which is carried out within NFI the today (~500 plots in total comprising edges).

Machine learning of process-based models for DestinE forest digital twin

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Destination Earth (DestinE) is a European Union initiative that aims to develop a digital twin of the Earth, which can simulate the Earth's systems and processes to enable informed decision-making for sustainable development. The architecture of DestinE focuses on simulating the inter-actions between natural and human-made systems using sophisticated physical models, remote sensing and in-situ data, and machine learning techniques. Using the novel high-resolution simulations of the Earth's atmosphere, oceans and land surface, a forest digital twin will allow to investigate the impact of climate change, natural hazards and human activities on the past, current and future state of the forests. To handle the unprecedented volume of observed and modeled data, and the level of detail required by the system, extensive use of advanced machine learning methods—also known as artificial intelligence (AI)—is foreseen. Currently, AI is often used as a powerful interpolation technique allowing to interpret observations and predict outcomes of physical processes at local to regional scales.

To make full use of AI in the forest science relevant to the DestinE initiative, it must be explicitly linked with physical models quantifying the temporal development of physical and biochemical variables describing a forest and its interaction with the atmosphere, hydrosphere, cryosphere and lithosphere. We present a study on how AI techniques can be applied to physical models of forest growth, productivity and reflectance in the Finnish boreal forest. We combine the large high-quality open forest data covering the whole country with Copernicus weather data and satellite imagery to demonstrate the utility of AI to retrieve the current structural and functional state of forests and predict their development over the time periods simulated by the DestinE digital twins.

Mapping of living and dead tree species in a complex forest area based on multi-temporal ALS data and CIR imagery

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Accurate information on the location and distribution of tree species is needed for targeted management and conservation of natural resources in different environmental contexts. This information plays a fundamental role in monitoring biodiversity, evaluating ecosystem services, and promoting sustainable forest management. Nonetheless, acquiring such data is typically a laborious and expensive process. Hence, there is a pressing demand for remote sensing techniques that can enhance inventory efficiency in a non-invasive way.

Over the past twenty years, the application of optical remote sensing has significantly advanced in the field of tree species classification. Furthermore, the integration of Airborne Laser Scanning (ALS) data holds immense promise for mapping tree species by offering a three-dimensional depiction of objects. ALS data enables the extraction of structural characteristics of trees using discrete returns or full-waveform data. This facilitates the capture of diverse tree architectures, which are influenced by variations in leaf distribution and branching patterns under varying environmental conditions.

The utilization of remotely sensed data for tree species mapping is a thriving field of research. Although certain studies rely on a single remotely sensed dataset, the mapping of tree species generally gains advantages from the integration of multiple data sources. In our study, we attempted to map tree species in a diverse study area such as the Białowieża Forest in Poland. Classification was carried out using Random Forest algorithm with the use of leaf-on and leaf-off airborne laser scanning data and CIR imagery. A total of 14 classes were distinguished, consisting of living trees such as: birch, oak, hornbeam, linden, alder, ash, maple, aspen, pine and spruce, and dead trees by class: dead pine, dead spruce, dead deciduous and snags. The highest levels of accuracies were obtained for classification based on point clouds from both seasons and including image information. Mean values of overall accuracy and kappa were equal to 82% and 0.80, respectively.

Based on the obtained results, it can be inferred that incorporating multi-temporal ALS data enables precise mapping of numerous tree species, similar to the outcomes achieved when adding information from CIR images.

Mapping the distribution of conifer and broadleaf canopies in uneven-aged mixed forests using unmanned aerial vehicle imagery and machine learning

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Uneven-aged mixed forests with unique characteristics such as species diversity, stand heterogeneity, and the irregular distribution of trees, have been recognized as important for their contribution to biodiversity conservation, ecological stability, carbon sequestration, provision of ecosystem services and sustainable timber production. Recently advanced technology of integrated unmanned aerial vehicle (UAV) imagery and machine learning can generate maps, which can provide valuable spatial information for sustainable resource management. Particularly, many researchers have accepted that the applicability of integration of remote sensing dataset and semantic segmentation-based machine learning for forest management purposes such as forest type classification, individual trees identification and forest fire detection. However, there are limited studies focusing on the integrated application of UAV dataset and semantic segmentation-based machine learning algorithms for mapping tree species groups in uneven-aged mixed forests. Thus, this study aimed to explore the feasibility of UAV imagery and machine learning to describe the distribution of conifer and broadleaf canopies in an uneven-aged mixed forest through semantic segmentation-based machine learning classification models. Our study was conducted in two sub-compartments of the University of Tokyo Hokkaido Forest, northern Japan. The aerial images were acquired separately for each compartment by using different UAV platforms (DJI-Inspire 2 UAV and DJI Matrice 300 RTK UAV). We analysed the RGB information of UAV images with 512 x 512 pixels, through two machine learning models (Random Forest and U-Net). Our results showed that the validation accuracy of the U-Net model was over 80% in both sub-compartments, while the Random Forest model often failed to distinguish conifer crowns. The results from this case study indicated that the integration of UAV imagery and semantic segmentation-based U-Net model was reliable to generate the conifer and broadleaf canopy cover classification map. Moreover, our research findings show the potential of an applicable methodology for detecting dominant tree species groups in uneven-aged mixed forests.

Monitoring forest health and tree species based on satellite imagery, cloud computing and artificial intelligence

T5.24 Moving towards digital forests for a sustainable future

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Abstract: A novel cloud-based approach was created to utilize high-resolution Sentinel-2 satellite imagery of the European Space Agency and Google Earth Engine platform. The image processing steps such as query, filtering, masking, visualizing, and analysing all took place in the cloud in order to create vegetation and water index (NDVI, NDVI change, Z NDVI, NDWI) maps and charts derived from satellite images, used for multipurpose such as land-cover surveying, tree species classification and forest disturbance detection in three Hungarian study sites. Forest disturbances include biotic (insects, fungi, virus), abiotic (fire, flood, windfall, ice break, etc.) and anthropogenic (illegal logging) forest damage types which are surveyed in Hungary on a regular basis.

Machine learning algorithms such as Random Forest, Minimum Distance Estimation, Support-Vector Machine and Gradient Boost Regression were utilized in Google Earth Engine to support land cover and tree species classification. The aim was to delineate the forests as accurately as possible, thus improving the accuracy of forest monitoring, and analysing the change in the extent of classes of tree species. Compared to the WorldCover remote sensing-based land cover map, the accuracy of methods was 70.3-80.6%. Random Forest showed the best agreement with the reference map with 80.6%.

The results indicated that the combined dataset of satellite imagery and ground-based reports provided suitable input for forest damage monitoring conducted with Google Earth Engine. The applied method successfully identified different types of forest damage on spectral index maps in the surveyed period with 78% Total Accuracy and the tree species with 82% compared to the validation set.

Open platform for point cloud processing algorithms and datasets of forest ecosystems

T5.24 Moving towards digital forests for a sustainable future

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Abstract: The use of three-dimensional point clouds to map and monitor forests have gained traction in the past years. Indeed, point clouds enable a three-dimensional representation of forests which opens the possibility to a wide array of spatial analysis and modelling. Wide range of technologies are capable of generating point clouds of forest ecosystems, varying from spaceborne through airborne to close-range. Each perspective provides data on different scales. Many studies attempt to compare them using different tools and algorithms.

In this study, we focus on close-range technologies that provide the most detailed 3D models and we propose an open platform with available processing algorithms (and their public implementations) together with an online database of existing forest point cloud datasets. The datasets and algorithms were identified in a previous work within the framework of the 3DForEcoTech COST Action. The list, guides and benchmarking are the main pillars to bring standardised solutions for a wide range of users and stakeholders within forest management and forest ecology research. Furthermore, we focused on gathering open access datasets generated by close range techniques (e.g., terrestrial laser scanning, mobile laser scanning, structure-from-motion, etc.).

The online platform was therefore envisaged as a way to integrate these findings into a modern, user friendly, and easily accessible medium for potential users. In this regard, the queryable database is planned as a one-stop gateway to facilitate interested users in accessing them, as well as a harmonised way to present them. Furthermore, a benchmarking of selected datasets and algorithms will also be conducted within the framework of a hackathon, under the aegis of the 3DForEcoTech COST Action. The results from this benchmarking hackathon will be integrated into the online platform and therefore provide further information on how each dataset and each algorithm/implementation may be useful for particular applications in forest science. The web-based database will provide users with metadata, user instructions, download instructions, as well as assessments as generated by the benchmarking process.

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Performance of mobile laser scanning in forest inventories

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Forest inventories are the primary source of information about the status and growth of forest ecosystems. Even after the advent of remote sensing manual methods remain the wide spread standard. Nonetheless the use of LiDAR sensors became popular over the last decades to collect additional information. Now with the recent introduction of mobile laser scanners (MLS) arises the opportunity to push the application possibilities of LiDAR sensors in forest inventories even further.

The research project will evaluate the benefits of close-range remote sensing with a MLS for forest inventories. Therefore two classical inventory methods will be compared to MLS measurements. First an angle-count sampling is conducted manually and by MLS, because it represents an extremely fast and well established sampling method. Second several plots with a size of 1 ha are fully inventorized manually and by MLS, as full inventories may become more attractive due to technological developments in the future.

At the moment of writing this abstract no preliminary results are existing. While for the angle-count sampling it is estimated that MLS will be as efficient as the manual sampling, it is very likely to have benefits in the full inventory. MLS will probably be faster, cheaper if compared with the cumulative costs of forest workers and provide access to a large amount of data which is not gathered automatically by manual inventory. This will allow to apply inventory data to a multitude of scientific and practical questions, not only from an economic but also ecological and social perspective.

Due to their high mobility MLS make it possible for the first time to gather close-range remotes sensing data in the form of high density point clouds in a full-scale forest inventory. The research of their benefits will enable prospective scientists and practitioners to evaluate their suitability for their own projects and generate additional data in a more efficient way.

Spaceborne SAR-based detection of forest disturbance – a monitoring system for Switzerland

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Forests provide a variety of services to society such as timber, biodiversity, and protection from natural hazards. Therefore, it is of high relevance to monitor the state of forests for adequate and sustainable management to maintain these services. Natural disturbances such as windthrows or bark beetle dispersal but also unfavourable climatic conditions, e.g. droughts, can abruptly lead to forests not being able to provide these services anymore. Remote sensing enables wide-area monitoring to detect such disturbances. Especially spaceborne Synthetic Aperture Radar (SAR) has the potential to provide data to monitor large areas at a high temporal sampling.
In the framework of this study, we develop a forest disturbance monitoring system for whole Switzerland based on Sentinel-1 (S1) SAR data. Using the full S1 constellation, a high temporal sampling is possible with data acquisition at least every three days. Based on the acquired SAR backscatter, time series are generated on the spatial scale of forest stands. Then, time series analysis methods are used to extract the moment of diverging backscatter. We assess 1) which types of disturbance and 2) at which spatial scale are possible to detect. Moreover, we analyse limiting factors such as wet snow that strongly affects SAR backscatter potentially hindering to use S1 data for disturbance detection.
The results reveal that the system mainly detects windthrows (>0.5 ha) and the detection accuracy is strongly dependent on the size of the disturbed area. Other disturbance types that are typically at smaller scales or happen more gradually than windthrows are less well detected.
S1 SAR time series show potential to monitor forest disturbance at the countrywide scale. Thus, a monitoring system based on S1 data potentially indicates disturbance-hit regions and facilitates quick and adequate forest management.

Synthetic Laserscanning data for improved area-wide forest-attribute estimation

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Airborne laserscanning data is routinely used in an increasing number of countries to estimate key forest attributes across wide areas in the so called "area-based-approach (ABA)". Given that the ABA has reached operationality, there is an ample interest to further improve and fine-tune existing work-flows and increase their level of automatization. To achieve this, sensitivity analyses that for example lead to a better understanding of how certain environmental (e.g., topography) of technical factors (laserscanning acquisition settings, applied algorithm, number and type of reference plots) influence a given ABA work-flow are helpful. However, such sensitivity analyses are often in some way restricted by data limitations as both field data and laserscanning data acquisitions are still costly.

One way to address these limitations is synthetic laserscanning in which realistic virtual 3D-forest scenes are created and used as input to laserscanning simulation software in which for example different laserscanning aquisition settings (point frequency, scan angle, etc.) can be simulated. In this contribution we present an advanced synthetic laserscanning work-flow in which we combine the outputs of a forest growth simulator (Formind, TreeFactory), with an individual tree library containing tree models derived from terrestrial and uncrewed aerial vehicle-based laserscanner data and the laserscanning simulation software HELIOS++.

We will present the basic concept and a numerical validation of the work-flow. The validation shows that realistic laserscanning point-clouds can be simulated with the work-flow but also that space for improvement still remains. We furthermore examined, how synthetic laserscanning data can be used to increase the efficiency of the ABA to estimate aboveground biomass based on real laserscanning data by supplementing real training data with synthetic training data. Our results show that across four datasets from temperate and boreal forests, reasonable estimates for forest biomass could be obtained using only synthetic training data (r^2 between 0.67-0.70 vs. 0.72-0.79 for real data) and that if only few real training data is available, synthetic data can improve model estimates when combined with real data. This highlights some first successful application of synthetic laserscanning data for improving laserscanning-based forest inventories in the ABA.

The model-assisted estimation of timber value in a forest property using geographically balanced samples and 3D UAV data

T5.24 Moving towards digital forests for a sustainable future

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Abstract: A common task in forestry is to determine the timber value of a forest property. While the valuation of timber in a forest property has traditionally relied on stand-level field visits, remotely sensed data acquired by an unoccupied aerial vehicle (UAV) is a potential source of auxiliary data for the valuation of timber. This is because forest properties are typically of a size that permits the efficient operation of UAVs. UAV data combined with a probability sample of field plots enable the design-based estimation of the timber value and its associated uncertainty.

We studied the estimation of timber value (€/ha) in a 40-ha forest property in Finland. We used a systematic sample of field plots (n = 160) and 3D image point cloud data collected by an UAV. We compared the efficiency of the field data-based estimator to that of a model-assisted estimator which uses both field and 3D UAV data. The sampling intensity was varied (40, 60, …, 140 plots) by subsampling the systematic sample of 160 field plots. The variances were estimated using an estimator assuming simple random sampling (SRS), and a variant of Grafström-Schelin variance estimator.

According to the estimated variances, the model-assisted estimator was more efficient than the field data-based estimator, which suggested that the sampling intensity can be reduced from 160 to 60 plots without any deterioration in precision. In the case of the MA estimator, the difference between the variance estimates computed by the SRS and Grafström-Schelin variance estimators was negligible.

We observed considerable efficiency gains when using 3D UAV data, which indicates that the use of 3D UAV data can enable a reduced field workload or improve the precision associated with the estimation of timber value in forest properties.

Three-dimensional Forest Ecosystem Monitoring and Better Understanding by Terrestrial-based Technologies - 3DForEcoTech COST Action

T5.24 Moving towards digital forests for a sustainable future

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Abstract: We are witnessing rapid development in generating highly detailed three-dimensional (3D) point clouds within forest environments by close-range technologies. Terrestrial and mobile laser scanner technology can be mounted on various devices and provide accurate data about individual trees. Additionally, advancements in computational power and algorithms have allowed for processing hundreds of 2D images into 3D point clouds through photogrammetry. Sensors equipped on unmanned aerial vehicles can also provide close-range above-canopy data.
Despite the technological advancements, the application of these technologies lags behind their development. Research often focuses on evaluating a particular technology's potential rather than addressing fundamental issues. For example, researchers have yet to determine how to place TLS within different forest types to fully reconstruct research sites and detect and measure biometric variables of all trees.
Processing the 3D point cloud data is also a significant challenge. Selecting the appropriate technology and data collection approach requires careful consideration, and processing the data with available algorithms is complicated. While algorithms are available from various research groups, the complexity of processing solutions varies based on the target characteristics that researchers want to measure.
To address these challenges, a network of scientists has been established (October 2021) under the 3DForEcoTech COST Action, with over 400 scientists from 50+ countries. The goal of the network is to synchronise knowledge, develop general protocols for data acquisition, processing, and fusion for forest inventory and ecological applications, and make novel technologies available to a broader audience. By unifying efforts, the network aims to progress the application of close-range technologies and unlock their full potential for forest assessment.
In less than two years, we have created a comprehensive list of all processing solutions with detailed guidelines, and benchmarking will follow to focus on various tree parameters. Multiple state-of-the-art reviews and experiments are ongoing where we address lidar data fusion, a new era of forest inventory, point cloud processing past-present-future, occlusion and more. We have organised multiple scientific meetings, internships, training schools and more. All are available on our website: https://3dforecotech.eu/.

Understanding drought-induced spectral changes in a mid-latitude forest ecosystem

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Forest ecosystem conservation is of crucial importance for preserving biodiversity, regulating climate patterns, and providing essential ecosystem services for human well-being. The Ticino Park temperate mixed forest represents the last remaining natural ecosystem of the Po Valley region. Recognized as a UNESCO-MAB Biosphere Reserve, this precious ecosystem has been increasingly impacted by natural and human-induced disturbances, including severe drought, exacerbated by climate change.

Remote sensing has proven to be a cost-effective tool for the indirect estimation and mapping of forest characteristics and conditions, at different spatial and temporal scale. This study aims on developing a better understanding of the relationship between drought-induced forest stress, spectral changes observed from Sentinel-2 satellite data and how these relate to functional traits and species composition. We assume that this will help to identify spectral indicators and metrics for the early detection of drought-induced forest mortality.

In 2022 summer, an extensive field campaign was carried out in the Ticino Park Forest, during which functional traits data (Leaf Area Index (LAI)) and Leaf Chlorophyll Content (LCC)) were collected within 31 forest stands. Furthermore, vascular plant species composition was analysed in 63 selected stands to characterize the different vegetation associations. We aggregated the vegetation surveys in 8 specific Syntax and calculate the corresponding Ellenberg indexes in order to ecologically characterise the sites. Moreover, to evaluate the severity and duration of drought events the Standardized Precipitation-Evapotranspiration Index (SPEI) was calculated.

Time series of Sentinel-2 images collected over the Ticino Park from 2016 to 2023 were processed to compute several vegetation indexes and derive LAI and LCC maps through the Sentinel Application Platform (SNAP) biophysical processor tool. LAI and LCC maps were validated using LAI and LCC field measurements. The temporal changes observed in the time series of the vegetation indexes and functional traits were then related to SPEI. Different from many earlier, data-driven remote sensing-based approaches to assess vegetation stress in forests, we try to actively account for expected variations in the spectral responses of forests depending on the species´ ecology and local environmental conditions.

What have been the recent trends in the development of forest ecosystems in Lithuania?

T5.24 Moving towards digital forests for a sustainable future

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Abstract: Numerous indicators are used to describe the status of forest ecosystems. The decline of certain variables while others improve does not necessarily suggest any trends in the condition of forests. This presentation aims to introduce the results of the national condition assessment of Lithuanian forest ecosystems, based on the principles of the System of Environmental-Economic Accounting—Ecosystem Accounting by the United Nations Statistics Division. In other words, we attempted to develop an integral index to independently describe the condition of forest ecosystems over time and across different areas.

Firstly, we mapped the spatial pattern of sixteen different forest attributes at the level of forest compartments and above. These attributes included the proportions of old-growth forests, openings in the forest canopy, mixed forest stands, natural regeneration, density, growing stock volume, tree mortality, carbon stocks in living and dead biomass, forest soils, and soil properties, such as the proportions of organic and drained soils. We also considered forest edge density and the distribution of forest land in the landscape. The best available data sources, particularly data from stand-wise forest inventories covering all Lithuanian forests regardless of ownership, were used to characterize two time points: the years 2000 and 2021.

Next, all independent attributes were linearly scaled on a range of 0-1, where 0 represented the collapse of the ecosystem and 1 indicated an ideal condition. Finally, weights were assigned to all independent characteristics using the Analytical Hierarchy Process, with input from a team of experts specializing in ecology, forestry, climate change, geography, and geomatics.

The main finding was that the condition of forest ecosystems in Lithuania remained rather stable during the two decades of the current century, with some minor decline. The proportion of mixed and natural forest stands decreased; however, the volume of growing stock and the proportion of old-growth forests increased. Additionally, the rate of afforestation decelerated.

T5.25 New directions for legal context of forest ecosystem services towards 2050

Analysis of the evolution of Albanian forest legislation and its new directions in relation to ecosystem services

T5.25 New directions for legal context of forest ecosystem services towards 2050

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Abstract: Forests have been performing their services in the ecosystem since they have existed. This is now a well-known and scientifically recognized fact. The importance of forests and their role in protecting the soil from erosion and degradation, preserving water resources, influencing the local microclimate, purifying the air, enriching it with oxygen, etc., are known and understood by society and different states in different ways. However, these positive impacts of forests were not defined as "ecosystem services." In different areas of the country, the many values provided by forests were mentioned separately, depending on the case (e.g., forests that protect the land from landslides, forests that provide shade for residents, travelers, or visitors, forests that maintain the freshness of water sources, etc.). The term "ecosystem services" is relatively new and did not previously exist, even in the country's forestry literature.This new concept was elaborated for our country during the elaboration of the "carbon sequestration subcomponent" under the Natural Resources Development Project.

The methodology used is based on a comparative analysis of national forest legislation, starting with the first recognized law (the Kanun of Lekë Dukagjini - mid-15th century), the first forest law (1923), the Constitution of the Republic of Albania and ending with the latest law "On Forests" approved in 2020.The purpose of this analysis is to assess how the national regulatory framework has adapted or evolved with respect to the valuation of ecosystem services provided by forests.In addition, this analysis will provide a link between the development of the national forest fund in different periods and the legal basis of those periods.This will give us a clearer understanding of the value of the regulatory framework in fulfilling the ecological functions of forests for ecosystems and communities. The results of the analysis show that the first improvement in the ecosystem services regulatory framework was associated with a commitment to implement a carbon sequestration subcomponent.Another finding is that the legal framework for ecosystem services will be further defined with the Decision of the Council of Ministers (DoCM) to be adopted in the coming months.

Keywords: ecosystem services, forest legislation.

Evolution of wildlife protection and management laws and recent trend of game derived forest byproducts in Japan

T5.25 New directions for legal context of forest ecosystem services towards 2050

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Abstract: Population of wild animals, especially deer (*Cervus nippon aplodontus*) and wild boar (*Sus scrofa leucomystax*), has been increasing for several decades in Japan. As a result, animal damages on agriculture and forestry have been expanding. The government worked to improve the related laws and promoted the effective use of hunted and trapped games. This study aims to clarify the evolution of wildlife protection and management laws and describe present status of wildlife damage prevention measures. Then the authors conducted surveys on production of forest byproducts related to wild games in several different places.

Hunting Act was first established in 1895. General rules of hunting and trapping was designated by the act. Wildlife protection area system was created in 1950 and the act was renamed as Wildlife Protection and Hunting Act in 1963. Populations of wild animals declined significantly during this period but has since been on the rise. Finally, the act was amended as Wildlife Protection and Management Act in 2014 and appropriate management of wildlife population has become an important issue.

In recent years, annual damage to crops by wild birds and animals is as high as 20 billion JPY. In addition, forestry damage is also considerable. Local governments have taken measures against animal damage by providing incentives for extermination of vermin. Central government began to promote the use of wild animals such as gibier, and many of local governments tried to facilitate such use with the help of local hunting club and entrepreneurs. In Hyogo prefecture, utilization of exterminated deer increased from 8.9% in 2016 to 26.5% in 2021. The meat in good condition is used for gibier, and the rest is sold for pet food, generating a large profit to local community. In addition, processed hides and antlers are also expected as important byproducts. This example shows the possibility of achieving both a reduction of animal damage to agriculture and forestry and revitalization of the local economy.

International Forest-Focused Policy: The Strenghts and Limits of its Efficient Creation and Implementation in Finland, Slovakia and Slovenia

T5.25 New directions for legal context of forest ecosystem services towards 2050

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Abstract: International forest-focused policy is characterized by fragmentation, the interference of other sectors into the issue and the absence of a legally binding agreement. Within the scientific field, controversies are being held about its efficiency under national conditions. The research aims to analyse three forest-focused international processes - the United Nations Forum on Forests, Forest Europe and the European Union de facto forest policy under the national conditions of Finland, the Slovak Republic, and the Republic of Slovenia. The theoretical framework is the Policy Arrangement Approach, which defines four dimensions of the political process. For the purposes of this research, it has been modified by adding the dimension of interactions. The interactions are examined in the direction from the national to the international level and vice versa. The research is based on document analysis and interviews. International resolutions, declarations, and strategic documents were analysed to identify the main goals and outcomes of the processes. From September 2022 to March 2023, eleven interviews in Finland, fourteen in Slovakia and five in Slovenia were conducted with key domestic forest policy actors to explore their perceptions of participating in and implementing selected processes. The results show that Finland is very active at the international level. It places great emphasis on its participation in international forest policy-making. Finland participates through national delegation, a common national statement and collaboration or individual partaking of various actors. Slovakia and Slovenia are represented in the processes within their geopolitical boundaries, mainly by governmental experts on forests. The success of their participation depends on the personal skills and commitment of the individual representatives, or on them chairing the processes. An example of this is Slovakia chairing of Forest Europe, which is based on the principle of rotation. Slovenia emphasises participation in the processes with a narrower focus and does not pay attention to the global process. Implementation takes place in all three countries through the transposition of principles into legislation and strategic documents. However, it is influenced by national specificities and forestry traditions. In addition, limiting factors are general definitions opening up a wide scope for interpretation.

Just Do It! Implementation of Payments for Ecosystem Services in the Czech Republic

T5.25 New directions for legal context of forest ecosystem services towards 2050

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Abstract: The contribution describes the process of potentially implementing payments for ecosystem services (PES) into forest management in the Czech Republic. Methodologically, the following steps were taken: 1) significant stakeholders and their efforts to advocate for direct payments to forest owners were analyzed; 2) the incorporation of their demands into conceptual and strategic documents was evaluated; and 3) the legislative process of implementing PES in forest management was analyzed. The greatest attention was paid to the legislative process. The results revealed critical points in this implementation, primarily 1) the fact that the EU does not allow notifications for "something for nothing" payments, which means mandatory payments from the state solely for forest ownership; 2) the lack of a definition for ecosystem services in the Czech Forest Act; and 3) the existing support for forest owners mentioned in the current Forest Act is not compatible with the PES principle. The aim of the National Agency for Agricultural Research of the Czech Republic project QK 23020008, titled "Payments for Ecosystem Services in Forest and Forestry" is to create a methodology for forest PES, including legislative adjustments. The presented contribution was prepared within the framework of this project.

Legal and Administrative Impacts of Climate Change on Forestry: The Case of Türkiye

T5.25 New directions for legal context of forest ecosystem services towards 2050

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Abstract: This study examines the legal and administrative impacts of climate change on the forestry sector in Türkiye. As the literature clearly states, climate change significantly affects the forestry sector, leading to changes in forestry policies and governance. The aim of this study is to assess the extent to which legal and administrative measures have been taken to address climate change in the forestry sector in Turkey and to evaluate the impact of these measures. The study was conducted using a legislative review method based on the legislation enacted in the last 20 years. Relevant legislative documents and literature were reviewed to analyze the legal regulations and administrative practices related to climate change in the forestry sector. The key findings demonstrate that Turkey has taken significant legal steps to cope with climate change in the forestry sector in recent years. The new legal regulations aim to: Strengthen forestry policies, Enhance biodiversity conservation, Improve measures against forest fires. These regulations aim to enhance the sustainability and adaptability of the forestry sector. However, the study also reveals certain weaknesses in the effectiveness of current legal regulations. It identifies gaps and challenges in the implementation and monitoring of climate change adaptation strategies. Additionally, the findings highlight the inadequate level of coordination and collaboration provided by the existing legislation. A more comprehensive and integrated approach is needed to combat climate change in the forestry sector. Strengthening legal regulations, improving forestry management and planning, and promoting research and innovation are areas that need to be developed. Furthermore, achieving more effective coordination and collaboration at the international level is seen as an important opportunity.

Legal arrangement of forest management in protected areas: persistent problem or modern challenge?

T5.25 New directions for legal context of forest ecosystem services towards 2050

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Abstract: Management of non-state forests is affected by both the internal economic efficiency of non-state forest enterprises as well as the by the external restrictions which are governed, except for the nature conditions, by the regulative state measures, characteristics of business environment, and principles accepted by the whole society. When non-state forests are located within the protected areas, their economic utilization is limited due to nature protection.

In Slovakia, there is a long tradition in both nature protection as well as forestry – it is proved by the fact that 57 % of non-state forests are located within the protected areas. However, there is also competition between the conception of traditional multifunctional sustainable forestry aiming at the production of timber together with the provision of other forest ecosystem services, and conception of the strict nature protection. Thus, there is a conflict that is complicated by different ideas about issues of nature protection in forests or, vice-versa, issues of forestry in protected areas. The fundamental question is "How shall we manage forests in protected areas?", or, in many cases, even "Shall we manage forests in protected areas at all?". The one of the ways how to deal with the issues of contradictions between forest management and nature protection is to establish a set of sound legal rules that would respect legitimate property rights of forest owners together with the justified interests of the whole society caring for effective nature protection.

The objective of the paper is to identify and analyse relevant legal factors that affect the management of non-state forests within the protected areas (regulative tools), particularly (i) specific legal conditions connected to restricted forest management within the protected areas and (ii) consequent restrictions of property rights including the identification of legal possibilities of solving such restrictions.

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New legal rules addressing societal demands for forest – Forest Act in Slovakia

T5.25 New directions for legal context of forest ecosystem services towards 2050

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Abstract: The Slovak forestry sector aims, based on science and forestry practise, to ensure the nature conservation in the framework of sustainable forest management. Maintaining and enhancing the biodiversity and resilience of forests is key to the sustainable provision of ecosystem services in a rapidly changing environment. The relations between nature protection and forestry are the subject of research in forestry and environmental science, while the interpretation of the achieved results can be roughly divided into two groups. On the one hand, the interpretation of these results by forestry representatives serves to support long-term sustainable and multifunctional forest management, and on the other hand, nature conservation representatives focus their attention on supporting non-intervention to protect the ecological value of the forest for the entire society. Within the individual interests of the interested parties, there should be an effort to identify the main conflicts and an attempt to resolve them to the satisfaction of both parties. Within our research, Slovak forest and environmental legislation was revised to identify and analyse controversial areas of the Forest Act and the Nature and Landscape Protection Act. Based on the results of the analysis and the conducted questionnaire survey among 20 stakeholders, a draft of the improved legislative intent of the new Forest Act was drawn up, which adequately takes into account the protection of nature and the landscape. It suggests new directions for development of forest and environmental legislation, especially in the following areas: forest protection, forest categorization, forest ecosystem services, forest management, logging and transport of wood, public access to forests, property rights, as well as state management of forest management. The goal is to ensure the provision of various and often conflicting products and services that the forest provides and the society claims their fulfilment, such as production of wood, forest fruits, recreation, protection against erosion, etc. We are leaning towards the possibility of introducing integrated forest management in Slovakia, where forest management will not be strictly separated from its protection.

THE ROLE OF ENVIRONMENTAL NGOs TOWARDS SUSTAINABLE FOREST MANAGEMENT IN LATVIA

T5.25 New directions for legal context of forest ecosystem services towards 2050

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Abstract: Realization of economic interests in forest sector are always dynamic, but what about protection of environmental interests? Environmental NGOs according to legal regulation has rights to receive environmental information, to participate in environmental decision making and to go to court in environmental issues. Process of environmental NGO activity in forest sector will be analyzed, exploring two recent cases in Latvia: 1)microreserve court case and 2)political decision to minimize cutting diameter – Constitutional court case (not finished yet). Environmental NGOs in both of these cases actively realized their rights and in first situation it resulted in Higher Court decision placing environmental interests higher than economic interests in forest management. This can be seen as important signal for legislator and decision makers to pay more attention to environmental interests instead of doing everything for endless economic growth, which is undoubtedly important to rise welfare in less developed countries. The question is how to find balance between environmental and economic interests (social as well) towards sustainable forest management. How to realize productive dialogue between conflicting interests to reach balanced decisions in situation where producers need more forest resources, but at the same time there is high pressure for higher level of nature conservation in forest.

Main aims of this work is 1) to study the development of Environmental NGO role in protection of environmental interests in forest sector and to illustrate it by analysis of two cases, 2) to give proposals what can be done to assume balanced decisions in forest sector.

Title: UK Bioeconomy Stable Wood Production and Tenure Rights post BREXIT

T5.25 New directions for legal context of forest ecosystem services towards 2050

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Abstract: The UK's bioeconomy heavily relies on sustainable and secure wood production as a crucial source of raw material. This poster/presentation explores the significance of tenure rights and examines the implications of BREXIT on the UK's bioeconomy, specifically in relation to wood production and forest governance.

Secure tenure rights are vital for promoting sustainable forest management and attracting investments in the UK's forestry sector. The amended Forestry Act 1967 and the UKTR and UK FLEGT Regulations (2021)sprovide a legal framework that grants landowners secure tenure rights, ensuring their ownership and control over forested lands. This stability encourages responsible wood production and supports the bioeconomy.

Post-BREXIT, the UK has the opportunity to develop its own tailored regulatory frameworks. The Agriculture Act 2020 sets out a framework for supporting sustainable forestry practices and land management in the UK, demonstrating the government's commitment to the stability and growth of the bioeconomy.

This study will highlight specific examples of how tenure rights have influenced stable wood production in the UK bioeconomy post-BREXIT. For instance, Scotland's Forestry Strategy 2019-2029 emphasizes the importance of secure tenure rights for enabling long-term planning and investment in wood production, showcasing a commitment to sustainable forest management practices.

The implications of BREXIT on the wood supply chain and forest governance will also be explored. Changes in trade agreements and regulations may impact access to international markets and disrupt the stability of the wood supply chain. Understanding these challenges and opportunities post-BREXIT is crucial for maintaining stable wood production in the bioeconomy.

Tenure rights remain a critical component for ensuring stable wood production in the UK bioeconomy post-BREXIT. The Forestry Act 1967 and the Agriculture Act 2020 provide a foundation for secure tenure rights and sustainable forest management practices. By leveraging these legislative frameworks and carefully considering the implications of BREXIT, the UK can continue to secure stable wood production, support the bioeconomy, and uphold its commitment to sustainability.

Keywords: UK, bioeconomy, stable wood production, tenure rights, forest governance, post-BREXIT, Forestry Act 1967, Agriculture Act 2020, UKTR, UK FLEGT Regulations, sustainable forest management, trade agreements.

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

A national centre for knowledge, analysis and monitoring to prevent and mitigate forest damage

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Forecasts on the consequences of climate change predict an increase of different types of forest damage, affecting both forest growth and biological diversity, thereby affecting goals in forestry as well as climate and biodiversity work. To meet these future challenges in a comprehensive approach and as national effort the Swedish government assigned a virtual centre at the Swedish University of Agricultural Sciences (SLU Forest Damage Centre) in 2021,. The centre is in charge to analyse, monitor and generate knowledge in order to protect forests against damage caused by different pests, pathogens, ungulate browsing, storms, fires or drought. It is a platform gathering research and environmental analysis around forest damage, and works in close collaboration with the Swedish Forest Agency and in continuous dialogue with various actors outside academia. The centre strives to be the natural first national port of call for forest damage issues in Sweden. The centre works across disciplinary boundaries, including natural and social sciences, and rest on four pillars: projects and knowledge support, research school, monitoring and analysis.

Derived from this set-up, the centre finances diverse types of basic and applied research projects, pilot studies or development projects connected to forest damage. Next, the research school is central both for knowledge development in the field and for the supply of competence within universities, research institutes, authorities and forest companies. The school collaborates closely with external stakeholders, including funding of PhD students. Moreover, the centre finances monitoring activities to reinforce and complement other ongoing monitoring activities in Swedish forests, producing additional data on forest damage and different damage agents. A major component of the centre is the analysis function, where experts on different types of forest damage collaborate closely internally and externally to investigate the risk for national pest outbreaks or damage incidents. Here, we gather experts on damage caused by insects, pathogens, wildlife, fire, drought, wind and snow as well as modelling and socioeconomic impact and consequences. Next to such risk assessments over time, a vital duty is to compile knowledge and provide support in the event of outbreaks or other incidents of forest damage.

Addressing Extreme Wildfire Events through Open Innovation Campaigns: Design and Implementation of a Challenge Design Workshop

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Extreme wildfire events (EWE) pose significant problems to forest ecosystems, human communities, and the economy and environment. Addressing these complex challenges requires innovative approaches that leverage open innovation and collective problem-solving. This paper presents the design and implementation of a co-creation-focused Challenge Design Workshop (CDW) for addressing EWE through an open innovation campaign (OIC). The workshop engaged diverse stakeholders, including local communities, forestry and fire management experts, regional authorities and policymakers, to collect and shape community problems into actionable challenges for searching for global socio-technical solutions. The goal was to directly engage the local communities of the 11 Living Labs, despite being geographically dispersed through Europe and South America, to identify problems from which to co-create challenges to divulge for the worldwide community in an open Innovation Campaign undertaken in the Fire Res project.

The structured workshop begins with collecting community problems through inquiries and community meetings by local partners. Multidisciplinary teams collaborate to transform these problems into well-defined local challenges. Trained local facilitators guided the teams and ensured a balanced representation of diverse perspectives. Globally, the problems outputted from local CDW were analysed and categorised to identify common themes related to EWE. The resulting challenges were specific, actionable, and relevant, addressing EWE across multiple geographical contexts.

Harnessing the power of OIC, the CDW created an environment where local knowledge and global expertise could converge to find global solutions—providing a platform for communities to voice their concerns and aspirations while fostering the co-creation of sustainable and practical solutions. The involvement of diverse stakeholders facilitated the development of comprehensive challenges encompassing multiple dimensions of EWE.

This paper presents the workshop's design, implementation, outcomes, challenges, and lessons learned. It emphasises the potential of engaging diverse stakeholders in open innovation practices addressing EWE and fostering new solutions. The findings highlight the importance of community engagement and integrating local knowledge for effective and context-specific solutions. The workshop framework serves as a valuable resource for initiatives tackling complex challenges related to EWE through open innovation and collective problem-solving.

An adaptive sampling and estimation method for National Forest Inventory to monitor the disturbances

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Since the early twentieth century, National Forest Inventories (NFIs) have been implemented in many countries to quantify and describe forest resources. In the past decades, forests have experienced a rapid increase in disturbances – storms, fires, insect damages, and so on – that have strongly impacted their state. Thus, new objectives for NFIs consist in monitoring the forest where disturbances occurred, to see how the forest reacts and if management action is required to repair. However, NFI methods were mostly conceived at a time when the forests' dynamic was low, for instance with periodicities in the surveys of 5 to 10 years. During these periods no changes to the sampling design are possible, which precludes any adaptivity. However, alterations of the sampling are necessary to estimate the impact of disturbances, which are by essence not predictable, for instance, to reassess existing plots and quantify the disturbance's intensity. Adaptability, therefore, emerges as a necessary characteristic of forest surveys to allow them to sustain monitoring activities.

The French NFI is a particularly relevant case study in that it was conceived as an annual sampling with variable annual sampling intensity, thus providing capabilities to support changes in its sampling. So far, French NFI has used two-stage two-phase sampling for stratification to collect the variables of interest in the forest, especially the characteristics of the trees. Post-stratification is used to improve the precision of survey estimators with the variance reduction. This study demonstrates and presents new estimators that include all of the sampling design and estimation requirements of adaptive monitoring with improved accuracy. In particular, the estimators accommodate variable sampling intensity and post-stratification, which permits disturbance-related monitoring.

Key words: forest inventory; monitoring; disturbances; estimation; post-stratification; variance

Basinox (Pseudomonas sp.) as a potential treatment against root rot (Heterobasidion spp.) in Norway spruce in Sweden

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Heterobasidion root rot is a significant problem for the Norway spruce, leading to notable losses in various industries that rely on this tree species. It results in a decline in both the quality and quantity of wood production. For the past 30 years, Swedish forestry has utilized the fungus *Phlebiopsis gigantea*, marketed as Rotstop®S gel, to treat freshly cut Norway spruce stumps. This treatment aims to prevent spore infections by Heterobasidion spp. and reduce the damage caused by root rot.
In this study, we investigated an alternative solution using a bacterial-based product called Basinox®, which consists of *Pseudomonas* sp. We evaluated the effectiveness of Basinox® in suppressing the colonization of the pathogen in fresh tree stumps. The study involved treating 360 spruce trees located in three sites across South Sweden during commercial thinning. We assessed the application of the product through both manual and mechanical methods and examined subsequent natural infection levels in stump discs. As a positive control, we used Rotstop®S gel, which has already been established as the most effective measure against root rot.
By analyzing the presence, number, and size of *Heterobasidion* sp. colonies on harvested discs, we calculated the control efficacy and infection rates for all the treatments. Control efficacy varied across the three sites, ranging from 20% to 70%. Infection rates also differed among the sites but were statistically significant and more effective than the negative control. This study represents the first trial of the Basinox® product under natural infection conditions. Based on the varying effectiveness of both Basinox® and Rotstop®S observed across the three locations, it can be concluded that both products performed similarly during this experiment.

Keywords: Root rot*, Heterobasidion, Phlebiopsis gigantea, Pseudomonas, Picea abies,* Basinox®, RotStop®S

Climate change and extreme weather events are challenging the health of boreal forests – and some will learn it the hard way

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Climate in the northern latitudes has warmed faster than the global average. While a phenomenon such as a degree of change in temperature or increase in thermal sums might sound trivial and far from everyday life, forests could not disagree more. Boreal forests have seen rapid changes caused by the progressing warming and extreme weather events in relation to their health.

Nested within the boreal zone, Finland has witnessed range expansions of forest pests and forest disturbances of the type once thought as unlikely. Yet, the degree at which the climate-induced risks are realized on the ground is dependent on the types of forest growing on them. While there are many unknowns in how climate change will affect our forests, forest health and biodiversity will go hand in hand. Unfortunately, the recent development in Finland´s forests has not only followed a path unnatural in relation to what would have been expected, but also one that – based on overwhelming evidence – is increasing their susceptibility against the changing climate and the damage agents that come along.

In this presentation, we draw together recent research on emerging damage agents and trends therein as well as data on the development of Finland´s forests, their structure and elements of diversity. We highlight the current trends and why they are undesirable, analyze the reasons behind them and take a look into the future. Finland has not experienced the types of damage that have hit Central and Eastern Europe, meaning that the country is in a position to make the necessary changes – unless it is willing to learn the hard way.

Connecting science to guidance on the ground: How do we manage riparian buffers to effectively support biodiversity?

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Riparian buffers are areas of natural, restored, or regenerating forest habitat alongside rivers. Riparian buffer strips have been proposed as a tool to help conserve freshwater biodiversity, water quality, forest biodiversity, and connectivity in oil palm plantations, with relatively little cost – and perhaps additional pest control benefits – to oil palm estates. Our recent research in Sabah has shown the importance of riparian forest buffers for supporting both terrestrial and aquatic biodiversity, and their potential to provide movement corridors for wildlife. Our results also suggest that there is little evidence of them either increasing or decreasing pest attack within the oil palm landscape. We investigated how riparian buffer width affects biodiversity, finding that wider buffers contain larger numbers of species, and that a small increase from 20m (current minimum width in Sabah) to 40m would more than double the number of species found in a buffer. However, we also found that the impact of wider buffer widths are context-specific, depending on which species are utilising the buffer, and also where it is placed in the wider landscape. For example, if the riparian buffer is linking two large forest patches a larger buffer width is recommended than if the river is running through an oil palm landscape without any connecting forest patches nearby. To aid decision-makers we have an on-going project engaging a range of stakeholders from oil palm companies, NGOs, government bodies, academics, and civil society to design a decision tree (the RiTREE – Riparain Decision Tree) that will provide guidance on recommended riparian buffer widths within a landscape to minimize biodiversity loss. This collaboration is an excellent example of how scientists and policy-makers can work together to synthesise current knowledge and make it accessible and relevant.

Drought-related calamities of European beech in Central Germany - causes, consequences, and measures (Buche-Akut)

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: The joint research project "Buche-Akut" assesses the vitality decline in European beech (Fagus sylvatica L.) since 2018 in the low mountain ranges of central Germany (Lower Saxony, Saxony-Anhalt, Hesse and Thuringia).

The aim of the project is to determine possible causes of the calamities, to evaluate their consequences, and to derive recommendations for the future silvicultural treatment of E. beech forests under changed climatic conditions. Inclusion of practical knowledge was key to the project. Information and experiences regarding silvicultural management of E. beech was gathered in interviews, stakeholder forums, and comprehensive literature analyses.

The investigation of possible causes was based on both remote-sensing methods and repeated phytopathological and forest structural investigations in 50 E. beech stands with different degrees of damage:

At each site, one dominant E. beech tree and three saplings were cut and examined for pathogenic fungi and insects in a laboratory. Using semi-annual terrestrial and mobile laser scans, morphological changes in crown and branch structure were recorded, allowing a quantitative evaluation of the damage in progress over a period of three years. In addition, the vitality of each individual tree was rated visually each year as a percentage of full-foliation, following the methodology of the ICP-Forest-Monitoring.

Furthermore, a systematic sampling was conducted on a 5 km grid in E. beech forests, where tree species, DBH and vitality of E. beech was recorded at 177 plots of 500 m². Additionally, data from ICP-Forest-Monitoring and external research groups provided ground-truth for the verification of remote sensing analyses:

Using satellite data (Sentinel-2 time-series) the vitality of E. beech forests was estimated based on changes in spectral reflectance in comparison to 2017 (prior to the unprecedented drought in Central Europe). The vitality assessment was done semi-annually for the entire research area starting in 2018.

Possible causes for vitality loss were assessed retrospectively by overlaying information on stand-structure and topography derived from (repeated) airborne laser scans (ALS) and soil maps, with the satellite-based assessment of vitality. Spatially interpolated historic weather and *in-situ* weather records were used in combination with ALS to model within-stand microclimatic conditions for the investigation period.

Effects of biotic damaging agents on the wellness of our forest and how they limit the forest growth under changing climate.

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Forests are challenged by a multitude of biotic and abiotic agents that affect their health and growth. One major challenge is arrising from the fact that trees have a much longer lifespan than many of the biotic threats. With climate change trees are faced with new and potentially stressing growth conditions while pathogens and pests can disperse and develope in new areas where the environment has become conducive to their growth requirements. The presentation will discuss emergent disease and outbreaks events that have been favoured by climate change and caused major setback for for the well being of forests with particular reference to conditions in Northern Europe. Depending of the size of outbreaks, their management can face large scale practical undertakings and require active communication with the public.

How a modern portfolio theory approach to forestry can help with resilient afforestation and restructuring?

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Trees and forests provide society with numerous valued benefits that extend beyond traditional timber supply. These include carbon sequestration for mitigating climate change, improved health and well-being, biodiversity conservation, and cultural significance, among others. In the UK and around the world many governments have set ambitious targets to expand forest cover in the near future. However, tree planting entails inherent risks. Trees are vulnerable to various hazards such as storms, pests and diseases, and drought, which are further exacerbated by climate change.

The study adapts modern portfolio theory from financial economics to the needs of forestry with multiple ecosystem services benefits and risks. We have developed a prototype model and a decision support tool to assist decision makers in achieving optimal outcomes for both future tree planting and restructuring existing forests. The model is based on the concept of diversification, recognizing that constructing portfolios of diverse assets characterised by imperfect correlations allows for a more favourable balance between benefits and risks compared to an undiversified approach. Our model integrates the best available experimental data, decision support tools, including the impacts of the latest climate change projections for the UK, and expert knowledge on trees and climate in the UK.

The main model output is the efficient portfolio frontier where each optimal portfolio differs by the relative species composition and the aggregated benefit-risk balance. The model and associated decision support tool enable decision makers to articulate their preferences regarding a wide range of benefits and risks, explore different scenarios, and select the most suitable portfolio for creating resilient and future-proof forests. In the majority of cases where multiple benefits are important the model suggests that diverse forests provide greater benefits for a given level of risk when compared to a monoculture.

How forest decision support systems can be used to mitigate forest damages in future climate

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Climate change poses significant challenges to forests, increasing the occurrence and severity of disturbances such as windthrows, wildfires, pests, and diseases. Effective decision-making tools are crucial for mitigating forest damages and enhancing resilience under changing climatic conditions. We explore the role of forest decision support systems (DSS) in addressing these challenges and present their potential in mitigating future climate-induced damages to forests.

We examine the key challenges associated with integrating disturbances and their interactions into decision support systems, using as motivating example the decision support systems for the high-resolution Norwegian forest resources map SR16.

How to choose right: forest resilience or vulnerability? Addressing key challenges of both approaches to learn from each other

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: The on-going increase in forest disturbances demands new knowledge, data and tools to anticipate and mitigate future impacts on forests. Minimizing disturbance impacts on forests can be achieved by enhancing forest resilience and reducing vulnerability. Although resilience and vulnerability seem complementary concepts and have been used interchangeably, they underlay distinctness while they focus on different challenges. Here we aim to disentangle the relationships between resilience and vulnerability in forest social-ecological systems, identifying the strengths and weaknesses of both concepts in order to improve assessments of forests under global change. In particular, we aim to answer the following questions: (1) what are the differences between them and their respective contexts that would justify a different use? (2) which elements can resilience and vulnerability, respectively, incorporate from the other to improve assessments? First, we highlight the differences between both concepts related to their origin/background, the used methodologies, their constituent components and their relevance, and the spatiotemporal focus. Resilience has its origin in the environmental and engineering field, whereas vulnerability has a strong background in the social and policy arena. As a consequence, vulnerability is frequently more operational than resilience. In addition, resilience focus on the temporal scale (identifying predictors and mechanisms behind resilience), whereas vulnerability focuses more on the spatial scale (comparing two different study areas). Adaptive capacity and disturbances are explicitly included in vulnerability assessments; in resilience, adaptive capacity is considered a mechanism to enhance resilience, and disturbances are not intrinsically addressed. We identify the limitations and weaknesses of each concept, and we specifically discuss whether the main limitations of one approach can be addressed by the other. Based on this analysis, we conclude that resilience and vulnerability in forests shouldn't be used interchangeably, and we show a guideline to identify when is it better to use resilience or vulnerability. The comparative understanding of the existing conceptual and methodological challenges of both concepts is of paramount importance to make them simple, intelligible and straightforward. Thus, a better joint conceptualization of resilience and vulnerability will increase the effectiveness in quantifying and managing the impacts of climate change in forests.

Linking forest fire modelling and simulation with decision-support systems in Sweden

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Forest fire is among the most important drivers of natural forest succession, shaping biodiversity, stand structure, and mediating biogeochemical cycles. Climate and land use alter regional fire regimes. In some regions, forests may exhibit more severe and frequent fire disturbances. New strategies should be developed to address future fire risks. Climate, topography and fuel properties exercise major control over fire behaviour. Among these, only vegetation structure can be manipulated in a short-term perspective to mitigate fire risks.

We explored the predictive power of vegetation data in estimating forest fire risks, relying on the ~100 fires above 10 ha in size that occurred in Sweden during 2016-2022. The model included growing stock volume of Norway spruce, Scots pine, and deciduous tree species, stand height and age, and soil moisture as independent variables. We developed a cellular automata model to simulate future fires and inform HEUREKA, a decision-support system commonly used by Swedish forest owners to guide their management decisions. Discrete soil moisture classes and proportional volume of Scots pine stand volume were important predictors. Our model predicted low forest fire susceptibility in deciduous and Norway spruce forests, and moderate forest fire susceptibility in Scots pine stands.

Near Real-Time Change Detection in Spruce Forests using Sentinel-2 Time Series

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Forests play a crucial role in carbon sequestration, biodiversity conservation, and providing ecosystem services. The monitoring of forests, their changes, and their health condition is of utmost importance for effective forest management and conservation efforts. Furthermore, the ability to monitor and assess changes in forest ecosystems is essential for identifying potential threats, understanding their impacts, and implementing timely interventions.

In recent years, the availability of satellite data has revolutionized the way we monitor and assess changes in forest ecosystems. Specifically, the Sentinel-2 satellite mission provides near-real-time monitoring capabilities and offers valuable insights into forest canopy dynamics and crown appearance through its reflectance data.

This presentation focuses on the methodology for near-real-time monitoring of changes in forests related to forest damage. Specifically, we perform analyses of time series of Sentinel-2 reflectance data to detect changes in spruce forest canopies in Norway. By analysing the temporal patterns of reflectance values across different spectral bands, we can identify changes related to forest health. For example, vegetation stress caused by factors such as drought or insect infestations can result in detectable changes in the reflectance signal. Similarly, disease outbreaks or deforestation activities can also be identified through characteristic shifts or changes in trends in the reflectance values.

We aim to create a monitoring and early warning system for spruce forests that detects deviations from the expected Sentinel-2 reflectance signal, which is related to vegetation with a changing health status.

Novel developments towards a holistic risk assessment system for the European spruce bark beetle

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: European spruce bark beetle (*Ips typographus*) (ESBB) mass outbreaks have caused enormous mortality in Norway spruce (*Picea abies*) dominated Central European forests in recent decades. These climate change driven abrupt forest transformations have severe ecological and economic consequences for many European countries. Important mitigation measures include a controlled conversion of pure spruce stands into more climate-stable mixed forests. Yet, spruce will remain a relevant and viable option, particularly within its natural range, such as the mountain forests of the Alps. Therefore, effective protection and management of spruce forests based on an accurate risk assessment is urgently needed to mitigate future natural disturbances.

In the project RAWLog, funded by the Austrian Waldfonds, we work on a comprehensive risk assessment considering the relationships between abiotic, biotic as well as operational factors that influence natural disturbances. Along with storm and snow damages, drought is assessed in the model framework since it has become increasingly important as an abiotic driver of ESBB infestations. Forest accessibility and work capabilities influence both forest predisposition and the scope and response time of interventions to disturbances. Our main goal is to develop the fundamentals of a freely available practice-oriented and dynamic ESBB early warning and risk management system with high temporal and spatial resolution for entire Austria.

The development of such a model framework is supported by recent advances in remote sensing, increased data availability and innovative modeling approaches. In particular, novel methods based on Sentinel-2 time series allow for a detection of tree species proportions and forest disturbances on an annual time scale with high spatial resolution of 10 m. Furthermore, simulations of ESBB development status and tree water availability enable an increasingly accurate and daily assessment of the current forest condition. Hence, the novel system will provide crucial support for silvicultural measures and risk management in Austrian forests under climate change.

Remote sensing to monitor and mitigate forest disturbances in a changing climate

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Historically, natural disturbances regimes have played a key role in shaping and maintaining many ecosystems. During periods of profound environmental change, disturbances also act as catalysts for ecosystem, and even biome, change.

Habitat suitability models predict that the possible distribution of tree species will shift considerably this century. These equilibrium-based models do not explicitly incorporate disturbances, leaving considerable uncertainty about the role disturbances will play in the transformation of forests globally. However, indications are that this role will be considerable, as evidence is growing that anthropogenic climate change is intensifying and accelerating several aspects of forest disturbance regimes. Increased forest disturbances can compromise a range of ecosystem services that communities have counted on locally for generations. Moreover, they may also weaken services that society as a whole counts on globally, such as the ability of forests to provide a sink for carbon in the atmosphere.

To help understand how forest disturbances are changing and to mitigate their impact on society, calls for operational forest disturbance monitoring systems are growing. In wildfire management, the use of remote sensing has a long legacy, because fire signals, be they thermal or optical, are easily picked up by satellite sensors that enable rapid mapping over large areas. Remote sensing is also used to monitor deforestation and stand-replacing harvest from the tropics to the boreal regions. Other forest disturbances, including by drought, biotic agents, wind storms, and selective and progressive logging, have proven more challenging for remote sensing-based detection and attribution. This presentation will review recent progress made in detecting and monitoring these forest disturbances by leveraging emerging analytical methods and new data streams.

Using harvester data for improved understanding of spruce root rot drivers and distribution

T5.26 New solutions for challenges in decision support for mitigating disturbances to increase forest health and resilience under climate change

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Abstract: Root rot is the most devastating pathogen in coniferous forests of the northern hemisphere, leading to reduced timber quality, growth losses, control costs and increased mortality. While traditional methods for mapping root rot have been slow and laborious, automatically collected and geopositioned harvester data provides a promising source of information for improving the current level of knowledge on the root rot situation. Here, we used harvester data to (1) study the drivers of root rot and (2) map the risk of root rot in spruce stands in Finland. We built a statistical model predicting the percentage of stems affected by root rot, using an extensive set of harvester data. The data contained over 12 000 clear-cut Norway spruce stands in southern and central Finland, where presence of root rot was determined on stem-level with an algorithm based on stem-specific cutting information from harvesters. The model consisted of two parts, a fixed component describing known drivers of root rot, and a random component describing the spatial patterns in rot occurrence. The fixed part included variables describing forest stand attributes, soil and climate conditions, and proxies for the past forest management intensity. The model was then used to map root rot risk, by predicting the probability of root rot (i.e., the probability for the share of rot-affected stems to exceed a predefined threshold) using spatial data sets of the variables in the fixed part of the model, and the known locations of root rot infected stands in the harvester data set for the random part of the model. With the exceptionally large data set, the results provide an improved quantification of the relationships between root rot and its drivers and refine the current understanding on spatial distribution of rot-infected stands. This information can be used to support forest management decisions aiming to control the spread of the root-rot and to eradicate it from the currently infected areas.

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

Bottom up meets top down: Data and tools for developing forest biodiversity metrics combining in situ and remote sensing

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Monitoring of changes, or drivers of change, in forest biodiversity is enormously challenging. As the forestry sector increasingly embraces their critical role in achieving global conservation targets and achieving a Nature Positive economy, there is a groundswell of demand for efficient and effective forest biodiversity metrics. *In situ* biodiversity data is invaluable for establishing biodiversity composition, status, and trends, but is a financial and logistic long-term commitment. Efficiently integrating strategic biodiversity data together with dramatic improvements in remote sensing data and analysis platforms offers a path for advancing meaningful forest biodiversity metrics.

Major developments in remotely sensed data collection, curation and analysis are providing new tools and insights into forest biodiversity. Highly scalable cloud-based computational platforms supporting globally dispersed, and highly collaborative, open science are being deployed, such as the Multi-mission Algorithm and Analysis Platform (MAAP), built and supported in close collaboration between NASA and ESA. Petabytes of relevant existing remote sensing data are being migrated to fully open cloud storage where they can be used *in situ* in those platforms, thus greatly expanding access and analysis capability, especially directly in regions with the highest inherent forest biodiversity. New instruments in, or soon to be in space, and their cloud native data streams, will provide far greater capabilities to monitor forest structure, health, extent, composition and phenology with higher cadence and expediency.

For example, harmonization of lidar data from ICESat-2 and GEDI has already led to significant advances in estimating above ground biomass (AGB). MAAP is now being used to merge and compare all of the major AGB estimates and deliver regionally specific estimations for reporting. The combination of LiDAR and SAR – especially from the upcoming NISAR and BIOMASS missions - will add enormous gains in detail, depth and cadence that will transform forest monitoring.

Biodiversity data from field efforts is also rapidly advancing, with increasingly effective outcomes for tools such as e-DNA, wildlife cameras, and acoustic recorders. Future efficient and meaningful forest biodiversity metrics and monitoring will arise from a strategic integration of site-specific biodiversity data together with products and tools emerging from the remote sensing community.

Combining satellite imagery and high-resolution airborne laser scanner data to monitor forest habitat types in Natura 2000 sites

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Priority forest habitat types (FHTs) within the Natura 2000 network are of highest conservation importance in Europe. However, they often occur in smaller areas and their conservation status is not well known. In our research, we focused on the following priority FHTs: I) 9180 *Tilio–Acerion forests of slopes, screes and ravines, II) 91E0 *Alluvial forests with Alnus glutinosa and Fraxinus excelsior (*Alno-Padion, Alnion incanae, Salicion albae*), and III) 91D0 * Bog woodland (*Sphagno-piceetum*) in three Natura 2000 sites in Slovenia.

The aim of our research is to determine the suitability of remote sensing data for automatic classification and monitoring of selected FHTs. Field mapping of FHTs was carried out in 2020, giving us a good knowledge of their spatial distribution in the Natura 2000 pilot areas. The results of the field mapping were supplemented with information on site characteristics based on data from ALS.

Based on the results, we will select the input data for automatic classification of FHTs and will be the following: I) LiDAR (ALS - Airborne Laser Scanner) and II) satellite imagery (Sentinel 1 and Sentinel 2). From the LiDAR data we will compute variables describing the relief features of the sites, the structure of the vegetation and some topographic features of the areas.

The model learned and tested in three pilot areas will be applied to other selected Natura 2000 sites in Slovenia, where no field mapping has been done before. We will compare the results of FHT classification in the original three pilot areas with the results in three additional selected Natura 2000 areas. Based on the results, we will evaluate the suitability of the input data and methods used to determine the distribution and monitor the state of the forest habitat types discussed.

A set of three different forest habitat types provides a wide range of input data suitable for each FHT. Adapted input data could also allow application of the methodology to other FHTs not discussed in our research. The results of our study are the starting point for the establishment of permanent monitoring of FHTs in Natura 2000 sites in Slovenia.

Ectomycorrizal morphotypes in structural variable retention of Pinus patula Schlltdl et Cham

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: One of the forest species most used in Mexico for timber harvesting is *Pinus patula*. Currently this species is under forest management in the north forests of Puebla state and in some sites, clearcut regeneration system is applied. This species, like all pine species are depending for their survival on ectomycorrhizae, given the ecophysiological importance of this symbiotic association. The aim of this work was to evaluate the effect of the clearcutting regeneration system on the structure of ectomycorrhizal communities compared with areas with variable structural tree retention of a *P. patula* forest in Chignahuapan, Puebla. Nine trees were selected within the areas of interest to obtain soil samples and to be able to extract the ectomycorrhized morphotypes, to be characterized both anatomically and its morphology. 3137 ectomycorrhized roots were counted in total, within which 33 different morphotypes were recognized. Four of them dominated more than 50% of the total relative abundance, among them *Cenococcum geophilum*. There was a negative effect on the diversity of morphotypes among the stands with forest management compared to the retention areas. Finally, it is possible to say that forest harvesting with clearcutting system has a negative impact on the diversity of ectomycorrhizae; however, the maintenance of retention areas can reduce this impact and contribute to the reestablishment of the diversity of ectomycorrhizal communities over time, as it is a diverse genetic reservoir of these communities.

Forest Diversity at Large: Sentinel-2 and Deep Learning for Tree Species Mapping with Mixed Pixel Resolution

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Accurate large-scale classification of tree species is crucial for monitoring, protecting, and managing Earth's invaluable forest ecosystems. Amongst a wide range of applications, it facilitates tracking of the geographical development of tree species in response to climate change, improves risk assessment maps for threats like bark beetle infestations or forest fires, enhances timber volume models for accurate resource estimation and is utilized by forest authorities and the local management level. Numerous studies have recognized the suitability of satellite imagery, particularly Sentinel-2 imagery, for this task.

We utilize a dense phenology Sentinel-2 time series, which offers consistent data across multiple granules, in addition to terrain and vegetation height data, to map tree species on the individual Sentinel-2 pixel level across the entire forested area in Austria. Aiming for the classification scheme to represent actual forest conditions more accurately, alongside pure tree species classes, we include mixed tree species and sparsely populated classes. Additionally, we employ synthetic data generation to enhance the training data, which was manually labeled via visual aerial photography interpretation. The models we apply are based on a residual network, tailored for time-series classification specifically, and a multilayer perceptron. Numerous studies have identified spatial autocorrelation to have a significant impact on the validation of thematic maps. We explore the effects of autocorrelation on validation by investigating two validation methods at diverse split and buffer distances: spatial split validation and a validation based on buffered ground reference probability samples provided by the National Forest Inventory (NFI). While a random training data holdout set yielded 99 % overall accuracy, the spatial split validation resulted in 74 % overall accuracy, emphasizing the importance of accounting for spatial autocorrelation when validating with holdout sets derived from polygon-based training data. The validation based on NFI data resulted in 55 % overall accuracy, 91 % post hoc pure class accuracy and 79 % accuracy when confusions in taxonomic proximity were disregarded (e.g., spruce-larch confused with spruce-beech). The significant decline in accuracy between spatial split and NFI validation highlights the disparity between polygon-based training data and ground reference forest data, especially in diverse forest areas.

Improving Neural Network Classification of Native Forest in New Zealand with Phenological Features

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Changes in vegetation Indices (VIs) over time can be used to describe the phenology, or temporal changes, in vegetation. It is unknown which of these so-called phenological features contribute most to the classification of land cover. Feature selection might be able to address this issue. In this work, phenological features were used to classify a 50 km^2 native podocarp forest in New Zealand using two-year Sentinel-2 (S-2) data (288 images) and single-date PlanetScope (PS) data. There were nine land cover classes assigned to the study area. Single-date PS and S-2 data were fused to create a base image with the same spatial resolution as PS (3.125 m/pixel) and 8 bands that contained spectral data from S-2. This fused image was used to create 30 VIs. By using time-series S-2 alone and harmonic analysis in Google Earth Engine, the phenological parameters amplitude (AMP) and phase (PH) were retrieved from these VIs. Three classification scenarios (fused bands & VIs, fused bands & phenological features, and fused bands & VIs & phenological features) were undertaken using a Neural Network for accurately classifying forests. To assess the effect of feature selection and to determine the most crucial features, Variable Selection Using Random Forest (VSURF) was performed on the three different scenarios. According to the results, VSURF could speed up the classification process while retaining a similar degree of accuracy. Phenological features improved accuracy from 90% to 94%, driven mostly by the Red-Edge Triangulated Vegetation Index-AMP&PH, Normalised Near-Infrared-PH, Greenness Index-PH, Water Body Index-PH, Normalised Difference Vegetation Index-PH, Normalised Green-PH, Red-Edge Normalised Difference Vegetation Index-PH, Leaf Chlorophyll Content-AMP, and Simple Near-Infrared and Blue Ratio-PH. These features represent variations in the canopy's morphology, biochemistry, and physiology. Overall, the results demonstrate that particular phenological characteristics can enhance the classification of native podocarp forests in New Zealand.

Mapping large European aspens using airborne lidar and image data in Finland

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: European aspen (*Populus tremula* L.) is a keystone species and pioneer in boreal forests. Despite its sparse and scattered occurrence in Northern Europe, aspen is regarded as a highly valuable species. Both living and dead aspens are important hosts for many forest-dwelling species, including birds, fungi, invertebrates and mammals. Keystone role of aspens poses requisite for the information of the abundance and occurrence of these trees at landscape level. This information is valuable in the planning and implementation of sustainable forest management and conservation. Also, the aspen occurrence in time-continuum would be informative from the landscape health and integrity point of view. The topic of this presentation is the evaluation the performance of the combined use of high pulse density (5 pulses/m^2) leaf-on ALS data and aerial images in the detection of large aspens. We define the large aspen by its diameter at breast height (DBH); analyses are repeated with different threshold values (18, 20, 22, 24 and 26 cm). The study is completed with the realistic population in Finland, which means that the portion of large aspens is very low among all the trees (approx. 0.50%). As the dataset was highly imbalanced, we adopted Synthetic Minority Oversampling Technique (SMOTE) to generate new instances of minority cases. In the best case (26 cm DBH limit), Random Forest algorithm identified 7 out of total 22 large aspens in the whole data of 33 195 trees. The most important metrics in the detection of large aspens were related to aerial images, especially near-infrared band. The importance of ALS metrics was lower. The most important ALS metrics were related to echo intensity, kurtosis of vegetation heights and lower percentiles of vegetation heights. Results of the metric importance were in line with the earlier knowledge; image and ALS intensity metrics are highly capable in the identification of broadleaved trees. SMOTE-RF outperformed the non-SMOTE-RF classification which highlights the capability of the minority oversampling technique in the case of imbalanced data.

Open spectral libraries to support forest biodiversity monitoring

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Remote sensing techniques contribute to significant advances in monitoring the biodiversity of forests at large scales. New technologies, especially ones based on remote or close-range spectroscopy, are expected to offer unprecedented solutions to monitoring plant species and their traits, both remotely from aircrafts or satellites or in the field using portable sensors. Spectroscopic technologies are based on measuring how plants interact with solar radiation: different plants absorb, reflect, transmit and emit solar radiation differently throughout the electromagnetic spectrum (350–3500 nm). This interaction is determined by biochemical and structural properties of the plant organs, and is thus also indirectly linked to species. Even though the basic spectral features of plants have been known for decades, the development of new hyperspectral remote or close-range sensing methods for forests has been hindered by a limited understanding of the variations in spectral properties of different elements forming forests such as leaves, bark and forest floor. In this presentation, we summarize recent studies from Aalto University that have collected and analyzed the (hyper)spectral properties of boreal and temperate forest elements in Europe. We report intra- and interspecific variations in the spectral properties of leaves, needles, tree bark, and forest floor and peatland vegetation, and discuss their significance in biodiversity monitoring. The data sets presented are available as open spectral libraries with digital object identifiers.

Operational solutions for biodiversity monitoring and mapping in forest ecosystems

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Maintaining and improving the integrity and biodiversity of forested ecosystems is vital for achieving the EU biodiversity strategy for 2030, Sustainable Development Goals (SDGs), and Kunming-Montreal Global Biodiversity Framework (GBF). Present data show that the tropics lost 11.1 million hectares of tree cover in 2021 (University of Maryland and available on Global Forest Watch 2022). In particular, 3.75 million hectares of loss occurred within tropical primary rainforests — areas of critical importance for carbon storage and biodiversity. We need operational solutions to tackle biodiversity challenges. Providing that biodiversity is multidimensional, there is no unique indicator to describe and/or monitor forest biodiversity. In this context, I highlight the importance to monitor forest ecosystem extent and predict forest biodiversity change and its direct and indirect drivers through the integration of state-of-the-art multi-sensor Earth Observation (EO) data, comprehensive in-situ data, and products, together with next-generation ecological models that account for uncertainty. The approach supports also, integrated efforts needed to consolidate data from in-situ and remote sensing present and future missions. This presentation will serve as an introductory background for this technical session.

Operational tools for monitoring key forest attribute layers at global scale

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Within the context of the EU action to protect and restore the world's forests (COM/2019/352), the European Commission has setup the EU Observatory on Deforestation and Forest Degradation (EUFO) to provide scientific evidence on global deforestation, forest degradation and related trade. We present an overview of the processing, layout and features of global datasets designed to monitor and quantify key forest attribute layers (FAL), addressing forest fragmentation, forest patch accounting, forest spatial pattern, and forest network coherence. The scope of the FAL is to mediate the various end-user requirements by providing an objective and tangible product composed of spatially explicit maps, intuitive quantitative indicators, and concise summary statistics.

The spatial forest coverage is derived from the Copernicus Global Land Cover dataset for the assessment year 2019. We outline the procedure of pre-processing the original Copernicus data segments into a continuous global forest mask that is compliant with the FAO forest definition. This forest mask is then analysed for the various FAL, summarising the spatial status of forest cover and its degree of forest degradation. The FAL analysis is conducted in a dual approach: first, using the original WGS84 map projection for explanatory and user-friendly visualisation on web portals and second, in equal area projection allowing statistical evaluation of the forest attribute layers. Spatially explicit maps and statistical summaries are derived for a total of 278 reporting units, comprised of 255 countries, 21 global ecological zones, the EU27, and the full global coverage. A technical report summarizes all details on the processing steps, datasets, and links to access to the resulting products. All operational tools to conduct the FAL analysis are open-source and freely available at https://forest.jrc.ec.europa.eu/en/activities/lpa/ for either interactive use in the desktop application GuidosToolbox, or for automated mass processing on Linux servers via the application GuidosToolbox Workbench.

Remote Sensing applied to Small-Scale Sustainable Forest Management for monitoring and logging detection in the Central Amazon

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Small-Scale Sustainable Forest Management (SSFM) is a management category in the Brazilian Amazon that promotes economic, environmental, and social development while benefiting small producers. It also contributes to deforestation reduction and forest conservation. A research study was conducted to evaluate the use of satellite images for identifying forest harvesting in small-scale sustainable forest management, particularly in areas with costly access. The study focused on the municipalities of Novo Airão and Iranduba in Amazonas state.

The research utilized high-resolution satellite images from the Sentinel 2 and Planet satellites, which are freely available. Three study areas were considered, including two Areas of Effective Exploration (AEE) that underwent harvesting and one Non-Harvested Area (NHA). Images were acquired in 2016, 2018, and 2019, covering data before and after the issuance of the Operation License (OL) for forestry harvesting. Processing and radiometric correction techniques were applied to enhance image quality.

The spectral values of the images were statistically analyzed to evaluate their response in harvested and non-harvested areas, aiming to identify any differences and spectral behavior patterns. Visual analysis of the images, along with post-harvest reports, confirmed the changes resulting from logging in the study areas. The images revealed evidence of logging, such as changes in forest cover characterized by varying color and texture gaps.

Comparing the Sentinel and Planet satellite images, both proved effective in identifying small-scale logging based on changes in forest cover. However, the spectral bands of the Sentinel images did not show the same similarity as Planet bands 2 and 3 (p-value=0.6 and 0.2). This indicates that Planet images provide more refined visual and spectral results due to their superior spatial resolution.

The study demonstrated that satellite imagery can efficiently identify forest exploitation in areas of small-scale sustainable forest management. This information is crucial for monitoring and controlling management activities, thereby contributing to forest conservation and sustainable development in the Amazon region.

The Application of Near Real-Time Data for Deforestation Monitoring in Aceh Province, Indonesia: How Could It Help?

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Indonesia's tropical forest is the third largest after Brazil and Congo with an area of around 126 million hectares (ha) of forest cover needs to be monitored. Many forest authorities are still relying on manual and conventional methods to monitor forest areas. Therefore, there is an urgent need to have access for remote sensing data with its computing capabilities to provide forest change information at various scales, places, and times. Finer spatial and temporal resolution (near real-time) data become the default characteristics in monitoring system. This study aims to find out what are the aspects that would improve by near real time data compared to existing conventional monitoring systems. Radar Alert for Deforestation Detection (RADD) is a near real time forest disturbance alert in primary humid tropical forests, using Sentinel-1's cloud-penetrating radar sensors. RADD becomes the main tool for primary data input to enhance forest monitoring system run by Forest Management Unit (FMU) in four districts of Pelalawan in Riau province, Aceh Tamiang, Aceh Timur, and Bener Meriah in Aceh Province, Indonesia. This study shows the utilization of near-real-time deforestation alert helps FMU in five important aspects by [1] expanding their monitoring area, [2] increasing the frequency of patrols, [3] speeding up the process of determining the patrol route, [4] speeding up the process of obtaining information regarding illegal land clearing activities to be forwarded to law enforcement, and also [5] facilitating updates on forest and land cover databases as an input of official data for local governments.

The Realities of Ecosystem Services: Acknowledging the Imperfect Nature of Trees and Forests

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: Throughout the course of civilization, trees and forests have consistently garnered admiration from people and societies, leading to their extensive manipulation and management on a global scale. However, the utilization of forests to fulfill societal needs often took place without proper management plans, particularly prior to World War II, and persisted in many parts of the world until the end of the 20th century. The devastating losses of pristine forests in Europe, East Asia, and eastern United States have been extensively documented. Moreover, the tropical rainforests continue to face large-scale deforestation in numerous countries. Nevertheless, there has been a growing recognition of the importance of understanding and preserving trees and forests. Various initiatives have been undertaken to protect trees and forests, as well as to safeguard threatened species. Noteworthy successes include the global distribution programs for species like Metasequoia and Gingkoes, which have helped rescue them from the brink of extinction. Additionally, the establishment of reserves such as national parks and the protection of old-growth forests in the Pacific Northwest of America serve as commendable examples. Meanwhile, it is important to acknowledge that there have been other human-induced changes in trees and forests that have proven to be mistakes, and in some cases, disastrous. Regrettably, these errors have not received full recognition from the public and policy makers. Notable examples include the large-scale introduction of Scotch pine to North America, the cultivation of fast-growing Eucalyptus in Southern Asia and Africa, and the conversion of deserts into irrigated monoculture popular plantations. Considering recently developed and evolving concepts such as sustainability, ecosystem management, and ecosystem services, it is crucial to review both successful and failed cases in the context of local landscapes and societal needs. This highlights the imperfect nature of our understanding and management of trees and forests. Given the importance of these natural treasures, it is essential that the perceptions of the public and policy makers are informed by the scientific community. By incorporating scientific knowledge, we can make more informed decisions, ensuring that they align with both ecological considerations and the needs of local communities.

Understanding land use change at the landscape level using machine learning for maximizing forest ecosystem services in the Andes

T5.27 Operational tools improving forest biodiversity Monitoring from space: Finding solutions to 2030 conservation targets

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Abstract: The Andean region maintains diverse forest ecosystems due to the variety of environments created by the great differences in elevation. These mountain ecosystems possess not only the function of producing timber and non-timber forest products, but also multiple functions, including biodiversity conservation that maintains genes, species, and ecosystems; global environment conservation that mitigates global warming and stabilizes the global climate system; landslide prevention and soil conservation that reduce surface erosion, surface collapse, and sediment runoff; and water source recharge functions that store water resources and regulate water quantity. These various functions provide various benefits (ecosystem services) to human life. Sustainable forest management is indispensable for the perpetuation of forest ecosystem functions, and for this purpose, it is important to accurately understand the current status of forests and their changes. The objective of this study is to develop a method to capture land use change at the landscape level surrounding forests using data from multiple satellite sensors using machine learning methods. The satellite data used will be Landsat satellite data and Sentinel-2 satellite data. The former has the advantage of long-term observation, while the latter has the advantage of capturing more detailed land use boundaries with higher ground resolution than the former. Therefore, we used a combination of these data and performed object-based classification using machine learning methods to identify land use change at the landscape level. In particular, from the perspective of forest ecosystem services, we proposed a method to capture the effects of new eucalyptus plantations, which use more water resources, and forest degradation and forest fires, which affect the supply of non-timber products, as trajectories in the reflectance spectrum. In order to maximize forest ecosystem services, it is necessary to identify the ecosystem services demanded by local residents and to work with them to develop afforestation, forest management, and land use allocations that do not degrade these ecosystem services. The results obtained from this method will be useful in building this consensus.

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

Missed opportunities for growth: key determinants and limitations of radial growth in boreal forests along a latitudinal gradient

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: The boreal zone is warming twice as fast as the global average due to climate change, with warmer spring and autumn temperatures significantly increasing the window of potential growth for boreal forests. Radial stem growth is a key indicator of tree vitality and is strongly linked to the health of a tree. Understanding the effects of climatic drivers such as temperature and moisture and photoperiod on radial growth is crucial for assessing the impacts of climate change on tree health. However, studies observing high-temporal growth responses to these rapidly changing conditions, especially in the boreal zone, remain scarce.

We analysed sub-daily radial tree growth from dendrometers for more than 200 trees of two boreal conifer species (*Picea abies* and *Pinus sylvestris*) at 10 sites along a latitudinal gradient (mean annual temperature, MAT, range from 6.8°C to 1.2°C) in Norway over two years.

Annual radial growth was positively correlated with MAT however there was large variation in the growth between individuals at each site with the role of individual tree characteristics and life history, microclimatic and soil traits explored.

As expected, growing season length (the number of days between the start and cessation of radial growth for the season) decreased with increasing latitude (from 78 to 54 days). Air temperature and photoperiod determined the start of the growing season, however most trees, irrespective of latitude, ceased growing by early August, suggesting a key role of photoperiod. We observed that the number of actual growth days (days where radial stem growth >0µm) was significantly lower across all sites, with growth only occurring on 14 to 61 days (30 to 70%) of the growing season. The number of growth days was a much better predictor of annual radial growth than growing season length.

Given that boreal trees showed radial growth only on a small percentage of possible days within a growing season and that the number of days of growth strongly determined the annual growth of an individual, our study highlights the need to better understand the key determinants tree growth at a daily level to reduce uncertainties in predictions under climate change.

Basin-wide patterns of Amazon forest sensitivity to drought

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: Amazon rainforests face intensifying water stress due to increases in vapour pressure deficit (VPD) and changing hydrological regimes. Embolism resistance (Ψ_{50}), defined as plant capacity to resist the disruption of xylem water flow as a result of air bubble formation caused by water stress is an essential metric of tree ability to persist under dry conditions. Measurements of $_{50}$ are only available for a relatively small number of Amazon forests, representing a major challenge for understanding large-scale forest sensitivity to drought and climate change. Here we evaluate the phylogenetic basis of Ψ_{50} across Amazonian tree taxa and find a high level of phylogenetic signal, with hydraulic conservatism preserved at family level. The phylogenetic signal found in our dataset allowed us to use species composition data from more than 500 inventory forest plots distributed across Amazonia to produce the first map of basin-wide embolism resistance. The resultant spatial distributions reveals how embolism resistance vary across the largest and most biodiverse tropical forest on Earth, indicating different ability across Amazonian forests to cope with a future hotter and drier climate.

Detecting distribution of Lantana camara in western region of Nepal using remotely sensed data

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: Remote sensing is a valuable tool for the management of invasive species. It can help to identify areas that are at risk of invasion, to track the spread of invasive species, and to monitor the impact of invasive species on native plants and animals. This study evaluates the utility of Landsat 8 Satellite data for detection, mapping and patch information extraction of the invasive weed *Lantana camara* in four district of western Terai of Nepal. Study area possess Tropical monsoon to temperate climate and major natural vegetation present in the area is *Shorea robusta* and associates species and *Pinus* in upper altitudes. Landsat 8 Operational Land Imager (OLI) satellite image of March 3 & April 19, 2022 was used to differentiate *Lantana camara* from the surrounding vegetation and other landuse using maximum likelihood classifier algorithm. The image was classified into six specific land cover classes including agriculture, urban, *Lantana camara*, forest, water-bodies, and sand/gravels/exposed soils. Out of 874991.0 hecter of the study area 47568.9 (5.44%) of area is colonizing by *Lantana camara*. The classification accuracy was assessed which give an overall accuracy of 76.27 % and overall Kappa Statistics is 0.60873. The study demonstrated the high potential for differentiation and mapping of *Lantana camara* using moderate resolution satellite imaginary at acceptable level of accuracy. The findings shows that moderate resolution satellite imaginary can contribute for planning to control *Lantana* invasion.

Ecosystem pressure-volume relationships and steady-state vegetation biomass

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: Water is a fundamental constituent of life, but not all water is available to life. In fact, life requires water within narrow limits of chemical potential: hence, the Dead Sea is largely dead, and the highest biomass systems occur in places with large quantities of 'free' water. To grow and reproduce, sedentary organisms must have a supply of water with a higher chemical (or water) potential than themselves. Thus, there is coordination in the water relations between organisms, communities and their environments.

The relationships between water potential and water content in plants and soil have long been of interest. However, there is increasing focus in understanding how these fundamental measures of water are linked at larger spatial and temporal scales, i.e., the scale at which land surface models operate and satellite remote sensing can provide information. Bridging the gap between fundamental tissue-level variables and ecosystem-level processes holds the potential for identifying large-scale vegetation thresholds and providing early warning signals of ecosystem change. Here we look at how these fundamental measures of water scale to landscapes and whether they can be informative of ecosystem organization over large spatial and temporal scales.

Using plot-level data from nine sites including tropical rainforest, savanna, temperate forest, and a long-term Amazonian rainforest drought experiment, we explore relationships between equilibrium vegetation water potentials and water stored in above ground biomass. The relationship between the water stored in biomass consistently scales with biomass across systems, as does the vegetation-level hydraulic capacitance, while the relative measures of water storage and hydraulic capacitance show no trend across ecosystems. Such cross-biome relationships hold promise for improving the interpretation of satellite remote sensing data.

We use this preliminary analysis to open a discussion on the extent to which community structure is fundamentally determined by the 'hydraulic environment', i.e., the supply and demand of water. Such probabilistic models are consistent with the predictable climatic distribution of natural vegetation types as first noted by Humboldt, and may lead to vegetation models that are more reliable over large spatial and temporal scales while having lower data requirements.

Estimating latitudinal patterns in stabilizing density dependence in forest communities

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: One of the most striking patterns in forest ecosystems is the latitudinal gradient in tree species diversity. A prominent explanation for the exceptionally high local diversity in tropical moist forests is that tropical tree communities are more strongly stabilized by specialized enemies leading to conspecific negative density dependence (CNDD). This biotic interaction is thought to prevent the dominance of individual tree species and promote coexistence. While the existence of CNDD is well established at all latitudes, there is still no conclusive evidence if and how CNDD differs between tropical and temperate forests. The few studies that have directly examined large-scale geographical variation in CNDD reported a pronounced increase in CNDD with decreasing latitude. However, these latitudinal CNDD patterns have been attributed to multiple statistical biases, including regression dilution, which are related to the use of static data and can create spurious correlations of CNDD with abundance and latitude. Here, we test several predictions arising from the hypothesis that CNDD is more influential for maintaining local tree species diversity in the tropics. To do so, we use dynamic forest inventory data from large permanent forest plots and a carefully designed analytical pipeline that aims to ensure high comparability across latitudes. Overall, our results support the idea that CNDD may stabilize diverse tropical tree communities more than temperate ones, but this stabilization appears more subtle than previously thought. Using the case of CNDD and the latitudinal gradient in local tree species diversity as an example, the presentation will outline the methodological difficulties and potential solutions associated with testing and quantifying large-scale patterns in ecological processes, such as across latitude or elevation.

Insect galls as indicators of ecosystem changes in the Mediterranean forests: comparison of patterns in fossil and contemporary data

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: Mediterranean forests are hotspots of biodiversity and the Mediterranean area is among the richest and most vulnerable biomes on Earth. Global Change poses a serious threat to this biodiversity and the resilience of these forests. To better understand and predict future changes in these ecosystems, paleoecological investigations are of critical importance.

Many studies focusing on temporal changes of forest biodiversity overlook one important aspect of ecosystem functioning: the interactions among living organisms influenced by the environment. The present study proposes a novel approach, integrating intensities of plant-insect interactions as indicators of forest changes over time. Plant-insect interactions play a crucial role in shaping the distribution, abundance, and diversity of both plants and insects within terrestrial ecosystems.

To investigate plant-insect interactions, a morphological guide of plant-insect interactions in the fossil record provides a useful tool to study these interactions across different ages, locations, and plant species. This method allows for direct comparisons between fossils and modern interactions, providing insights into the historical dynamics of these interactions.

We examined plant-insect interactions around the Aegean Sea including a period of 20 million years. By analyzing 2,500 fossil leaves and 4,000 contemporary samples, we observed notable changes in these interactions. The prevalence of galls on leaves showed a significant increase in regions with higher temperatures and decreased precipitation, indicating a potential shift under climate change. Additionally, our study uncovers changing associations between specific plant species and insect galls, shedding light on the evolving coevolutionary dynamics over time. By unraveling the intricate web of plant-insect interactions and their responses to changing environments, these findings provide crucial insights into the understanding and managing of Mediterranean forests in the face of Global Change.

Soil water limitations to forest temperature buffering across space and time

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: Forests can buffer understory microclimate and biodiversity against high temperatures. Buffering of high temperatures in forests results from a combination of canopy shading and cooling via evaporation and transpiration and varies therefore in space and time. In the context of climate change, the buffering capacity of future forests against increasingly frequent heatwaves and droughts is conditional on stable canopies and a sufficient amount of soil water. Dry soils limit evapotranspiration – the most efficient surface cooling mechanism. Up to now, we know too little about the strength of the relationship between soil moisture and temperature buffering as well as about its interaction with canopy cover, topography, geographic location and forest type. Here, we analysed temperature and soil-moisture time series of European forests investigating how day-to-day fluctuations in soil moisture drive temperature offsets, i.e., the difference between reference temperatures from daily climate reanalysis grids and temperatures inside the forest. We modelled offsets of daily maximum temperature as a function of soil moisture in interaction with canopy cover, topography and weather conditions. We found that site-specific offsets became more negative (in other words, the cooling effect was stronger) when soil moisture was higher. This relationship was also contingent on canopy cover, topographic heat load, the daily evaporative demand of the air above the canopy as well as macroclimate. In a warming macroclimate with increasing frequency of drought events, these soil-water limitations on forest buffering will become more and more critical and several forest regions risk losing their buffering capacity. Therefore, we must urgently adapt forest management practices to not only secure continuous canopy cover but also to keep the water in the soils, for example, by closing drainage ditches or adaptive thinning to prevent long-term soil water depletion from evaporative loss. We demonstrate that accounting for spatiotemporal variations in the local water balance will aid in making more realistic predictions about the buffering function of forests across landscapes and biomes and over time.

Tree species composition along environmental and disturbance gradients in tropical sub-montane forests

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: Understanding the environmental and disturbance determinants of tree species dominance and community composition in an ecosystem, is important for informing management and conservation decisions, through maintaining or improving the existing forest composition and structure. This study was carried out to quantify the relationship between forest tree composition structure and environmental and disturbance gradients, in a tropical sub-montane forest of Eastern Usambara. Vegetation, environmental, and anthropogenic disturbance data for 58 plots across Amani and Nilo nature forest reserves were obtained. Agglomerative hierarchical cluster analysis and canonical correspondence analysis (CCA) were used to identify plant communities and analyze the influence of environmental variables and anthropogenic disturbances on tree species and community composition respectively. Four communities were identified and CCA results showed that the variation was significantly related to elevation, pH, Annual mean temperature, temperature seasonality, phosphorus nutrients and pressures from adjacent villages and roads. Likewise, environmental factors (climate, soil and topography) explained the most variation (14.5%) of tree and community composition in relation to disturbance pressure (2.5%). The large and significant variation in tree species and community patterns explained by environmental factors suggests a need for site-specific assessment of environmental properties for biodiversity conservation plans. Similarly, the intensification of human activities and associated impacts on natural environment should be minimized to maintain forest species composition patterns and communities. The findings are useful in guiding in policy interventions that focus on minimizing human disturbances in the forests and could aid in preserving and restoring the functional organization and tree species composition of the sub-tropical montane forests.

Understanding forest change from patterns along elevational gradients: Lessons from a multi-state monitoring network in the northeastern United States

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: As climate warms, tree species are expected to migrate to higher latitudes and elevations, but mixed evidence suggests that our understanding of the mechanisms driving tree migrations is still rudimentary. Since seedling establishment is required for tree migration to occur, experimental studies increasingly investigate how climate affects tree seedlings and their interactions with other organisms (e.g., non-woody plants, soil microorganisms, herbivores). Field studies along climatic gradients spanning species range limits can detect early stages of species range shifts and improve our understanding of climate-induced migrations under field conditions with many interacting factors and taxa. We used generalized linear mixed effects modelling and ordination to investigate how tree seedling recruitment, abundance, composition, diversity, and species associations with other plants and soil fungi vary from low-elevation temperate deciduous to high-elevation conifer forests in four states of the northeastern U.S. Forest plant communities were surveyed on 2,580 plots in total (each 1×1 m large), both under forest canopies and in canopy gaps. We also characterized soil depth and chemistry, microclimate, and tree root colonization by mycorrhizal fungi.

Tree seedling spatial patterns relative to conspecific adults were consistent with the early stages of upslope migration for boreal conifers (particularly in canopy gaps) but not for temperate deciduous species (regardless of canopy environment). Greater canopy tree mortality and openness in high-elevation forests supported conifer seedling establishment upslope of conspecific adults. Seedling distributions were related primarily to climate, and secondarily to edaphic conditions. Diverse tree seedling banks were associated with the high diversity of other understory plants. Tree seedling associations with other plants were more numerous in species rich low-elevation forests and less common (and more positive) in species-poor high-elevation conifer forests. The moss layer supported higher tree seedling abundance and diversity at high elevations, while the high cover of understory vascular plants had an opposite effect at all elevations. Tree seedlings formed complex interaction networks with other plants and fungi along climate-edaphic gradients, suggesting that the entire forest community needs to be considered when predicting or managing climate-induced tree migrations. Observational gradient studies play an important role in improving our understanding of climate-induced tree migrations.

Use of Satellite Imagery for Monitoring Land Cover Changes in a Taiga Region of Canada Subjected to Climate Change

T5.28 Predicting the future of forest ecosystems from contemporary spatial patterns

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Abstract: Satellite imagery has become an important tool to monitor and map land cover changes. There are currently archived millions of satellite images with a nearly continuous record of global land surface data since their inception. In this study, we used Landsat optical imagery acquired in 1984-1985 and 2019-2020 and topographic variables to assess the land cover changes along the eastern coast of James Bay in Eeyou Itschee (Québec, Canada). With the 2019-2020 map, Sentinel-1 SAR imagery was also used. These images were classified by applying the Random Forests classifier. The classification overall accuracies of 93.7% and 97.9% were achieved for the 1984-1985 and 2019-2020 images, respectively.

Significant land cover changes occurred between 1984-1985 and 2019-2020. The greatest decline was observed in the bareland vegetation class. Tidal flats, shrublands, fens with very low vegetation and tundra or health cover also experienced declines. The greatest increase was observed in the burned areas. Deciduous forests, bedrock, shrub fens and muskegs also experienced an increase greater than 100% over the period.

The changes in the land cover are the result of three main factors. Firstly, there is a northward migration of forest cover and tundra vegetation, mainly in response to climate change. In addition, intolerant broadleaf forests and shrubs have replaced areas of coniferous forests due to the recent increase in wildfires. Local climate warming would also be responsible for the melting of discontinuous permafrost, causing an increase in the areas covered by muskeg. Secondly, the James Bay coast is subjected to a postglacial isostatic rebound, characterized by the rise of the land over the sea level, replacing tidal flats by marshes and various classes of terrestrial vegetation. These land cover changes impact the wildlife that inhabits or migrates through the area and indirectly on the native human communities that depend on these natural resources.

T5.29 Role of university and experimental forests in the forest education and long-term forest research

Asian network of long-term forest monitoring in university and experiment forests

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: Long-term monitoring and inventory data are important in changing environments. Many projects aim for long-term forest monitoring; however, few continue for a long term due to lack of funding and labor. Forest research organizations and university forests have an advantage in this regard. Especially university forests because they manage their own forests. The University of Tokyo Forests (UTF) has accumulated long-term monitoring data, such as meteorology and hydrology data, permanent plot data, plant and animal inventory data, and others for a long period of time. In 2016, UTF started networking with Asian university forests for long-term forest monitoring, including Seoul National University (South Korea), National Taiwan University (Taiwan), Kasetsart University (Thailand), Universiti Malaysia Sabah (Malaysia), Hainan University (China), Universitas Gadjah Mada (Indonesia), and University of Sri Jayawardenepura (Sri Lanka). These universities hold or manage university forests and research sites in different climate and vegetation zones of the Asian monsoon region. The network aimed to promote the development of long-term research field stations for stable and continuous monitoring and to establish a multilateral research cooperation network between the core institutions. Collaborative research has been done by the three research groups (RG): Climatology and hydrology, Ecology and biology, and forest management. Six plenary symposia, three plenary workshops, and two interim symposia were held. In 2019, two RG workshops focusing on hydrology and bark and ambrosia beetles were held in South Korea and Taiwan, respectively. Even during the COVID-19 pandemic, online collaboration continued. The project produced two special issues the Journal of Forest Research and the journal Water, and three books. A booklet introducing experimental watersheds and weather stations in Asian University Forests Consortium was also published.

Elevating visitor management in a protected area through visitor profiles: The case of Make it Makiling

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: The Mount Makiling Forest Reserve (MMFR) a protected area under the management of the University of the Philippines was declared as an ASEAN heritage park in 2013 and has implemented an intensive visitor management program that is based on volunteerism among its stakeholders including the university students. The visitor management program entitled, "Make it Makiling!" is an annual activity implemented particularly during the Catholic observance of the Holy Week when daily visitors to the forest reserve average around 1,200 per day. The goal of the program includes deepening awareness and appreciation of visitors on the value of mountain ecosystems; promote ecotourism practices; ensure visitor safety and enjoyment; and encourage volunteerism in the conservation of mountain ecosystems. The study highlights conducting annual exit surveys by student volunteers to establish visitor profiles and using it as a feedback mechanism towards improving the visitor management program. Variables such as socio-demographics, motivation, preferences, perception, and suggestions were solicited through the visitor survey. The paper chronicles how the information is used to design and implement innovations every year. Specifically, improvements on interpretation materials and waste management measures were made. After four years of its conduct, organizers of "Make it Makiling!" has mainstreamed its implementation and integrated its results in planning for the program.

Filling the gap in project management competences in forestry research projects: a scoping study

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: Project Management (PM) is the use of specific knowledge, skills, tools and techniques to ensure the fulfillment of project objectives in scope. PM contents has been included in the last years in many University degrees related to forestry, engineering and life sciences, as well as in specific bachelor's and master's degree programmes. As the earlier study programmes usually did not include these contents, many of the researchers who are currently managing research projects has not been trained in PM. Is therefore of interest to know how researchers with different levels of knowledge in PM face the challenge of managing research projects. Another key issue is to evaluate the knowledge and us of PM tools and techniques by the different rols in the project governance structure, such as the PI, the research team, or external partners, but also by research agencies and project funding and evaluation institutions. Even though eventual knowledge gaps in PM could be filled in doctoral study programs, it is currently unknown the extent to which these contents should be covered to provide training tailored to the researcher's needs.

The main goals of this research are: 1) to know the degree of instruction received in PM, 2) the knowledge of tools and techniques of PM, and 3) the perception of importance of different PM tools and techniques by researchers, as well as the need of improvement in training in the field of forestry research by comparing to other research areas. We elaborated an online survey, which was distribured among scientists responsible of managing research projects in different areas, including forest research organizations, Universities, and research institutions. The survey was divided into three groups of questions related to: 1) the level of training in PM, 2) the level of use and knowledge of different tools and techniques of PM, and 3) the perception of importance and knowledge gaps of different tools and techniques of PM when applied to research projects.

This study raises awareness of the importance in knowledge and skills of PM, incorporating improvements in the organization of forestry research and doctoral study programs.

Learning from Talking Trees How Climate Change affects Trees and Forests

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: Climate change is affecting forests, trees and ecosystems of different species in many ways. Besides, complex topographic conditions may modify the impact of climate change on forests regionally, depending on the position of an ecosystem in the luv or in the rain shadow of mountain regions or on altitude. Knowledge of students and of the general public, however, is limited on how local environmental conditions may affect the response of trees to climate conditions.

By combining climate modelling, dendroecology, and educational research, the interdisciplinary project BayTreeNet studies the local climate dynamics in Bavaria (southeast Germany) in new approach. The study area shows a complex topography, with middle and high mountain regions and dry basins between. To explain interconnections between weather situations and forest ecosystems in Bavaria, we implemented internet-connected "talking trees". Ten of those trees accessible to the public were equipped with a sap-flow sensor, electronic dendrometers and an internet-based transmission unit. School classes interpret the real-time tree responses to changing weather conditions and on-site weather data, and translate the current tree responses into simple text messages via "Twitter". All weather data, tree data, and explanatory text messages are displayed on the project Homepage https://baytreenet.de. By comparing the different activities of trees within the network, the local tree responses to current weather conditions can be related to specific weather types with specific local response patterns. Such an approach allows a deeper understanding of climate change and local ecosystem responses.

By forecasting the probable future frequency of specific weather types using a climate modelling approach, tree responses future occurrences of weather patterns can be simulated. For a better understanding of climate change impacts, the educational research will utilize climate modelling results and dendroecological findings to develop an empirically founded teaching concept. We present the main concepts, methodology and results concerning student learning progress and citizen science about climate change impacts on forest ecosystems.

Long-term monitoring sites for forest stand dynamics research and education at Seoul National University Forests, Korea

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: Long-term monitoring enables to detect changes in forest ecosystems and effects of forest disturbances, thus one of key activities in forest sciences. University forests are ideal sites for long-term research thanks to long-lasting researchers including professors, researchers, graduate students, and university staffs from several years to decades. Thus, many university forests are a key hub for long-term research including long-term monitoring. Seoul National University Forests consist of three regional university forests and two of them maintain long-term monitoring sites. Long-term monitoring has been conducted to understand changes in tree species composition, forest structure and disturbance effects in secondary broadleaved forests and *Pinus koraiensis* plantations in Taehwa University Forest, and an *Abies Koreana* dominant stand and riparian forests in Nambu University Forest. Permanent plots that ranged from 20 m x 20 m to 1 ha plot were established in the long-term monitoring sites. Annual monitoring includes tree species, diameter at breast height (DBH), and tree demographics (death and ingrowth). The long-term monitoring sites were used for class programs as well. Classes including forest ecology, silviculture, tree physiology, and hydrology have actively used those long-term monitoring sites. We have observed effects of disturbances on stand structural changes and different patterns of temporal changes in species composition among sites. The impact of typhoons increased with tree height in sites in plantations. Rates of changes in species composition and stand structure differed depending on stand developmental stages and elevational locations. Gap creation by windthrow at high elevations decreased tree species and increased subtree and shrub species recently. The findings provide insights into changes in forest structure and contribute to the knowledge for forest management. Long-term monitoring sites of university forests were used by researchers from various organizations, thus provide excellent basis for both domestic and international research cooperation. Maintaining long-term monitoring sites costs quite budget and efforts. Active investment and research cooperation would help to strengthen the role and function of long-term monitoring in university forests, which have contributed to education of younger generation and innovative technology in forestry.

Long-term silvicultural, ecological, and meteoro-hydrological data and research at the University of Tokyo Hokkaido Forest, northern Japan

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: The University of Tokyo Hokkaido Forest (UTHF) was established in 1899, having 22,717 ha of forest in northern Japan. UTHF has collected and analyzed extensive long-term data relating silviculture, ecology, and meteoro-hydrology under an organizationally stable observation system. This paper presents the types and contents of long-term data accumulated at UTHF through forest management and monitoring, as well as research outcomes. In 1958, UTHF initiated a long-term experiment of the stand-based silvicultural management system on a business-scale. Natural forests are classified into several management types, with single-tree selection harvest as the primary silvicultural system. Each year, the UTHF staff conducts a ground forest survey for spatially explicit stand classification, field measurements of forest inventory plots, and single-tree selection for harvest. These operations have enabled the recording of stand-level information for silvicultural planning and management for over 60 years. Additionally, UTHF has recently incorporated the use of unmanned aerial vehicles to capture aerial photographs prior to each forest management planning session. To assess the effects of the silvicultural managements, UTHF has established more than 100 permanent plots within both managed and unmanaged stands. Furthermore, to understand the structure and dynamics of unmanaged forest ecosystems, UTHF established two core long-term ecological research (LTER) plots in the 1990s. The Maeyama plot covers 36.25 ha of hemiboreal forests dominated by boreal conifers and deciduous broadleaves, which is the largest forest plot in Japan. The Iwanazawa plot also covers a large area (18.75 ha) in a riparian cool temperate forest, where genetic structure and gene flow of some riparian tree species has been analyzed. Since 1914, meteorological observation has been conducted at several weather stations, revealing significant patterns of climate warming in UTHF. In 1985, four years after a massive typhoon disturbance, a gauging weir was established in the Maruyamasawa experimental watershed for evaluating the effects of forest recovery and succession on water-related ecosystem services such as low-flow and flood-flow mitigations.

Relationship between microclimate and forest canopy characteristics using lidar data

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: Since the shade of trees reduces direct sunlight, lowers temperatures, and maintains moist conditions, forest canopies protect understory plants by buffering against climate change. In addition, the complexity of canopy structure creates a heterogeneous microclimate on microscopic spatiotemporal scales. Under the extreme climate condition to come, the gentle microclimates provided by canopies can act as microrefugia that serve as havens for species in unfavorable local conditions. These buffers aid to conserve ecological functions and forest biodiversity. Therefore, it is important to understand how the characteristics of forest canopies, such as cover and structure, are related to their effect on mitigating harsh climate conditions. Our study aims to (1) determine the best resolution for indicating the relationship between canopy characteristics and microclimate and (2) identify the most influential canopy characteristics. The study was conducted in the academic forest located in Gyeonggi province, South Korea. We used both UAV and Backpack LiDAR for data collection on the canopy structure and topology. A thermal imaging camera was employed to measure land surface temperature, as a proxy for microclimate. We generated data at 0.5 m, 1 m, 5 m, and 10 m resolutions to analyze the relationship between land surface temperature and canopy characteristics data, and then we identified the most significant variables. The result showed that the data at a 5 m resolution had the highest r-squared value (0.58). We could not observe a consistent pattern in the accuracy of the analysis for other resolutions. Tree crown height was the most important factor followed by canopy variance, LAI, and canopy cover. Despite the relatively low r-squared value, we found a suitable resolution to assess the relationship between land surface temperature and canopy characteristics. Further research is needed to validate the consistent results across a broader spatial context. In addition, since land surface temperature can be influenced by other climates such as wind and moisture, considering the climatic factor would also be essential.

Seedbed for Applied Silviculture: Fostering Early Scientific Training of Young Foresters for the Southwest Colombia's Forest Ecosystems

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: Research seedbeds have emerged as a learning strategy that allows students to address real technical problems through autonomous learning, collaborative work, and the production of scientific knowledge under the guidance of seedbed tutors. In 2018, the Seedbed for Applied Silviculture was established within the Forest Engineering program at the University of Cauca in Popayan, located in the southwestern region of Colombia with the aim to consolidate the scientific initiation of forestry students. The southwestern region of Colombia encompasses diverse natural forest ecosystems and forest plantations, offering significant research opportunities. However, it also present substantial challenges in terms of conservation and management. Currently, the seedbed consists more than 20 students at different stages of their academic careers, all engaged in research across four main lines of investigation: 1) Native species propagation for ecological restoration of degraded areas, 2) Assessment of the impacts of forest plantation establishment on flora, fauna, and landscape in cattle ranches of southwest Colombia, 3) Exploration of the dendrochronological potential of native species for hydroclimatic reconstructions and forest management planning, and 4) Silviculture, management, and wood technology of native Podocarpaceae species for their utilization in commercial timber, biomass, and pulp production. The seedbed has successfully supported the completion of nine undergraduate theses, involving a total of 15 students. Additionally, the progress of three ongoing master's theses, and the preparation of six research papers, which have been submitted to peer-reviewed journals and are currently undergoing the process of review. Engagement in the seedbed has resulted in benefits for students' academic performance, as evidenced by improved grades in their courses, increased opportunities to pursue advanced studies at the master's level, and enhanced employability. Our experience with the seedbed demonstrates that this learning approach strengthens investigative skills through collaborative work, motivating students to delve deeper into their fields of study through research, diverging from traditional formalist methodologies in classrooms.

The training and experimental forests in Estonia ─ more than 100 years of experience

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: Higher forestry education started in Estonia in 1920, when the Department of Forestry was established at the University of Tartu. It only took a year, and already the students had the opportunity to do summer courses in the university's own training forest.
The presentation gives an overview of the role of the Järvselja training and experimental forest, which is inextricably linked to higher forestry education in Estonia. The presentation is based on numerous writings written by different authors about this symbolic object of Estonian forestry. The changing role of training and experimental forests in different decades is discussed, starting from the initial concept and gradually moving today's position in forest science and education. Moreover, in addition to the academic contribution, at certain decades the training and experimental forest centre transformed to the centrum of the local community.
Using the example of the Estonian University of Life Sciences, the management and operating model of the forest centre is shortly described and analysed. Approximately 10,500 ha of forest owned by the university is managed by an independent foundation. The strengths of the symbiosis between the university and the forest centre can be highlighted as the continuity of long-term research, the preservation of experimental areas and continuous monitoring, which can unfortunately sometimes be interrupted in commercial forests.
Activities in the current century are characterized by new research directions and the establishment of modern infrastructure for this purpose, e.g. the Station for Measuring Ecosystem-Atmosphere Relations (SMEAR) and Free Air Humidity Manipulation (FAHM) experimental site.
The experimental forests serve as a micro-model of sustainable forest management, where a balance is sought between management, nature conservation, social and cultural activities. Over the course of a century, related organizations have been reorganized and generations of researchers have changed, but the goals of the partners have remained largely the same: to provide new knowledge about forests and their management.

Universitas Padjadjaran arboretum offers biodiversity resources for long-term research and education

T5.29 Role of university and experimental forests in the forest education and long-term forest research

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Abstract: Higher Education Institutions (HEIs) can contribute to protecting biodiversity by undertaking conservation projects within their campuses or nearby areas. The Universitas Padjadjaran (Unpad) in West Java, Indonesia, is an example of a HEI that has established an arboretum within its main campus, covering an area of approximately 10 hectares. West Java is also one of the most biologically diverse regions in Indonesia, with a rich variety of flora and fauna. The arboretum has developed various ecosystems over the past two decades, including farmland, lakes, and forest with four springs which provide various ecosystem services. This arboretum has been found to be home to a diverse range of plant and wildlife. There are several collections of endemic plants such as *gayam* (*Inocarpus fagifer* (Parkinson ex F.A. Zorn) Fosberg), *bisbul* (*Diospyros discolor* Willd.), *kecapi* (*Sandoricum koetjape* (Burm.f.) Merr.), *lame* (*Alstonia schoolaris* (L.) R.Br. and *lobi-lobi* (*Flacourtia inermis* Roxb.). Interestingly, ten species of bamboos in Arboretum Unpad have been identified and consisted of four genus such as *Bambusa*, *Gigantochloa*, *Phyllostachys*, and *Schizostachyum.* We have documented 46 birds, 9 amphibians, 16 reptiles, and 16 butterflies. The arboretum is also as corridor for migratory for raptor groups such as crested honey buzzard (*Pernis ptilorhynchus*), Chinese sparrowhawk (*Accipiter soloensis*), crested goshawk (*Accipiter trivirgatus*). Some species as food sources for birds such as *Ficus benjamina* L., *Ficus fistulosa* Reinw. ex Blume, *Antidesma bunius* (L.) Spreng., and *Canarium indicum* L. The high biodiversity present on the campus provides an excellent opportunity for young scientists to conduct long-term research. To ensure the sustainability of such research programs, the establishment of a forest dynamic plot is crucial. Additionally, to promote biodiversity knowledge and encourage conservation efforts, ecotourism programs were provided to the public which can have a significant impact on society. Consequently, universities are not only focused on providing quality education but also on establishing a more environmentally friendly campus environment to gain a competitive advantage. It is essential to note that investing in sustainability can lead to significant cost savings for universities in the long term.

T5.30 Simulation and automation in modern forest operations

A discrete-event simulation approach to evaluate harvesting operations on steep terrain with winch-assisted mechanized felling and grapple yarding

T5.30 Simulation and automation in modern forest operations

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Abstract: Harvesting operations in steep terrain in Chile are typically performed by manual felling and traditional cable yarding systems. Due to increasing concerns to improve workers' safety and productivity levels, fully mechanized operations are increasingly being adopted. In these operations, felling is performed by winch-assisted shovel loggers and yarding by skylines systems with grapple carriage. In these systems, the shovel logger is tasked with felling and bunching trees and placing piles directly under the yarding line, and shoveling piles to subsequent adjacent felling lines. We developed a discrete-event simulation approach to simulate the harvesting operation by replicating the complete work sequence of both machines. The approach requires the following inputs: i) an implicit field observation-based abstraction of the machines' work to define work cycles and the manner in which machines move throughout the harvest unit, ii) estimation of lines installation times and of machine work times for both machines, iii) digital georeferenced layers including a digital elevation model, planned felling and yarding lines containing the sequence in which machines will operate along these lines, and tree locations with volume data per tree, and iv) general parameters of both machines. The approach generates: i) digital layers including tree assignments to work positions (locations from which the machine while stationed is felling, pilling, or shoveling trees without travel), felling lines, yarding lines, and volume piled under each 5-m segments along yarding lines, and ii) shovel logger reports with estimations of work time (PMH), felled and shoveled volume (m^3), and productivity (m^3/PMH) aggregated by work position, felling line and day, and yarder reports with work time (PMH), volume (m^3), and productivity (m^3/PMH) aggregated by 5-m yarding segments, yarding line and day, and final report with productivity and operating time (PMH) required to harvest the unit. The approach was implemented as an add-in for ArcGIS Pro V2.4 and applied to a timber harvest setting in south-central Chile to show its functionality. The iterative use of the approach can be used to evaluate alternative placement and the number of felling and yarding lines as support decision-making on operational timber harvesting planning on steep slopes.

Application of mathematical models for the optimization of harvestable wood of the species Clathrotropis brunnea Amshoff.

T5.30 Simulation and automation in modern forest operations

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Abstract: Mathematical models for timber volume optimization in Colombia are a tool that have been recently explored, given the need to promote solutions that contribute to the planning and management of timber resources, it's considered essential to promote these tools in forest management areas in order to provide information on native species of economic importance, facilitating the efficient use of resources and ensuring sustainable use.

The main objective of this research was to propose a prescriptive mathematical model based on linear programming principles for the allocation of cutting patterns, maximizing the volumetric yield of Clathrotropis brunnea logs. With the cubing data obtained in the field, a tapering model was adjusted to predict the diameter at any height of the trunk, in this way a cutting simulator was designed in MATLAB software version 9.3 that integrates in a script the mathematical modeling, where the user defines the length of the log and in an automated way the program assigns efficiently the cutting patterns according to the diametric class.

The result was the adjustment of the tapering model capable of explaining 85% of the data that make up the forest profile of the species, where the root mean square error (RMSE) was 4.02, the mean absolute error (MAE) was 2.95 and the predictive efficiency indicator was 89%.

It was possible to identify that the proposed model presents increases of up to 20% in volumetric performance. The results of this research are remarkable because they provide methodological and practical elements in the use of mathematical models as planning tools in harvesting, facilitating the analysis for trees of the same species, allowing to know before harvesting the commercial volume of individuals, the amount and types of products that are generated considering or not a market demand, with this method the subjectivity of the decision makers is eliminated and an adjustable cutting plan is provided according to the user's requirements.

Automation of the measurement process of stacked roundwood – Past milestones, current status and perspectives

T5.30 Simulation and automation in modern forest operations

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Abstract: The measurement of roundwood plays a crucial role in its acquisition phase, since the volume is the basis for billing. As the costs derived from the acquisition process range approximately from 60% to 85% of the final product costs, the accuracy in this process is of utmost importance. In addition, the measurement of roundwood is a further important aspect to quantify the stored carbon (CO_2) extracted from those forest stands in the current context related to climate change.

In many countries, this process takes place in landings. Traditionally, the stack volume has been estimated using manual methods. Moreover, the real volume of stacked roundwood has been measured manually by adding the individual volume of each stacked log or estimated using conversion factors, which were calculated empirically based on statistical bases. Those statistical bases were limited due to the high costs required for collecting sufficient data. Thus, those traditional methods were costly, time-consuming and prone to provide inaccurate estimations.

However, the successive implementation of new technologies has increased the accuracy of the estimations of the gross and net volumes of the stacks as well as the efficiency of the measurement process, estimating the gross volume of the stacks in shorter periods. Whereas the photogrammetric methods have been providing reliable estimations of the gross volume as well as the stacking densities for the last years, LiDAR data-based methods have newly been developed, which also provide reliable stack volumes. 3D simulation models have recently been developed to estimate reliable and accurate specific conversion factors for each tree species and assortment based on wide statistical bases. Finally, the implementation of Artificial Intelligence in this field is currently emerging and crystallizing in new promising automatic methods for reliably estimating the gross and net volumes of the stacks.

This presentation will offer the audience a comprehensive overview of the methods currently used in Europe and America for measuring the stacked roundwood, a historical review and the perspectives and potential concerning the development of new measurement methods in the near future. Moreover, the main advantages and disadvantages of the methods will be described.

Digitalized and (semi-) automated design of cable roads by combining different sources of geospatial data and high precision mechanical analysis

T5.30 Simulation and automation in modern forest operations

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Abstract: Cable-based technologies have been a backbone for harvesting on steep slopes. The planning of a cable road is a complex task. It essentially comprises the definition of the start and end points of a cable road, as well as the intermediate supports. It must be ensured that the permissible forces (in particular skyline tensile forces) are not exceeded, that there is a sufficient clearance between the load path and the ground, that suitable anchor trees are found and that at the same time the number of intermediate supports is minimised as far as possible. On the other hand, for ergonomic and silvicultural reasons (work safety, damages to the forest), the skyline should be as high as possible. In practice, the search for a solution is often iterative; especially with long lines, several attempts may be necessary until a good line is found.

We will present a QGIS plugin ("Seilaplan") that assists in designing cables roads by searching automatically for the optimal cable road layout. However, it also allows a manual editing of the cable road. As the plugin is embedded in a GIS system, elevation data can easily be accessed and incorporated. Further, of particular relevance is also the integration of individual tree data and vegetation height models in order to identify suitable supports and anchor trees already in the office. The plugin is designed for Central European conditions and assumes a standing skyline (fixed anchored skyline at both ends). For the calculation of the mechanical properties of the skyline a close to catenary method is used. When testing the feasibility of the cable road, care is taken that 1) the maximum permissible stresses in the skyline are not exceeded, 2) there is a minimum distance between the load path and the ground and 3) when using a gravitational system, there is a minimum inclination in the load path. The newly developed method calculates the load path curve and the forces occurring with a high accuray.

The presented qgis plugin is a key element towards digitalization in forest operations in steep terrain and already widespread in Switzerland.

Experts' preferences for future machine systems

T5.30 Simulation and automation in modern forest operations

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Abstract: The two-machine system, with the harvester and the forwarder, have dominated the Swedish logging operations during the last four decades. There have been attempts with other systems without wide success. Technology for automation, remote operations and other energy carriers than diesel have developed significantly in other sectors recently, opening for similar development of forest machines and systems. However, which technologies and which machine systems to combine them in, have not been evaluated recently. This study aimed to map potential future machine systems on concept level for logging costs 10 years from the study's data gathering, and further to provide a basis for decisions on which system has enough potential for further evaluations with a higher level of materialization. The study was designed with a Delphi-approach, where 10 participants anonymously answered questions on a website. The participants worked with development in forest companies, a forest owners association, and a forestry research institute. The questions were about: 1) Ranking which criteria they valued the most, such as safer working environment and lower total costs, when choosing future machine systems. 2) Grading the likeliness for statements about external factors state in 10 years, such as whether they agreed or disagreed that diesel would be more available and the availability for automation would increase. 3) Ranking of a set of machine systems with different combinations of technologies. The participants responded to each set of questions two times, and saw the groups average results from the first round, before they answered the second round. The results from the study will be presented, along with interpretations and planned steps towards an increased level of materialization for the most promising machine systems.

FOMO: A forest operations annotated image dataset

T5.30 Simulation and automation in modern forest operations

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Abstract: FOMO-AID: An annotated image dataset for forest operations

The transformation of forest operations through the integration of computational technology and machine learning promises significant increases in efficiency and innovation. Yet, the full potential of these technologies, particularly computer vision (CV), remains untapped due to the scarcity of comprehensive, annotated image datasets for algorithm training. This limitation impedes automation, reliable decision support, and innovation in forest management.

To address this challenge, we are developing the Forest Operations Machine-Optimized Annotated Image Dataset (FOMO-AID). We are advancing the field of research with our novel image annotation methodology. This method involves augmenting the StanForD communication system of forest machines with data captured by onboard cameras. These images are then processed and automatically annotated, contributing to a more comprehensive understanding of the machines' operational environment.

The FOMO-AID dataset serves as a valuable resource for training and testing CV models, encompassing a broad range of forest conditions and operations. In the spirit of open science, we aim to openly publish the FOMO-AID dataset to stimulate innovation and encourage the adoption of state-of-the-art CV technology in forest operations.

Global route planner adapted for autonomous forest regeneration of mixed tree species

T5.30 Simulation and automation in modern forest operations

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Abstract: Introducing mixed species stands offers a promising solution to mitigate the risks associated with monocultures and unlock a multitude of benefits. However, the implementation of such stands presents its own set of challenges, including the need for complex management and increased costs.

One way to overcome these challenges is to introduce autonomous forest regeneration systems. Through high sensing capabilities and precise auxiliary tools, such systems will have the capabilities to manage the intricate variations within the site and incorporating mixed species stands.

Through the research presented in this paper, a specialized route planner has been developed specifically for the sequential planting of mixed tree species. Based on pre-generated maps of areal tree species distribution, this planner generates routes taking machine properties, such as seedling capacity, arm reach, and turning radius into account. These routes should enable the required autonomous regeneration work in such a way that the pre-generated species distribution is achieved with low climate footprint and still with high efficiency.

The assumption was made that the autonomous forest machine can smoothly transition between different species, and the seedlings are picked from cassettes. The machine has a limited capacity for accommodating a certain number of cassettes. Prior to executing the planting in a specific area of the stand, the machine provides information on which cassettes should be loaded.

Results show that the routes are planned so that the vehicle does not drive over sections where planting has already taken place or other no-go areas, while still being able to perform the regeneration task.

It can be concluded that the route planner developed in this research enable sustainable autonomous precision forest regeneration.

Learning forwarder trafficability from real and synthetic data

T5.30 Simulation and automation in modern forest operations

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Abstract: Forwarder trafficability is a function of terrain and vehicle properties. Predicting trafficability
is vital for energy efficient planning- and operator-assisting systems, as well as for remote and autonomous driving. Inaccurate or insufficient information can lead to inefficient paths, excessive fuel usage, equipment wear, and soil damages. Training trafficability models require data in a quantity hard to collect solely from in-field experiments, especially considering the need for data from situations ranging from very easy to non-traversable.

To circumvent this problem, we perform in-field system identification for a forwarder in the Nordic cut-to-length system, to obtain a calibrated multi-body dynamics simulation model traversing firm but potentially rough and blocky terrain. By letting the real-world forwarder drive in very difficult terrain, the model is able to reflect a wide range of real conditions. The model is used in simulations, where collecting large amounts of data from a variety of situations is easy, cheap, and hazard free. Using this data, a deep neural network is trained to predict trafficability in terms of attainable driving speed, energy consumption, and machine wear.

The resulting predictor model uses laser scanned terrains to efficiently produce trafficability measures with high fidelity and accuracy, e.g., depending on the vehicle's precise location, speed, heading, and weight. Trafficability on wet and weak soil is not addressed in this work. The predictor model is machine specific, but general enough for practical application in diverse terrain conditions. Our emphasis on energy consumption enables elaborate calculations of emissions, profoundly contributing to sustainable forest operations. Apart from the benefits from reduced emissions, the model can also be used to optimize extraction trail routing, which is a major contributor to the total extraction cost. Rough terrain trafficability is only part of an optimal route, but it has been neglected in previous research. We see big potential in combining our predictor model with existing route optimization methods to achieve a more complete result. By creating an open library of annotated machine data and code for preparing input terrain-data and running the trafficability model, we enable adoption of the results by others and application in existing and new software.

Optimizing Support Systems for Cut-To-Lenght Machine Operators - Current Use and Future Visions

T5.30 Simulation and automation in modern forest operations

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Abstract: Cut-to-length (CTL) timber harvesting machines have information systems, assisting systems, and decision support systems to help the operators with productivity and overall operational performance. These support systems alongside machine engineering and harvest work implementation are associated with ergonomics, and they have the power to increase or decrease operators' work ability, productivity, and work fluency with exact and essential or overwhelming and irrelevant information. Timber harvesting operations have a clear demand for easing the harvesting work, lowering the threshold for beginners, and supporting professionals to longer their work careers. Gaining a deeper understanding of operators' perspectives on technical development and solutions can help address and overcome the challenges in the CTL machine development work toward automated systems. This study investigates decision-support systems currently used by operators, how they utilize them, the difficulties they encounter in their daily work, and their visions for the future support systems based on their experiences.

The study utilizes elements of the contextual interview method by interviewing operators via phone while they are actively working. This approach allows operators to connect their thoughts and experiences closely with their work, which makes it easier for participants to explain and demonstrate tasks while working. Furthermore, it prompts participants to discuss tasks or actions that they may overlook or forget to mention in a traditional interview setting. The interview questions cover topics related to current work methods, work demands, and work challenges, and the interviewees rate different future visions of technical solutions and assisting technologies on a scale of -3 to +3. The participants selected for this study are based in Finland and operate either new or relatively new machines to ensure their familiarity with the latest technological advancements. The participants' age and work experience vary.

This study highlights the operators' perspective on the future visions of the CTL machines, the development needs for automatization, and improved human-machine interaction. The research results provide insights into the operators' viewpoint regarding the effectiveness of the existing (decision) support systems and technical solutions, as well as challenges and obstacles on operational performance and productivity.

Pathfinder – A decision support tool for operational planning of integrated mechanical site preparation and planting on forest regeneration areas

T5.30 Simulation and automation in modern forest operations

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Abstract: Manual planting is arduous and mechanical site preparation includes a high dose of whole-body vibrations when traversing the terrain. At the same time, there is an evident lack of skilled labor in silviculture operations in boreal forestry. Efficient regeneration methods are crucial to sustainable forestry, and in Sweden, where 99% of the planting is manual, the interest in mechanized planting is rising. Autoplant is a collaborative project among Swedish forest companies, manufacturers and researchers within silvicultural technology. The aim is to develop an integrated autonomous scarifying and planting system with high precision, low environmental impact, and a good work environment. A decision support tool, Pathfinder, was developed for the operational planning of the forest regeneration, including route planning for the machine. Pathfinder consists of two modules. The first module relies on harvester production data, digital elevation models, depth-to-water maps, soil data and so-called no-go areas for culture or nature conservation. It proposes the net area that will be subjected to scarification and planting, as well as which species to plant in different zones of the area together with desired density. The second module uses the output from the first (boundaries of the net area and plant density) together with DEM (critical slope), forcing passages (e.g., temporary bridges), and machine data (e.g., machine working width, maximum slope, loading capacity, and time for U-turns) as input. There are various factors to consider when improving route efficiency for the machines, among which minimizing the number of U-turns is crucial. A multi-step solution approach is developed to find optimal routes. The main steps include finding common directions of slope, combining shorter paths into longer and then combine them into full routes. Finally, the model suggests a set of vehicle routes considering planting and/or fuel capacity of the machine. These routes make up the overall planting solution that the machine follows, either autonomous or with an operator. The tool is tested on clearcuts throughout Sweden (3-10 ha). The results have been validated in the field both by researchers and forest owners.

Pioneering Automation in Forestry: AORO's Crane Automation Journey and Implications

T5.30 Simulation and automation in modern forest operations

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Abstract: In recent years, automation technology has been transforming various industries, and now it has reached the realm of forestry with the groundbreaking development of AORO – the world's first fully unmanned forestry machine capable of performing forwarding tasks without human supervision. This achievement marks a significant milestone in the evolution of forestry operations and holds immense potential for revolutionizing the industry.

AORO is equipped with an array of sensors integrated into both the vehicle and the crane, enabling it to operate autonomously. Leveraging a range of advanced robot algorithms, including computer vision, localization, object recognition, and motion control strategies, AORO achieves full autonomy by enabling precise navigation and crane control.

In this engaging presentation, we will provide a comprehensive overview of the process involved in automating the crane of AORO, which is the culmination of nearly two decades of research. We will delve into the intricacies of the various sensors and algorithms employed to accomplish this feat. By elucidating the technical details, we aim to offer attendees a deeper understanding of the complex automation systems that underpin the functionality of forestry cranes.

To support our claims and illustrate the capabilities of AORO, we will present experimental results obtained during the development process. These results will not only serve as evidence of the progress made but also highlight the challenges encountered along the way. Moreover, we will outline the innovative solutions that were devised to overcome these obstacles, showcasing the ingenuity and adaptability of the research consortium.

Beyond the specific achievements of AORO, our presentation will address the broader implications of automation technology in the forestry industry. Drawing parallels with similar algorithms implemented in industrial setups, we will underscore the potential for automation to revolutionize forestry operations. By reducing the reliance on human intervention, automation can enhance efficiency, minimize safety risks, and optimize resource utilization. We will discuss the transformative impact that automation can have on the forestry industry, paving the way for a more sustainable and productive future.

SENSING TECHNOLOGY AND AI ALGORITHMS FOR DETECTING TREE QUALITY FEATURES AND OPTIMIZING BUCKING DURING HARVESTING OPERATIONS

T5.30 Simulation and automation in modern forest operations

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Abstract: Achieving the highest value from a plantation resource is reliant on quality, timely and accurate measurement of key-value influencing tree quality features (e.g. sweep, branchiness) to support optimized stem bucking decisions. Due to the difficulties associated with the measurement of tree quality features in the field during forest inventory work, these attributes are usually excluded from optimal bucking procedures. At harvest time, in addition to diameter and length measurements, current onboard machine optimization systems rely on operator assessment of other key features like stem sweep, limb diameter, limb angle, and internal characteristics like stiffness and strength. These repeated observations, judgments and operations performed by the operators may result in reduced productivity and value losses. Emerging and new sensing technology like LiDAR, photogrammetric point clouds, and high-definition stereo imaging, represents an opportunity to leverage more accessible and affordable data collection to capture some of the factors that are currently estimated by operators with accurate measurements and improve the value recovery.

In our study, we present a non-destructive, automated methodology to optimize stem bucking based on point cloud data acquired with a mobile laser scanner (Hovermap LiDAR system), which maximizes tree value. The raw point cloud was processed with machine learning algorithms, which enabled the automatic detection of the trees in the plot as well as the estimation of diameters at different tree heights and stem sweep. This information was then used as an input to a dynamic programming bucking algorithm which optimized the value of each tree based on market and tree data. The methodology was tested on two Radiata pine plots located in South Australia, consisting of about 50 trees each. The bucking results were compared for three sets of input data: two generated from point cloud data collected with the LiDAR scanner (including and excluding sweep) and one generated from a taper equation based on manual DBH measurements. The metrics used for the comparison included total value, value per product, total volume, volume per product, and the number of logs per product.

Spur road segmentation using text-to-image synthesis for autonomous driving in forest machinery

T5.30 Simulation and automation in modern forest operations

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Abstract: Sustainable forestry operations require addressing safety and workforce challenges, leading to an interest in automation. Autonomous driving in forwarding is a key topic in forestry automation. Safe navigation along the planned path is critical for successful autonomous driving. To achieve accurate autonomous driving, it is necessary to obtain precise information in each navigation process, including sensing and path planning. However, conventional self-localization methods such as Global Navigation Satellite Systems or Simultaneous Localization and Mapping (SLAM) face limitations in a forest. Moreover, it is essential to keep redundant sensing for secure autonomous driving to avoid excessive dependence on single self-localization.

To address these challenges in autonomous driving for forestry, this study proposes a vision-based road segmentation system. The information on the road region serves not only as corrective information during path planning but also as features in SLAM, with broad applicability in autonomous driving in a forest.

The study aimed to develop a system for estimating the drivable area on a spur road using camera images to provide information for self-localization and path planning. Road detection in a forest has already been proposed by using machine learning. However, it is labor-intensive to create a dataset for segmentation. Thus, the proposed method uses text-to-image synthesis to simplify the preparation of the dataset by generating road images in a forest from text and labels. Additionally, it is easy to add the external class to the dataset using text-to-image synthesis. Therefore, the proposed method aims to estimate not only the road class but also the road-edge (buffer) class.

The results showed that the model trained on the dataset combined with the synthesized and real images achieved satisfactory accuracy of 40.8% in the intersection of union for spur road segmentation. A comparison with a dataset from a real forest indicated a 2.24-point improvement in estimation for the newly added class.

In conclusion, this study presented a method for spur road segmentation with easy dataset preparation, thereby contributing to the advancement of autonomous driving in forestry machinery.

Towards autonomous forwarding using deep learning and simulation

T5.30 Simulation and automation in modern forest operations

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Abstract: Fully autonomous forwarding is a challenge, with more imminent scenarios including operator assistance, remote-controlled machines, and semi-autonomous functions. We present several subsystems for autonomous forwarding, developed using machine learning and physics simulation,
- trafficability analysis and path planning,
- autonomous driving,
- identification of logs and high quality grasp poses, and
- crane control from snapshot camera data.

Forwarding is an energy demanding process, and repeated passages with heavy equipment can damage the soil. To avoid damage and ensure efficient use of energy, it is important with a good path planning, adapted speed, and efficient loading and unloading of logs. The collection and availability of large amounts of data is increasing in the field of forestry, opening up for autonomous solutions and efficiency improvements. This is a difficult problem though, as the forest terrain is rough, and as weather, season, obstructions, and wear present challenges in collecting and interpreting sensor-data.

Our proposed subsystems assume access to pre-scanned, high-resolution elevation maps and snapshots of log piles, captured in between crane cycles by an onboard camera. By utilizing snapshots instead of a continuous image stream in the loading task, we separate image segmentation from crane control. This removes any coupling to specific vehicle models, and greatly increases the limit on computational resources and time for the challenge of image segmentation. Log piles are normally static except at the grasp moments and given good enough grasp poses, this lack of information is not necessarily a problem.

We show how snapshot image data can be used when deploying a Reinforcement Learning agent to control the crane to grasp logs in challenging piles. Given pile RGB-D images, our grasp detection model identifies high quality grasp poses, allowing for multiple logs to be loaded in each crane cycle. Further, we show that our model is able to learn to avoid obstructions in the environment such as tree stumps or boulders. We discuss the possibility of using our model to optimize the loading task over a sequence of grasps.

Finally, we discuss how the solutions can be combined in a multi-agent forwarding system with or without a human operator in-the loop.

Will the harvester-forwarder system continue to dominate in Sweden?

T5.30 Simulation and automation in modern forest operations

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Abstract: In Sweden, the cut-to-length logging system consisting of a harvester and a forwarder has dominated harvest operations since the late 80s. Its adaptability to harvesting conditions, such as tree size, terrain, and product specifications, as well as the low interdependence between the harvester and forwarder, are often quoted success factors. However, with advancements in automation, energy carriers, and remote control, emerging machine systems may challenge the supremacy of the harvester-forwarder system.

Our study will support decision-making by simulating alternative machine systems and assessing their viability for further evaluation – in a higher degree of materialization. These discreet event simulations will be conducted using the ExtendSim software. The analysis will incorporate existing productivity functions developed for harvesters and forwarders, as well as the harwarder system whenever relevant. Operating times and downtimes will be modeled using extensive datasets from harvest operations. To estimate the costs associated with each simulated system, we will collaborate closely with forest officials and machine manufacturers.

We will share the potential of the simulated systems and whether further evaluation is recommended. Our study will provide new insights and a foundation for future research and development.

T5.31 Taking advantage of technology in education

A Bibliometric Analysis of the Economics of Restoration Field

T5.31 Taking advantage of technology in education

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Abstract: Bibliometrics is a method for monitoring, measuring, and studying bibliographic data, and it offers valuable insights into the past, present, and future trends in academic literature. This paper presents a bibliometric analysis of the Economics of Restoration as an example of the use of bibliometrics in forest-related disciplines. The analysis focuses on co-authorship, direct citation, co-occurrence, co-citation, and bibliographic coupling networks to explore the dynamics of the Economics of Restoration. While bibliometric studies have been conducted on various topics in environmental sciences and economics, limited research has focused specifically on the Economics of Restoration field. By conducting a comprehensive bibliometric analysis using multiple databases, including Web of Science, Scopus, and Lens, key authors, documents, themes, countries, and productive journals in the field of the Economics of Restoration are identified. The analysis utilizes bibliometric maps made with VOSViewer software. Co-authorship links reveal patterns of collaboration among authors, countries, organizations, or journals, while direct citation links provide insights into the relevance of documents, authors, or journals. Co-occurrence links identify important topics addressed in publications, and co-citation and bibliographic coupling links offer valuable information about the core documents and emerging research topics within the field. The results demonstrate how the application of bibliometrics in the Economics of Restoration provides insights into the evolution of the field, from conceptual and methodological developments to addressing pressing topics such as forest and landscape restoration challenges, climate change, and land use change. Moreover, the analysis highlights advancements in economic valuations and cost-benefit analysis, emphasizing the measurement of benefits derived from restoration efforts. This bibliometric analysis serves as an example of the potential of bibliometrics in forest-related disciplines. It showcases the power of bibliometric techniques in tracking and analyzing research progress, identifying research gaps, emerging trends, and potential areas for future exploration within the field. By employing bibliometrics, policymakers, educators, and researchers in forest-related disciplines can make evidence-based decisions regarding research policies, funding allocation, and curriculum development. Ultimately, the integration of bibliometrics in forest education can facilitate evidence-based decision-making and foster the advancement of knowledge in forest-related disciplines.

Boosting Digital Skills & Competencies in Forest Education: the FOREE Erasmus+ project for digital technologies integration in forest training sector

T5.31 Taking advantage of technology in education

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Abstract: Among the top priorities of the European Policy Agenda there is the enhancement of digital skills and competences for work and life. Indeed, digital technologies improve methods of processing, storing, and transmitting information, while contributing to the creation of knowledge and fostering progress. The forest education sector would benefit by the integration of digital technologies. However, it is important to identify first the issues and the opportunities of partial or total digitalisation, to understand the place of digital technologies in the chain of converting information into knowledge, skills, and competences and to define the ways to support the form and content of the knowledge transfer process.

The Erasmus+ 'FOREE - Boosting Digital Skills and Competencies in Forest Education' project aimed at overcoming the reservations of forestry teaching staff towards digital teaching through knowledge exchange and innovative approaches for conceptualization and implementation of e-learning formats, and at improving further the skills of combining digital learning formats and contents with on-site teaching.

Specifically, the objective of FOREE was to develop National guided pilot Train-the-Trainer course (ToT) and MOOC on blended learning models to guide the transition of the European forestry education sector from purely classroom/field-based courses into a flexible hybrid education system through the complementary use of digital learning concepts, tools and platforms and their broad application in adult forestry training courses. Additionally, the project developed an online and free-access toolbox reporting the information on the main digital tools and technologies with regards to their applicability to the forest education sector, helping the trainers to identify the best options for their teaching activities.

The FOREE Erasmus+ project consortium involved five organisations of four European countries (Italy, Estonia, Germany, Austria), including three forest education centres, one university with excellence in blended learning models and a cluster organisation with competence in digital transformation. The project's results are scalable at the European level.

Cocreating simulator based training of forest machine operators

T5.31 Taking advantage of technology in education

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Abstract: Many Swedish forest machine training programs utilize forest machine simulators for skills training. However, these simulators don't support the training of the economical and biological effects from harvesting. Moreover, many schools lack knowledge and experience on how to utilize this training tool efficiently with the students' learning in mind. Thus, since 2016, SLU has worked together with two training schools in Sweden to develop the simulator based teaching and training and increase the skills level of the future workforce. Through an ethnographic approach, new simulator features, harvesting scenarios and classes were developed and evaluated. The classes encompassed a bland of theoretical instruction, machine simulator training, and utilization of a secondary simulator (Heureka) for the evaluation of long-term ecolocigal and economic implications of previously managed individual stands. Initially, machine instructors found the machine simulators insufficient and unnecessary, and the pupils' simulator training was restricted. Moreover, simulators were insufficient in supporting the needs of both teacher and pupil. However, by the combined coreative process, attitudes were changed, training was improved, simulator features developed, and both safety and skills were enhanced. Variations between schools and trainers resulted in checklists for successful simulator training, several simulator-training classes, and an open Swedish web-portal for forest machine simulator classes joining all forest machine training schools in the country. While improving the simulators and their usage, the education of new forest machine operators have improved and the satisfaction of both students and teachers have increased.

Conversational Agents in Forest Education: Exploring their Innovative Role in the VirtualForest Project

T5.31 Taking advantage of technology in education

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Abstract: Despite significant progress in recent years, the forest sector is seen as a late adopter of new Information and Communication Technologies. The Erasmus+ VirtualForests project (https://virtualforests.eu/) aims to address these issues by enhancing online, distance, and blended learning in the forest sector. It specifically focuses on increasing international student access to open educational resources in a sector that is currently underrepresented in online studies.

In virtualized university courses in forestry conversational agents can play a pivotal role in assisting students. These software tools use natural language processing to interact with humans, have proven successful in many educational contexts, including tutoring and question-answering.

As part of the VirtualForests project, a conversational agent has been developed using Google Dialogflow (https://cloud.google.com/dialogflow). It serves as a teaching assistant for the distance online course "Introduction to Forestry and Natural Resources" in the Joint European master's degree on Mediterranean Forestry and Natural Resources Management (MEDFOR, www.medfor.eu). It is designed to handle concepts related to forestry activities across various topics and can answer direct questions posed by the learner. In addition to providing initial responses, it can offer more information, give examples, highlight related concepts, and engage in small talk to interact more naturally with learners.

While the use of conversational agents is not a novel concept, the approach proposed in the VirtualForests project aims to leverage their ability to mimic human interaction. This is done to increase student engagement, reduce feelings of isolation, and enhance learning outcomes. They also alleviate the instructors' burden in solving simple but frequent doubts and are available 24/7.

At present, a preliminary knowledge domain has been implemented into Dialogflow and is being tested by domain experts. Conversation logs are analyzed to refine the knowledge domain, identifying missing relevant concepts, and considering alternative question formulations. Following this, the conversational agent will be made available to actual students, and its utility assessed. A different approach being explored deals with using generative AI to create virtual agents supporting a natural conversation while always providing accurate answers.

Keywords: Conversational agents, higher education, forestry, dialogflow

Digital online platforms for peer review of teaching - from individual teacher/ing to collective university education

T5.31 Taking advantage of technology in education

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Abstract: Digital platforms have shown their power in several sectors of society - from Facebook to Amazon and from Airbnb to LinkedIn. Today online learning and course platforms are providing home for more than 100 thousand courses. Some of the platforms, such as edX and Coursera, are university origin and provide both non-credit short courses and formal education with degrees. Others, e.g. LinkedIn, are platforms for individuals and business educators offering non-certified non-academic education.

Despite rapid increase in the number of online courses online most of higher education is still typically taken place within an individual class taught by a university teacher through a learning management system (LMS) such as Moodle or Canvas. It is clear that the potential of providing Zoom and Teams teaching was enormously untapped during COVID era. However, after all this (r)evolution some main elements of the platform economy related to higher education are still in the waiting room.

University teachers typically work alone with their courses. This is an individual and introverted approach and is dramatically contrasted to the research approach. Presumably, teaching could utilize peer-review processes similar to research and also take advantage of modern co-creating tools akin to service design. It is likely that so-called peer-review of teaching (PRT) could be efficiently managed through digital online platforms.

PRT is a system for development, review or evaluation of university teaching by colleagues or university pedagogical experts (Zeng 2020). In most studies PRT has shown to have potential and usefulness for improving teaching. Unfortunately PRT has needed a lot of administrative resources at the university level. It is this structure with extra paper work in addition to the general, introverted attitude that has been an obstacle to using PRT.

This R&D project is exploring online forest education platforms in the spirit of PRT in the following services: teaching (academic) portfolios, critical friend matching, and shared and co-created learning materials such as a handbook of forest education. Forest education lacks behind STEM and business online education. This provides an opportunity to benchmark other disciplines before piloting PRT services.

Education and Training Using Virtual Reality Technology – an application in forestry

T5.31 Taking advantage of technology in education

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Abstract: Forest and wood harvesting operations are one of the industrial sectors with the highest risk of accidents at work. In semi-mechanized logging operations, the great majority of accidents generally occur using chainsaws during tree felling and processing operations. These situations frequently cause serious and often fatal injuries. In many cases, the accidents occurred to badly trained and inexperienced operators, with a short employment history. One solution to reduce these harmful events is to support workers employed in this sector with training applications. This research presents a description of a training program to operate with chainsaws in tree felling and processing operations using a Virtual Reality (VR) application called ForestVRoom. VR is a useful educational tool that can integrate conventional training methods due to its potential for providing an immersive experience associated with extensible and flexible interactions. This study amplifies the existing immersive VR technology and proposes a multi-user platform to improve the interaction between participants. ForestVRoom is a collaborative symmetric VR application that bases mostly on 360° videos as content. This innovative education method was compared to the traditional theoretical lesson based on a slide show and was validated with a specific qualitative user experience questionnaire with an internal consistency and reliability evaluation. Questionnaires were administered to a sample of 45 students in undergraduate and master's degree programs at the School of Agriculture and Forestry at the University of Florence. The findings showed that the combination of traditional didactics and symmetrical collaborative VR leads to an increase in knowledge and especially in the ability to understand situations in a real forest site providing an immersive and attractive experience in a risk-free environment. In conclusion, VR training applications can improve workplace safety and advance the digitalization of forest engineering.

Education practice concerning forest observation and wooden flooring tours using VR technology

T5.31 Taking advantage of technology in education

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Abstract: Japan is fortunate to have a wealth of forest resources, and a significant portion of low-rise housing is constructed using wood. Students learn about forests, timber, and wooden houses in their science, technology, and home economics classes. For several years from 2020, people's movements were restricted to prevent the spread of COVID-19. As a result, students lost opportunities to witness and experience the wonders of nature and everyday life beyond the confines of school, such as observing forests and visiting model wooden houses. Therefore, we created a video teaching material that captured a tree observation garden and a room with wooden flooring rooms using a 360-degree omnidirectional camera that could record the spread of space. Furthermore, we employed a 3D printer to create multiple tree trunk models that accurately depict the local vegetation. A question about trees was presented to students along with a video recreating how the students observed trees while walking, so that students could acquire knowledge about trees while watching the video. Shooting data related to several types of wooden flooring rooms with different colors and grains were captured using virtual reality (VR) goggles and saved. By simply pressing a switch on the VR goggles, students could experience the atmosphere of various rooms with different colors and wood grains. Because of conducting lessons using our video teaching material, the students were able to recognize the expanse of the space of the forest and wooden house. Therefore, it can be postulated that using VR technology would be beneficial for understanding forests and wood.

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Evaluating the Effectiveness of AI Language Models in Generating Scientific Abstracts: An Case Study of Forest Landscape Restoration Research

T5.31 Taking advantage of technology in education

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Abstract: Scientific abstracts play a critical role in summarising research findings and facilitating efficient dissemination of knowledge. We use well-established guidelines of CAB Abstracts, and the Collaboration for Environmental Evidence for writing informative scientific abstracts and executive summaries to test the effectiveness of different AI language models (e.g. ChatCPT, Google Bard), in generating high-quality abstracts. The test set of English language articles is drawn from a recent systematic map on Forest Landscape Restoration research. The testing also compares AI-generated English-language abstracts for reports in a range of languages (French, German, Spanish, Greek) - both academic articles and grey literature.

Criteria-informed prompts are tested in each of these AI models to generate abstracts from the main body text of the selected research. These AI-generated abstracts are cross-compared with author-generated abstracts and scored for compliance with guidelines. A series of recommendations will be produced for iterative prompts to use in order to generate the most effective scientific abstract/executive summary. This is akin to training scientists in the necessity for effective question framing for their research. This novel approach shows significant potential for improving the abstract creation process and the overall quality of scientific communication.

The results of this study will provide insights into the suitability and efficacy of AI language models in generating scientific abstracts. The findings will be helpful to students and early-career professionals, particularly those for whom English is not a first language when confronted with the necessity of preparing an executive summary or scientific abstract based on their research.

Fire Education Platform: a tool for knowledge transfer about wildfires

T5.31 Taking advantage of technology in education

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Abstract: Extreme wildfires pose a global threat, and the European Commission is investing considerable resources in researching and developing new models and approaches to tackle them. One of FIRE-RES project's main goals is to share knowledge, raise awareness, and engage society. Extreme wildfires are not a common or well-understood process in Europe. In order to have a common culture of risk, society needs to be aware of it, understand it, and accept it. An online tool called Fire Education Platform is being developed to address this gap, aiming to share best practices related to wildfire communication and awareness among countries.

This international multimedia tool gathers information from different countries, targeting multiple audiences (politicians, educators, students, and local communities), explores the fire culture concept and scope in Europe, analyzing topics such as the ecology of fire, fire risk, and its social dimension (oral and artistic practices, traditions and fire use by local rural communities). It will follow an interactive model, with local knowledge provided by citizens and scientists from all over Europe covering the various stages of the fire cycle. The platform will be open-access and displayed in five languages.

The platform is being developed with a common core, which includes fire culture and arts, fire news, a fire encyclopedia, and data on the FIRE-RES project written clearly and easily. The separate core includes three areas: to teach, targeted at teachers and educators; to learn, targeted at the general public; and to apply, targeted at the professional sector. Within the common core, 90 traditional tales have been retrieved so far. Most of the tales are European, though the other continents are also represented. For the collaborative design of the platform, a survey with 24 questions was launched in the 13 country partners of the project, aiming to assess the real needs of future users. The Fire Education Platform is expected to be online in 2024 and contribute to improving and fostering more and better knowledge on fire among all types of public to increase fire resilience.

Game Engines—The Newest and the Most Versatile Platforms for Forest Education: Hyrcanian Forest Use Case

T5.31 Taking advantage of technology in education

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Abstract: The new era of distant education and communication prompted the scientific community to indulge more in technology and make a virtue of virtual platforms, entailing prerequisites for raising technology literacy and encouraging interdisciplinary research and cross-boundary means of education. Game engines have long been known as a platform specifically designed for game developers and gamers worldwide, whose merits remained unraveled to scientists not long ago. Here, we discussed the architecture of creating a virtual educational forest platform, without which attaining the true meaning of "Digital Twin" would be insurmountable. These steps include 1) creating the virtual replica of the physical assets of the forest site via photogrammetry, laser scanning, or just acquiring the premade and archived 3D tree scans from world-famous repositories such as Quixel Megascans; 2) coupling the previous virtual replica with the static inventory data (e.g., forest structure characteristics or silviculture prescription data collected by forestry practitioners); 3) replacing the static data with dynamic and (near)real-time data through sensors as a core process of internet of things (IoT) and generating a true digital twin of the forest, and lastly 4) embedding environmental modeling plugins to the digital twin which can enable to model and simulate specific analyses such as forest fire modeling/mapping, deforestation risk analysis, and so forth. These four steps would make the backbone of any digital twin structure, regardless of the study scope and the environment they are to be applied. Also, we showcase the tremendous merits of a game engine called Unreal Engine in making a photorealistic, live-like forest environment of an example site in the Hyrcanian Forest, fused to static data (i.e., steps 1 and 2). Furthermore, we discussed the making process of a virtual tour of a sample forest trail in northeastern Iran generated by linking several 360 panoramas captured by smartphones or professional fisheye lenses. Such interactive and responsive products can be represented in different formats such as desktop, web, and particularly as an immersive experience by VR, all designed to be simple, user-friendly, and aligned with countries with the least technological advantages.

Methodology of technology to promote experiential learning that approaches the long-term aspects of forests

T5.31 Taking advantage of technology in education

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Abstract: Forests contain long-term phenomena such as succession that are beyond the human scale. In applying the various technologies that are becoming increasingly popular in recent years to forest education, methodologies that approach the long-term aspects unique to forests are required. The University of Tokyo Cyberforest research project has installed and operated fixed-point cameras and microphones in forests since 1995, and has been archiving images and sounds for more than 25 years. We have considered, through a number of practical studies, methodologies for using this vast audio-visual archive to present the long-term aspects of forests beyond the human scale as part of an experiential learning approach on forest education.
The Cyberforest project began capturing 15-second video without audio every day around 11:30 a.m. in October 1995 by installing a fixed-point camera in the University of Tokyo Chichibu Forest, and added a fixed-point microphone in October 1998 to capture video with audio. In 2010, a satellite Internet connection was installed at the same location, and the operation was shifted to live audio streaming and 20-second interval time-lapse still image transmission for several hours each day. The same audio-visual distribution in this post-2010 format has been conducted at seven other locations, including the University of Tokyo Fuji Iyashinomori Woodland Study Center, the University of Tokyo Hokkaido Forest, and Shinshu University Nature Education Park in the Shiga Heights.
We have developed educational materials that represent various timescales of forests using the audio-visual live streaming and archives from these Cyberforest sites through practical researches in various types of educational situations. As a result of more than 20 times of practical research in a wide range of educational situations, including primary education, secondary education, higher education, and social education, the direction of developing educational materials that represent multiple timescales based on plant phenology was considered to be effective. In addition, since the forests presented in the visual images and sounds are essentially different from actual forests that are comprehensively perceived by the five senses, it was considered desirable for learners to have a certain experience of actual forests to compensate for the gap by their imagination.

Oppertunities for Digital Final Projects in Silviculture Education

T5.31 Taking advantage of technology in education

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Abstract: Science and art are often two terms used to describe and define silviculture. It is critical for students to have foundational knowledge in silvics and stand dynamics. However, most silviculturists would agree the art part of silviculture comes in during the implementation of that foundational knowledge when developing and implementing silvicultural prescriptions. Incorporating nuance, creativity, and art into undergraduate and graduate education can be difficult, especially when it comes to assessment. I developed a final assignment that uses digital technologies that allow students to display their foundational knowledge (the science) while developing and implementing a silviculture prescription of their own (the art). Students use their smart phones or other methods to digitally record a 5-minute presentation. Within those 5-minutes students work through a rubric describing their site and the silvics of the species, their goals and objectives for the site, their silvicultural prescription, and link the silviculture to other ecosystem attributes (e.g. forest health, biodiversity, climate resilience). Students have shared presentation that span the gamut from working in regional forest ecosystems, to highlighting regional and international locations while on trips during the semester, to highlighting silvicultural options in video games like minecraft. Since students create their own goals and objectives, students are able to bring their perspective and think critically and often "out of the box." Additionally, the final project can be shared with family and friends provide opportunities to share what silviculture is and expanding opportunities for conversations around forest management practices.

Supporting ubiquitous learning in forestry with CHEST, a multidomain application using Linked Open Data

T5.31 Taking advantage of technology in education

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Abstract: The widespread use of mobile devices can help to blur the barriers that students might find between what they learn in the classroom and the world around them through ubiquitous activities. Traditionally, teachers prepare the contents for their planned learning scenarios. Major barriers for this approach are the authoring effort and the difficulties to reuse content from other contexts. These limitations can be addressed with Linked Open Data (LOD), a federated database of interlinked sources from multiple domains such as forestry. Notable examples of LOD sources include Wikidata and DBpedia. However, accessing and managing LOD need expertise on semantic technologies, uncommon to most user groups (including teachers). We propose CHEST to address these challenges.

CHEST is a multidomain platform that exploits LOD sources to support ubiquitous learning situations. CHEST includes map-based user interfaces for teachers and learners with different capabilities that can be used in web, Android, and iOS devices. Forest domain teachers using CHEST can annotate as LOD features such as trees, author learning tasks associated to a feature (e.g., which is the species of this tree?), or create itineraries. They also explore available information coming for a variety of sources such as OpenStreetMap and Wikidata, allowing them to reuse existing environmental data and thus reduce the authoring effort. For example, if the leaf type of a tree is annotated in OpenStreetMap we can obtain information about it in Wikidata to enrich the tree's description. Teachers can supply meaning to the tasks thought the itineraries. In the itinerary they must pick the trees that they students should visit, and they can select learning tasks (generated by other teachers or on the fly using templates and available information) or add their own tasks. Students can follow the itinerary and carry out the learning tasks proposed by their teachers.

With CHEST prototype we have proven the possibility of using forestry data generated by the OpenStreetMap community, combined with information from other repositories, for educational purposes. As future work we want to use information from forestry repositories that research groups are translating into LOD to automatically generate more meaningful learning tasks.

Teaching and training in silviculture: a case-study in Brasov, Romania

T5.31 Taking advantage of technology in education

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Abstract: Silviculture has always been a major discipline in the forestry curricula throughout the world. This is also the case of Romania, where the first forestry school established in the second half of the 19th century considered Silviculture as a genuine milestone in the foresters' curriculum so dedicated this discipline a large amount of both teaching and practicals hours.

The same situation was encountered in the Faculty of Silviculture and Forest Engineering, part of Transylvania University of Brasov. It was established in 1948, as a continuation of the Faculty of Forestry within the Polytechnic School of Bucharest, founded in 1923. Since its early ages, the discipline of Silviculture in Brasov was dedicated two terms (full 3rd year of study, in a 5-year B.Sc. course), with 3 hours of teaching + 3 hours of practicals/project per semester (*Forest Biology* in semester I, *Silvicultural interventions* in semester II). This situation has changed dramatically since the application of Bologna system in Romania (2005/2006 academic year), the number of hours per semester (second in year 2 and first in year 3) for Bachelor degree (240 ECTS) being reduced to 2 (teaching) + 2 (practicals/project). Consequently, a lecture derived from the previous Silviculture course (Special Silviculture, showing the practical application of silvicultural interventions by forest formations) is taught in the 2-year (first semester) of the Master course (120 ECTS), with 2 hours of teaching and 2 hours of practicals.

Currently, the Silviculture lecture is facing the same challenges as in other parts of the world: allocation of similar time budgets as purely classroom-based disciplines, limiting drastically the use of field tours as part of teaching process, increasing diversity of students (both B.Sc. and M.Sc., many of them from high schools and professions not related to the Forestry field), limited staff at forest district level, with less time for apprentice training, making very difficult the planning and conducting of field tours and hosting students.

The remote-distance teaching, forcibly used during the pandemic, is definitely not a solution in Silviculture - students need a hands-on training in order to achieve the desired level of practical knowledge and experience in this field.

Training the Next Generation of Logging Equipment Operators with Forest Machine Simulators

T5.31 Taking advantage of technology in education

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Abstract: A forest harvester simulator is a specialized software that aims to train individuals who operate forest harvesting equipment. The program creates a virtual environment that accurately replicates the experience of operating the equipment, with realistic graphics and physics models. The main objective of this simulator is to provide a safe and cost-effective training method for operators before they operate the equipment in real-world conditions. By using the simulator, operators can develop their skills, reduce the risk of accidents and equipment breakdowns, and increase productivity.

However, despite the many benefits of forest machine simulators, their use is still limited in some countries like Thailand due to the high cost of the technology. To make the simulators more widely available, ongoing efforts are being made to explore low-cost or open-source simulator technology. To address this gap, a recent study introduced a basic simulator into Thailand's circumstances.

The study aimed to achieve two objectives. Firstly, it compared the learning outcomes of simulator-trained operators, including factors such as the learning curve, biofeedback (pulse and temperature), and productivity. Secondly, it examined the effect of personnel parameters on the learning outcomes, including factors such as professional versus unprofessional backgrounds, male versus female operators, and gaming experience versus inexperience.

The Ponsse basic simulator was utilized to provide training for the candidates. The simulator offered a variety of forest stands and species to simulate real-life logging operations. The candidates were divided into four sub-groups based on their knowledge or experience in logging operations and their experience with simulation gaming. Prior to the training, all candidates received a brief introduction to the simulator. To evaluate the effectiveness of the simulator training, the performance of the candidates was measured and compared between groups. The performance metrics evaluated included productivity, error rates, and completion times. Additionally, surveys were conducted with the candidates before and after the training to assess their perception of the effectiveness of the training. The surveys included questions about their confidence, perceived competence, and satisfaction with the training. A detailed description of the measuring procedures, methods, and results will be presented at the conference.

What is the effect of forest education on knowledge and management decisions?

T5.31 Taking advantage of technology in education

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Abstract: An underlying assumption for providing forest education is that it produces impact. This is perfectly reasonable and matches our experience. However, how this impact is manifested in knowledge level, attitudes and subsequent measures in forestry is rarely investigated and quantified. This is an important area to investigate not only since education needs to be evaluated but also since knowledge and information are profound parts for forest owners to contribute to achieving the forest policy goals as well as societal goals for climate and health, where forestry plays a significant role.

Linnaeus University has since 2001 conducted courses for forest owners and other interested, and a total of over 5 000 people have attended one of the courses, Sustainable Small-scale Forestry. The course set-up has been adapted to distance with physical meetings in the forest combined with own studies and written submissions. The effect of these academic courses on forest owners' knowledge and management decisions has never been studied. Course evaluations are certainly carried out, but these have limitations in that they represent an indirect way of examining knowledge acquisition, where the participants indicate the perceived knowledge acquisition, quality, and usefulness of the course.

We investigated participants' factual and self-assessed knowledge levels, attitudes, and measures in forestry before and after the course using both quantifiable and open-ended questions.

The results showed an increased ability to elucidate solutions to silvicultural examples in planting, pre-commercial thinning, and overall forest management. The self-experienced knowledge level decreased for areas where the students were exposed to new knowledge. Also, there was an inclination to shift forestry measures, but a more significant impact occurred in decision-making with more mindful decisions.

T5.32 Teaching and training in silviculture: contemporary challenges and future prospects

Blended learning in academic forest education: experiences after educating 5 000 forest owners

T5.32 Teaching and training in silviculture: contemporary challenges and future prospects

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Abstract: Private forest owners own 60% of the European forests. However, little adapted academic education has been offered for them; traditionally, it has served the need of the State to manage its forest and the need of companies to buy timber. In 2001 academic courses for forest owners started at Linnaeus University in Sweden. The number of students, their performance and continuing studies are of interest to forest owners, employers, educators and society but were never compiled. This is a follow-up of some aspects of 22 years of education.

Since many potential students already worked, studied, or were even retired, some part-time distance-based approach was assumed to fit the student group's needs and was tried. The courses were conducted as blended learning courses with excursions, lectures in- and outdoor and field-based homework in a digital learning platform, providing terminology and science in forest mensuration, ecology, silviculture, growth and yield and economics and has been used by several forest companies in further education.

In the first year, 112 students registered (37% women), and 46% completed the introductory course. By autumn 2022, more than 5 000 students had attended the courses, almost 50% being women. Over the years, the courses have been developed with continuation courses with a continuation rate of 75% for introductory courses and extended to programs of two and three years of length full-time.

The courses serve as an example of how academic education can be organised and implemented in a forest education system addressing the need of the forest sector for an educated workforce. From a societal point of view, as a concept of Life-long learning, the courses are an example of opening new knowledge fields and careers. Forest owners are introduced to forest management, bringing terminology, networks, and competence. Future development includes courses for European forest owners.

EVOLUTION OF SILVICULTURE EDUCATION IN CENTRAL MEXICO

T5.32 Teaching and training in silviculture: contemporary challenges and future prospects

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Abstract: Silviculture education originated in central Mexico approximately 90 years ago, with the establishment of the first School where a BS degree was offered. Curricula and field practices focused on temperate pine-oak forests. At the beginning, around 1930, the fundamentals were adapted from schools founded in the United States with a philosophy focused exclusively in wood production. This stage lasted approximately 40 years, mainly training undergraduate students in the only existing school. Later, in the decade of the 80's of the 20th century, and in accordance with global policy and trends on sustainability, the teaching philosophy evolved to multi-objective forestry, which spread with the establishment of forestry careers in the north of Mexico. At the same time, in central Mexico, the first graduate program related to forestry sciences was founded, offering a course in advanced silviculture, focused on ecological and quantitative fundamentals in the application of silvicultural practices, although the emphasis remained on timber production. Currently, there have been changes in the focus Silviculture orientation aligning with international trends, forestry education and research policies in the country, as well as regional demands for the different species under management. New teaching trends consider multi-purpose Silviculture and Silviculture with emphasis on ecological principles. Nowadays, student´s demand for forestry courses, and particularly for both Master Science and Ph.D. students, along with other forestry professionals, not only include forest goods, but also multiple ecosystem services. This is also evident in the forested areas of northern Mexico, where existing large areas with temperate forests, and in the south, where the evolution of the teaching of tropical forest silviculture requires a particular approach.

Handbook for teaching and learning forest sciences in colleges and universities

T5.32 Teaching and training in silviculture: contemporary challenges and future prospects

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Abstract: Universities around the world are responding to the challenges of globalisation, the spread of higher education to increasingly diverse groups of students and the growing demands placed on them by national governments. The quality of teaching and teaching excellence are factors with which universities compete to attract the best students to their degree programmes (French & O'Leary, 2017). This global competition for the best students also applies to forestry education. Universities provide pedagogical training for their teachers to support their development in teaching excellence.

Pedagogical training requires textbooks and for academics, professors and senior lecturers, there are many textbooks about teaching and learning in colleges and universities (e.g. Biggs & Tang, 2009; Lindblom-Ylänne & Nevgi, 2009; Marshall,Fry & Ketteridge, 2014; Moore, Risquez & Walsh, 2007). There are some handbooks for teaching and learning a specific discipline such as geography (Walkington, Hill & Dyer, 2019), business education (Thomsen et al., 2021), and political science (Ishiyama, Miller & Simon, 2015). However, to our knowledge, there is no handbook or textbook for the educators of forestry and forest sciences in colleges and universities.

The editors of the *Handbook of teaching and learning forest sciences* are Anne Nevgi, Mika Rekola, and Niclas Sandström (alphabetical order). The topics of the *Handbook* may include the following areas: Challenges of Forest education, Developing and designing curriculum and courses of forest sciences, Educational technology, digital platforms and artificial intelligence in teaching and learning, Teaching subject areas (specific teaching methods for subjects), In-class teaching techniques, and Developing teaching competency of forest educators.

The timeline for the editing and writing of the Handbook and developing the interactive website will be 2-3 years starting from autumn term 2023. Handbook will be published as an e-book with links to an interactive website, and as a physical book. In the session, the organisation of the Handbook will be presented, and how the Handbook and it's interactive website can be used in self-study, in peer review of teaching, in developing and planning one's own teaching, and in pedagogical training.

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

An approach to model natural forest regeneration using commonly available data.

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: Forests are one of the most essential ecosystems and are therefore crucial for human wellbeing. Changes within the climate and disturbance system are causing increasing uncertainties for forest development. Yet, the variability of the initial stages of forest development, the forest regeneration phase, remains high. Trees are characterized by a high life expectancy and individual forest development phases can often last for decades. These life history traits lead to a high vulnerability of forests, as environmental conditions can change significantly in global change during the same period. Therefore, the forest regeneration phase, which is the developmental phase with the highest adaptive capacity of forest ecosystems, is of critical importance. Nevertheless, our understanding of the interaction of environmental conditions and the quantification of effect sizes leading to successful natural regeneration remains insufficient.

We developed a statistical model to estimate regenerative success using data commonly available for larger forestry companies. Specifically, we combined wall-to-wall site classification data composed of soil moisture, nutrient supply, tree species shares and volumes with in-depth data on local tree parameters such as mean quadratic diameter, stand basal area, and crown projection. We used a Generalized Additive Model (GAM) to analyze the occurrence and density of natural regeneration. The GAM allowed us to model any non-linear relationships and specifically we used a GAM implementation that is able to model so-called "compositional data". By doing so, we were able to model the occurrence of different regeneration tree species simultaneously. This approach allowed us to consider the dependencies between the co-occurrence of several tree species within one regeneration plot.

A regeneration model, which is generally applicable while using readily available parameters, enables forestry companies to guide large-scale planning of natural regeneration. For forest science regeneration models are able to inform primary forest growth and biomass models to better estimate current and future regeneration potentials and possible forest development trajectories. Regeneration models enables a climate-adapted and resource-efficient way of steering tree species composition and thus the shape of future forests.

Bayesian calibration of process-based model PREBAS using multi-source data

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: Process-based models simulate the ecosystem carbon dynamics based on plant physiological and ecological processes. These models are extensively being used for quantification of forest fluxes and stand dynamics and assess the possible future changes in forests associated with changing climate. However, the simulations from these models require information on physiological, structural, and functional traits for model parameterization. The uncertainties in the parameter estimates have a significant effect on the accuracy of model output. Hence, the calibration of the process-based model parameters is crucial to make model outputs comply with measurements. The present study focuses on the calibration of PREBAS, which is a coupled model consisting of two modules, PRELES - a canopy photosynthesis model for estimating gross primary productivity (GPP) and a simplified water balance and CROBAS - a tree growth model. PREBAS was calibrated using extensive multi-source dataset including multi-temporal forest stand structure data from permanent growth and yield experiments, national forest inventory data, foliage and stem biomass data from the old growth, uneven-aged forest, and multi-site GPP and evapotranspiration data from Eddy covariance (EC) sites across Finland. The daily meteorological input was prepared from CRU JRA V2.1 forcings dataset which was bias-corrected using the spatially downscaled girded weather observations from meteorological stations, whereas for EC sites, the meteorological data from EC towers were used. Bayesian calibration of model parameters was carried out for three species, Scots pine (Pinus sylvestris L.), Norway spruce (Picea abies [L.] H. Karst.) and silver birch (Betula pendula L.). The Bayesian calibration effectively reduced the uncertainty of PREBAS parameters and predictions. On comparing the posterior distributions of the parameters, major changes were observed in the CROBAS parameter estimates, whereas PRELES parameter estimates did not diverge much from the prior. This was also reflected by the higher improvements in the simulated forest structural variables and biomasses, against smaller improvements in simulated fluxes. The study emphasised on the importance of the comprehensive, multi-source data covering a wide range of climatic conditions, forest structures, development stages, and management practices for model calibration, which allows to increase the reliability and robustness of PREBAS for its application in regional simulations.

Carbon stocks in tropical forests: disentangling the response of forest structural components to environmental drivers across spatial scales

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: The critical role of tropical forests in the global carbon cycle is well-known. Yet, there remain uncertainties regarding the spatial distribution of forest aboveground carbon stocks (AGC) substantially limiting our potential to develop relevant conservation and restoration strategies for these ecosystems. In particular, the lack of convincing relationships between forest AGC and its environmental drivers represents an unstated and major source of uncertainty. In this study, we hypothesize that this lack of consensus results from the omission of a key concept in forest ecology: the AGC of a forest community is not a single entity but the product of distinct forest structural components (e.g. basal area, mean quadratic diameter, stem density and wood density weighted by basal area) each responding differently, and sometimes antagonistically, to environmental drivers (e.g. climate, soil properties and topography). Gathering forest inventories from 606 plots across three tropical regions (i.e. South America, Asia and Africa), we studied the influence of environmental drivers on several forest structural components and AGC, using linear regressions and controlling for spatial autocorrelation in model residuals. In addition, we tested the influence of the climate data sources by testing the sensitivity of the results to different climate datasets (e.g.WorldClim, ERA5, CHIRPS and TRMM). Preliminary results unveil significant and strong relationships between environmental drivers and each forest structural component (with an average RMSE of 18%), whereas no or weak environmental influence was identified on AGC (with an average RMSE of 34%). It confirms the hypothesis that the link between environmental drivers and forest AGC is indirect through specific and antagonistic relationships between environment and each forest structural component. Interestingly, we identified a strong influence (with an average RMSE of 8,2%) of soil properties (i.e. clay content and pH) and topography (i.e. elevation and slope) on the wood density weighted by basal area. These results highlight the necessity to study the drivers of forest structural components across tropical regions to understand the spatial distribution of tropical forest AGC. This research provides key insights for future studies on forest AGC drivers as well as conservation-restauration strategies.

Characterizing structural complexity and dynamics of birch stands using UAVLiDAR and field inventories

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: Among the numerous consequences of global changes, the loss of resilience in european temperate forests could lead to significant ecological and economic disaster. Currently, many tree species of sylvicultural and heritage importance, such as European beech (Fagus sylvatica), are no longer suited to their current site conditions, and this situation will only worsen in the future. It is therefore urgent to identify new resilient tree species with high sylvicultural potential in order to adapt forest composition to global changes. Among these species, birch (Betula pendula Roth.) shows promising characteristics for the future forest diversification from an ecological and economical point of view. However, we still lack a deep understanding of the functioning of this species, especially key informations that would enable the development of its silviculture. In this study, we combined trunk-centric field inventories with threedimensional canopy data acquired through UAV-LiDAR to characterize the structural complexity and dynamics of the stand. We examined individual trees, analyzing their morphology, foliage, crowns, and trunks, and then aggregated the information at the stand level to characterize the influence of stand structure on individual growth monitoring with high resolution automatic point dendrometers. Through this research, we have highlighted certain autoecological specificities of this species that will enhance silvicultural recommendations for future plantations or stand enrichments. By adapting silvicultural standards to this fast-growing pioneer species, we have the opportunity to develop a more close-tonature forestry approach with low initial investment requirements, while benefiting from high-quality wood with a great potential for woodworking purposes.

Contribution of Three-North Afforestation Program to forest greening in Northern China during 1978-2022

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: In response to land degradation in arid and semi-arid regions, China has launched the world's most ambitious afforestation project, known as Three-North Afforestation Program (TNAP, 1978–2050), which also known as "Protective Forest Project", was designed to increase forest coverages for protecting agriculture, reducing soil erosion, and controlling desertification over an area of 42% of China. However, temporal-spatial variation patterns and potential causes of forest greening are not well understood in Northern China, and it is not clear whether forest greening (area and quality) is due to climate change or engineering contributions. Here, we extracted the forest increase area using multi-source remote sensing data and analyzed whether it is consistent with climate change. In addition, the temporal-spatial variation patterns of forest quality were analyzed. Then, combined with the climate data, the relationship between forest quality change, climate change, and TNAP was analyzed. The forest area shows an overall increasing trend from 1978 to 2020, among which, the increase in forest area from 1978 to 2000 is mainly contributed by TNAP, while from 2000 to 2020, it is mainly a combination of climate change and TNAP. The quality change of the forest mainly shows a decrease first and then an increase; among which, 65% were related to TNAP and 35% to climate change. The above results highlight that the TNAP plays a crucial role in forest greening in Northern China. While climate change's role in forest greening in Northern China is relatively weak, it cannot be ignored.

Developing a site index model of sugi planted forests using time series digital crown height models derived from aerial photograph and airborne LiDAR

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: A site index prediction model for sugi (*Cryptomeria japonica*) planted forests was developed using tree height growth data calculated as the difference between time series digital crown height models (DCHMs). The study was conducted at the Tano Forest Science Station, University of Miyazaki, Japan. The data sources included digital surface model (DSM) and digital terrain model (DTM) derived from airborne LiDAR data captured in 2013, as well as a DSM derived from a digital aerial photograph taken in 2016. DCHMs were developed at a resolution of 0.5 meters for both 2013 and 2016 within the sugi planted forests. The DCHMs were then resampled at a resolution of 20 meters using local maximum filtering to produce dominant tree height maps. The difference in dominant tree height between the two years, at a resolution of 20 meters, was calculated as the dominant tree height growth distribution map for the period of 2013 to 2016. Topographic factors such as solar radiation index, wetness index, and topographic exposure index were computed using the DTM resampled at 20-meter resolution. A model combining the site index prediction model and the height curve model was parameterized using dominant tree height growth, stand age (derived from a forest map), and topographic factors. The estimated parameters indicated that the site index was higher in areas with lower solar radiation, higher wetness, and lower topographic exposure. This study utilized spatial big data, specifically DSMs and DTM, which allowed for a broader examination of the relationship between site index and topographic factors compared to traditional data sources (e.g., sampling plot surveys). As a result, a robust model was developed to predict site index for a specific site using topographic factors and dominant tree height for specific ages at that site. Finally, the effect of climate change on predicting site index and dominant height growth was assessed by comparing the model's predictions with actual tree growth data obtained from stem analysis.

Environment-induced growth changes in forests of Finland revisited

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: After a rising trend from the beginning of 1970s, during which the overall annual growth of the forests of Finland increased by more than 70 %, a recent reduction has been observed. We analyzed the development of annual growth, focusing on the component not explainable by changes in growing stock or forest structure.

The data originate from the Finnish National Forest Inventories. We developed models predicting periodic (5 years) annual volume increments per hectare with properties of the trees and the stands as predictor variables. Deviations from model-predicted values in large areas were interpreted to be induced by environmental variation. The development was analyzed separately for three species groups: Scots pine, Norway spruce and broadleaves.

We observed a rising growth trend not explainable by forest structure. The species groups produced rather a similar pattern in different parts of Finland: from the 1960s to mid-1990s, measured volume increment was mainly below the model-predicted level, thereafter above it. During the current century, the difference between measured and predicted annual volume increment has shown a downward trend for Scots pine. For Norway spruce, the difference of measured and predicted growth has continued to increase in southern Finland but shows little change in the north. For broadleaved species, a recent increase was detected as well, though not as large as for Norway spruce. The geographical pattern of the environment-induced growth component was described in more detail via maps using a 75 km × 75 km grid. The key question is: are we witnessing a turning point of the long increasing growth trend, or are the recent years just a temporary downturn, a part of natural variation.

Forest dynamics and demographic processes in the largest primeval beech forest of Europe

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: Forests dominated by European beech (*Fagus sylvatica*) are known for their pronounced continuity and a small-scale disturbance regime. At larger spatial scales, this results in an ecosystem which is in steady state, while at smaller spatial scales considerable dynamics can be observed. It is assumed that the continuity of species composition in this ecosystem relies on the crown plasticity, shade tolerance, and longevity of beech, and that these traits allow beech to outcompete other species such as maple (*Acer* sp.). However, the main demographic processes recruitment, growth, and mortality reflecting these traits and their contribution to the long-term structural dynamics of these forests are not well understood.

Here, we analyse two datasets with different spatial and temporal resolution, both gathered in the primeval beech forest of Uholka-Shyrokyi Luh, the largest remnant of primeval beech forests, to gain insight into the dynamics of beech forests in the absence of anthropogenic influences. First, we investigate the structural and compositional changes using kernel smooths, capturing the small-scale dynamics of structural attributes such as basal area and tree density. Subsequently, we analyse the influence of both competition and disturbances on the demographic processes using spatially explicit species-specific models for recruitment, growth and mortality. Finally, we assess the contribution of the demographic processes to beech dominance using a three-stage Lotka-Volterra-type model. This allows us to shed light on the feedbacks between forest structure, demographic processes and compositional changes at different spatial scales in primeval beech forests.

Forest ecosystem resilience evaluation using time-series NFI plots and remote sensing data stack

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: The state of forest resilience could substantially change as a result of climate change and disturbance. It is challenging to characterize the resilience of forest ecosystem. Here we intend to develop an indicator system for the evaluation of forest ecosystem resilience. Through the 9 repeat cycles of NFI plots, both the individual tree and the plot level factors are analyzed. Tree level growth trajectory, stand level parameters and its environment factors are analyzed with the consideration for stand natural development, management activity, and disturbance agents. Then the 35 years Landsat remote sensing data stack is built according the stand development and disturbance events. Both the pixel level and forest stand level are compared. The results in the typical forests of China will be investigated. As an arising topic, this preliminary result will provide a feasible way for the forest ecosystem resilience evaluation.

Identification of tree heights in the Chiquitano Dry Forest using UAV LiDAR technology

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: Annually, the areas affected by fires in Bolivia range from 1.1 to 9.2 million hectares with a total of 24 million hectares impacted in the last 21 years. Restoring the ecological functionality of ecosystems degraded by forest fires is a high priority in the country to reverse the loss of biodiversity and carbon storage. One of the regions most impacted by fires in the country is the Chiquitano Dry Forest, a transition zone between the Amazon rainforest and the dry forests of the Chaco and Cerrado. In recent years, satellite monitoring in combination with field information has been fundamental to understand how regeneration processes occur in this forest. One of the field tools to perform these analyses is the use of LiDAR technology that has been implemented in the Unmanned Aerial Vehicle (UAV). In this study, field inspections were conducted in an area located in the Boque Chiquitano, in which three plots of permanent vegetation of 20x50m were installed and woody individuals with DBH diameters>2.5 cm at breast height (1.3 m) were measured. Two of the plots had some type of disturbance (fire, cattle, selective extraction) and one had no recent disturbance. These plots were overflown by a DJI Matrice 300 RTK UAV with a Zenmuse L1 LiDAR sensor attached. The results obtained show that the data obtained by the LiDAR sensor allows the identification of tree heights, helping in the evaluation of large extensions of wooded areas that require a lot of field effort to make the measurements. However, the methodologies used in this study underestimate the total number of trees in the plots, the size of the crowns and do not obtain real diameters. A possible explanation for this is that many trees are infected by vines and that the vegetation in the lower stratum is dense, confounding the tree diameters. The tools for classifying the information obtained by the LiDAR sensor still need to be further improved.

Recreating structurally realistic tree maps with airborne laser scanning and ground measurements

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: The estimation of forest attributes representing aspects of structural biodiversity from vast areas is difficult not only because of the lack of agreement on what constitutes a structurally diverse forest, but also due to difficulties regarding the detection of small trees. However, there is a consensus that a structurally diverse forest should have large variation in tree size (i.e., height and diameter), as well as some clustering of trees, as regular tree pattern is typical for managed forests. We developed a framework for building structurally representative tree maps using airborne laser scanning data which were corrected based on a limited number of ground measurements using data from two locations in Finland. In the proposed method, an individual tree detection algorithm is optimized so that the number of undetected trees and false detections is minimized. The ground measurements are then used to train models for the number and location of undetected trees and false detections. This model can then be applied to other areas in the proximity of the ground measurements to build tree maps, with the location, height, and diameter for each tree. The methodology was shown to reproduce the species-specific numbers of trees and size distributions as well as the spatial pattern of the trees with sufficient accuracy for practical use in large-scale mapping of forest attributes. For species detection additional spectral data was used.

Spatially explicit modeling of nonlinear growth patterns in plantation forests over broad geographic scales

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: Spatially explicit models that account for nonlinear patterns in forest growth are critical for managing forest values that depend on stand age, such as forest product yields or carbon sequestration rates. Process-based models account for nonlinear growth patterns but tend to be coarse in spatial resolution and computationally expensive to run. Conversely, empirical models can account for variation at finer spatial resolutions but are generally limited to linear rates over distinct time spans to date. In this talk, we present an empirical nonlinear growth modeling approach that accounts for spatial variation at 1 x 1 km spatial resolution and is applicable across broad geographic scales (all low- and middle-income countries). Using a global dataset of thousands of observations of aboveground biomass stocks and stand age in monoculture plantations, we map nonlinear growth patterns for distinct plantation types at 1x1 km spatial resolution. Specifically, we use statistical models and a large raster stack of climatic, edaphic, and topographic variables to estimate, for each pixel, localized growth parameters necessary to predict aboveground biomass for each plantation type at any given stand age. Our modeling thus represents a data-driven approach that accounts for spatial variation in key constraints on forest growth and is applicable at relatively fine spatial scales. Potential applications of our modeling approach include mapping spatial variation in optimal rotation lengths across landscapes or tracking of carbon sequestration at finer temporal and spatial resolutions. However, key challenges exist for improving, extending, and validating our models, including the incorporation of remotely sensed data products, future climate projections, and the influence of management factors. In addition to presenting our growth modeling approach, we will discuss these challenges and potential opportunities to overcome them.

Spatio-Temporal Analysis of Forest Inventories: Challenges and Approaches for Modelling Ingrowth Dynamics

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: National Forest Inventories (NFIs) are crucial in monitoring forests and their ecosystem services in many countries. Such inventories have evolved over the years, adapting sampling strategies to address new threats and advancing monitoring devices. This study uses statistical spatio-temporal methods to analyze data from complete and ongoing forest inventory cycles in Switzerland, specifically focusing on ingrowth within forests. In the Swiss NFI, ingrowth is defined as trees that meet the caliper threshold of at least 12cm diameter at breast height (dbh) between two consecutive inventories. Our analysis includes the spatio-temporal modeling of the number, the tree species and the dbh of ingrowth trees based on roughly 5’500 plots that have been measured since 1983.

We use multivariate spatio-temporal modeling techniques based on the realization of a stochastic process. In this context, we examine the difficulties of applying these models to the Swiss NFI data, particularly the fundamental change in sampling periods after the third inventory cycle, when serial sampling changed to continuous sampling with 1/9 of the plots remeasured every year. In addition, the assumptions of these models, such as translation and rotation invariance, and their implications are discussed in more detail. Moreover, we emphasize computational burdens and bottlenecks resulting from the increasing size of NFI datasets. The findings shed light on the intricacies of forest ingrowth processes in space and time and offer valuable insights for sustainable forest management. Furthermore, with this study, we contribute to the broader field of analyzing NFI data since these models can be adapted, for example, to other demographic processes such as mortality or growth.

Study on single tree survival model of mixed stands of Larix olgensis based on mixed effect model and survival analysis method

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: Accurate prediction of tree mortality is a very important part of forest growth and

yield model system. Constructing a tree survival model based on mixed effect model and survival analysis method can improve the precision of tree mortality model. Taking the data of 20 sample plots of mixed stands of *Larix olgensis*, *Abies nephrolepis* and *Picea jazoensis* in Wangqing Forestry Bureau of Jilin Province, northeastern China as the example, the tree mortality and survival model was constructed based on 6 parameter distribution models of survival analysis method (exponential distribution, Weibull distribution, log-normal distribution, log-Logistic distribution, Gompertz distribution, Gamma distribution), stand factor and site factor were added into the model as covariates. The sample plot's random effect was considered and compared with the simulation effect of the traditional model. With the increase of initial DBH, the risk of tree mortality decreased and the survival rate increased; with the increase of BAL, the risk of mortality increased and the survival rate decreased; with the increase of stand density per hectare, the probability of tree mortality increased and the survival rate decreased; the good-fitness of Weibull distribution model was the best; compared with the fixed effect model, the simulation accuracy of Weibull distribution model was greatly improved after considering the sample plot's random effect, and reached a very significant degree. In forest management, if we want to improve the survival rate of trees, we should adopt scientific and reasonable management methods and management time to avoid excessive stand density.

The role of microclimate for predicting forest regeneration

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: Forest microclimate is a topic of increasing scientific attention because of its importance for local biodiversity, global change impacts on forest ecosystems, and the interactive effects between forest canopy and regeneration. One of the expected outcomes of increased consideration of microclimates is improved predictability of ecosystems, particularly of species occurrences and responses to climate change. Nevertheless, relatively little is known to date about the extent to which microclimate products derived from topographic, biological, and macroclimatic variables improve the predictability of forest dynamics. Here, we assess the degree to which predictions of forest regeneration – a crucial process for species distributions and forest composition with a high potential to be sensitive to microclimatic effects – can be improved by accounting for sub-canopy microclimate temperatures from European forests. To this end, we fit species-specific regeneration models with data of small trees from national forest inventories and quantify how much variation in tree regeneration is explained by microclimatic temperature offsets in addition to macroclimatic variables. Our results provide an indication of the usefulness of gridded microclimatic products that integrate many environmental variables for projections of forest dynamics and whether it is necessary to consider feedbacks between large and small trees, not only in terms of seed production but also in terms of structural feedbacks manifested by microclimatic variation.

Visualizing big forestry data with Forest Explorer

T5.33 Temporal, spatial and big data - Challenges for modelling climate change impacts on forest tree and stand growth

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Abstract: Forestry sciences heavily rely on data collection to facilitate sustainable forest management and research activities. To achieve this, permanent and extensive data recording systems, such as land cover maps and forest inventories, are employed. However, these datasets are typically isolated and consist of disparate data types, which poses challenges for their integration. To address this issue and deal with the variety challenge of Big Data, Linked Open Data and Semantic Web technologies are particularly well-suited. In the EU project Cross-Forest (https://crossforest.eu/), we have published a comprehensive Linked Open Data resource encompassing the contents of forest inventories and land cover maps from Spain and Portugal, henceforth the Cross-Forest dataset. It can be accessed through the SPARQL endpoint at https://crossforest.gsic.uva.es/sparql/, although this is not very convenient for target users from the forestry domain. To support this user group we propose Forest Explorer, a web application providing an interactive map for easily browsing the contents of the Cross-Forest dataset. The application is available at https://forestexplorer.gsic.uva.es/ and only requires a device with a web browser (including desktop computers, tablets, and mobile phones). The application includes panning and zoom controls for navigating to the area of interest. Depending on the zoom level, the amount of detail is adjusted: first aggregated inventory data per region, then land cover patches, plots, and finally trees as the user zooms in. Forest Explorer further empowers users with various customizable controls to tailor the displayed information, including taxa filters so as to obtain information about specific species, genera, families or classes, as desired. The application allows a professional usage, as well as a more casual one for scientific disseminators, data scientists, or citizens. Over 11,500 users have already employed Forest Explorer thus far. The application has been featured multiple times in the media, describing potential uses, impacts and opportunities for management. A technical description of Forest Explorer can be found in [1].

[1] Vega-Gorgojo, Guillermo & Giménez-García, José & Ordóñez Alonso, Cristóbal & Bravo, Felipe. (2022). Pioneering Easy-to-Use Forestry Data with Forest Explorer. Semantic Web. 13. 147-162. 10.3233/SW-210430.

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

Do current systems of account of Northern Eurasia forests meet requirements of Sustainable Forest Management?

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Historically forest management in countries of Northern Eurasia (mostly comprising territories of the former Soviet Union) was oriented on estimation and regulation of the resource groups of ecosystem functions and services of forests. Transition to Sustainable Forest Management (SFM) in conditions of rapid climate change requires urgent analysis and reconsideration of some background principles, tools and technologies of forest management, and consequently modification (in some cases developing new) forest information systems based on major principles of applied systems analysis. The major requirements to such systems are i*nter alia* 1) ability to provide continuous operative monitoring of all forest ecosystem functions and services, part of which are not defined by current forest inventories and monitoring now; 2) early detection of changes in forest ecosystems, particularly of their resilience/ vulnerability due to impacts of new climates; 3) immediate use of new knowledge in practical forest management; and 4) permanent process of education and training of forest professionals and decision makers. Ideally, the major goal of such a process is development of unified national information spaces on forests and forest management, i.e. system integration of basic components of national forest inventories, forest monitoring and economic inventories. In essence, the ideal pattern of such a transformation should be nationally oriented models of local forest monitoring is based on integration of multi-remote sensing and ground data, and realized, for instance, in a form of Integrated Land Information System.

Implementation of such systems over vast areas of NE requires political will, understanding new needs by policy makers, availability of resources, and substantial time. However, there are important urgent problems, consideration of which would also serve as preliminary steps of future development of the mentioned systems, such as analysis and selection of optimal systems of forest management in accordance with changing functional destination of forests and local interactions between ecosystem services; modification and harmonization of forest related primary and derivative indicators used in different fields of knowledge; new methodologies and forms of development empirical and “semi-empirical” modelling systems connecting remote sensing and ground measurement; others. The presentation considers potential links with European research on the topic..

Advancing forest inventorying and monitoring in a time of rapid global change: A case study from Switzerland

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Global environmental change issues are rapidly affecting forests, and currently, in most countries' forest inventorying and monitoring (IM) initiatives face many limitations and challenges which hinder scientific understanding, the development of timely policy responses and leads to the suboptimal use of resources. To address the gaps and challenges of current IM, there is an urgent need for a "new age" of advanced forest inventorying and monitoring (AIM) in Europe that incorporates novel tools and technologies and collaboratively integrates different ongoing systems, especially at increased temporal resolutions. In this talk, we introduce the Advanced Inventorying and Monitoring for Swiss Forests (SwissAIM) initiative, which was collaboratively developed over the past three years. This can be used as a useful case study to guide the development of AIM across other regions of Europe and even more broadly across the globe.

SwissAIM will build upon and promote synergies between existing IM programs (e.g. national forest inventory - NFI, ICP Forests Level I, and biodiversity-focused initiatives), incorporate minimally invasive and destructive measurements, and draw on novel tools and technologies. This will aid with timely reporting of forest conditions and changes, and lead to a better understanding of forest processes and dynamics which ideally will help to guide timely policy and management decisions. We will present four main steps undertaken in the development of SwissAIM, including: (i) developing a vision and long-term strategy, (ii) designing the system, by collaboratively identifying research questions, survey and plot design options as well as variables and methods of interest to different stakeholders, (iii) prototyping the design and methods, and, (iv) promoting collaborative governance and engagement. We will also present some key messages and lessons that emerged through designing SwissAIM, which could be useful for others developing AIM programs in Europe.

Blending satellite, process modelling and ground observations for regular updates of European forest carbon dynamics

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Europe's forests play a major role in the continent's climate change mitigation plans, and also provide many other benefits to society. Systems are needed to accurately monitor forest dynamics and carbon cycling (and changes therein) to underlie both science and policy. Here we present a novel approach for such a forest monitoring system that combines high-resolution remote sensing of forest disturbances with process-based modelling to provide a spatially and temporally consistent pan-European assessment of forest carbon cycling over the last two decades. Recent advances in disturbance detection mean that it is now possible to quantify forest disturbance occurrence, intensity and agent at 30 m resolution annually based on the Landsat archive across the European continent. We use this information to force a process-based demographic forest model, LPJ-GUESS, with prescribed harvest and disturbances, constraining what has hitherto been the most uncertain part of modelled forest dynamics. Initialising LPJ-GUESS with actual forest structure based on forest age and composition information derived from national forest inventories ensures that the model results represent the observed structure of European forests. Using the model as a link between these two strong observational constraints and the wider body of forest process understanding, we are able to calculate the unobserved carbon fluxes with a much higher degree of confidence than previously possible at this scale. Key output variables include net exchange of carbon between the forest and the atmosphere, forest growth rate and tree mortality rates. Potential future improvements would include incorporating ground-based information on growth, harvest and mortality, which would further constrain the modelled dynamics whilst maintaining pan-European consistency. Our approach can be applied operationally for regular updates and can contribute to the wider effort to assemble a continental-scale forest monitoring system, as well as having the potential for application in other regions and ecosystems of the world.

Drivers of forest biomass change in Europe and Russia

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Forest biomass stock and change are important indicators of ecosystems health, biodiversity, climate change adaptation and the success of mitigation efforts, among others. Remote sensing instruments and data processing techniques have improved significantly over the recent decade. However, validation of changes and identification of drivers observed changes are often not properly quantified. We use well established tool (Geo-Wiki.org) for visual interpretation of very high resolution imagery and vegetation indices to confirm changes in biomass reported by several remote sensing-based products, incl. CCI Biomass and to sort out the drivers of changes, incl. natural regrowth, forest management (planting, thinning, harvesting), natural disturbances (fires, pests, wind, flooding) and land use change. A stratified random sample was made based on a number of land cover, forest and biomass change maps. This makes it possible to estimate the area of changes associated with one or another driver at regional scale. We will present to which extend biomass change can be confirmed by visual interpretation of very high resolution imagery and Sentinel-2 time series, as well as drivers of biomass change in Europe and Russia for 2010-2020.

The work is supported by the Horizon Europe EYE-CLIMA project (101081395) and the European Space Agency IFBN/GEO-TREES project (4000114425/15/NL/FF/gp).

From litter to soil carbon - harmonizing soil carbon stock estimates for a common European forest monitoring system

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Forest soils are a major, but challenging to estimate, C reservoir. In a context of global changes, monitoring and predicting possible changes in soil C stocks in forest ecosystems is essential. Improving the estimation of soil C responses to forest management practices and climate would help decision-makers to frame appropriate climate mitigation strategies. However, accurate field observations of litter-derived C inputs are particularly scarce at large scales and different methods are used to obtain such estimates e.g. in National Forest Inventories (NFIs). Within the EU-funded project PathFinder, our study aims to derive European-wide harmonized soil C inputs and stock estimates since 1990s, and further develop the current estimation methodology.

Here, we use observations of litterfall and deadwood production from plots in the pan-European forest monitoring network of the "International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests" (i.e. ICP forests). Litterfall and deadwood observations, together with repeated stand inventory data, are used to improve current regional allometric functions by biogeographical regions and forest types. For validation purposes: (i) harmonized estimates of soil C inputs are compared with independent net primary production (NPP) estimates from MODIS, and (ii) historic changes in soil C stocks simulated with the model Yasso20 are compared with measured soil C stock changes from additional ICP forest sites.

Overall, this study will provide a harmonized framework for estimating and reporting changes in soil C stocks in European forests, which can be applied in NFIs for predicting soil C stock changes in response to different scenarios of forest management and climate.

Global estimation of forest biomass: a review study

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Accurate estimates of aboveground forest biomass (AGB) and carbon stocks are increasingly demanded for enhancing our understanding of the global carbon cycle related to climate change. Mapping and estimation often go hand-in-hand, using techniques such as model-assisted or model-based inference. In this context, many projects across numerous countries continue to face challenges in obtaining accurate AGB estimates. Further, the studies tend to report contradicting results, thus implicitly highlighting the many sources of uncertainty that affect results from this type of large-area survey. The purpose of this study was to review large-area AGB surveys conducted around the globe between 1993 and 2023 from the point of view of the methodologies used in various parts of the assessment schemes. As a basis for the review, we propose ideal methodological standards for different parts of a comprehensive AGB survey. It should be noted that fulfilling all parts of our standards is probably impossible in practice, and thus the standards should mainly be seen as a tool for identifying which parts of large-area AGB surveys tend to be more problematic than others. In the standards, we make a distinction between surveys adopting design-based inference (through model-assisted estimation) and surveys adopting model-based inference. The standards comprise a set of criteria. For each criterion, we specify indicators of quality and reliability. Examples of criteria are the properties of the remotely sensed data used, properties of the field data used, the statistical procedures applied, and the methods adopted for quality assurance and quality control. For each criterion, we grade the studies from 1 to 5 ("poor", "fair", "good", "excellent", and "outstanding", respectively), and summarise the results across all studies for each criterion. We do not reveal our grading of individual studies but use the overall results for identifying what parts of surveys tend to be more problematic than others, and for discussing what developments would be relevant from the point of view of enhancing the overall quality of large-area AGB surveys.

Is the regression to the mean in remote sensing inventories a problem for forest planning?

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Information about the forest resource is needed to make decisions about future forest management. Traditionally, this information has mainly been gathered in the field. However, as improved sensors have emerged, remote sensing has become a commonly used technique for forest inventory. One of the most important changes this has meant for forestry is the availability of spatially detailed wall-to-wall maps of forest attributes. For example, wide-scale airborne laser scanning campaigns have been performed in some countries, and satellite-based systems like the Sentinel-2 continuously produce multispectral images on the continental scale. Estimates from these remote sensing inventories are of varying quality. However, they have the strengths that they are objective by nature, produce similar data for large areas, and provide a clearer error structure compared to traditional forest inventories in operational use. On the other hand, a profound weakness with model-based inventories is the regression to the mean, i.e., estimates for small attributes are overestimated while estimates for large attributes are underestimated. For example, small trees will be estimated to be taller than they are in reality and vice-versa. Such errors could lead to problems in making implementable forest management plans. In this study, we will address this topic by quantifying the risk of suboptimality in both economic and ecological terms from basing decisions about forest management on remotely sensed information. We evaluate forest planning performance for two inventory methods (airborne laser scanning and satellite imagery) in a business-as-usual scenario extended with concerns towards biodiversity values and carbon sinks. The results will provide insights into the effect of the regression to the mean for the benefit of the development of new remote sensing techniques and planning models. The results may also provide knowledge for the upcoming European Union processes regarding large-scale forest monitoring with remote sensing.

Mapping and estimation platform for EU wide forest monitoring with integrated field and remotely sensed data

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: The HorizonEurope project PathFinder (https://pathfinder-heu.eu/) will provide tools and design participatory processes for supporting evidence-based policies in the EU that foster synergies between forest-based bioeconomy and biodiversity. One of the objectives of the project is to develop a mapping and estimation platform for EU-wide forest monitoring based on integrated use of field and remotely sensed data. Here we present the main components and key functionalities of the platform.

The amount of data available for forest monitoring has been rapidly increasing over the past ten years. The influx of 10-30 m resolution satellite imagery (e.g. Sentinels and Landsats) and supporting Earth Observation (EO) based products (e.g. Copernicus pan-European forest High Resolution Layers), together with the growing amount of field measurements result in massive volumes of data. The only way to take full advantage of the synergies that the datasets offer is to utilize Big Data storage and processing approaches with effective inter-platform connections.

The PathFinder processing platform maximizes the use of existing components, linking them into a connected system of components allowing integrated use of field data with remotely sensed data and auxiliary datasets. Key components of the platform include:

1. Pre-processing of satellite and other auxiliary datasets.
2. Database of harmonized NFI field datasets
3. Extraction of remote sensing and auxiliary variables for field plots, ensuring the compliance with data restrictions such as secret plot coordinates.
4. Creation of high-resolution forest attribute maps integrating remote sensing and field data.
5. Estimation of forest statistics using NFI field data as the only source of information and in combination with wall-to-wall auxiliaries (typically products of EO data analysis) with the nFIESTA (new Forest Inventory ESTimation and Analysis) tool developed in the H2020 project DIABOLO.
6. Distribution of harmonized results through dedicated distribution channels (e.g. FISE).

The platform concept allows flexibility in the execution of each of the main components. Many of the components can be run in multiple platforms allowing to maximize the benefits of individual platforms. Similarly, the platform offers several models and estimators for forest attribute map creation and forest statistics estimation, and implementation of new ones.

MoniFun - Co-creating a blueprint of a harmonised European Forest Multifunctionality Monitoring System

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: The Horizon Europe project MoniFun will co-create—via an interdisciplinary, multi-actor approach—a blueprint for a harmonised European Forest Multifunctionality Monitoring System (EFMMS) that consolidates fragmented qualitative and quantitative information on forest multifunctionality into a comprehensive, interoperable system integrating existing platforms and data sources with innovative tools, to fulfil the needs of diverse stakeholders, policies, certification schemes and society. After mapping information needs, experts from different fields of forest multifunctionality will co-create harmonised indicators on thematic areas (forest resources in Europe; forests & climate change; forests & biodiversity; forests & society). Routines using partners' data will be developed and validated to: a) combine field plot (national forest inventories) and remote sensing (Copernicus) data to map forest multifunctionality; b) use artificial intelligence to monitor rapid changes in forests in real time; c) produce harmonised statistical estimates with accuracy and granularity meeting information needs; d) nowcast and forecast ecosystem services related to resilience needs under climate and halting biodiversity loss over various timespans; and e) feed the Forest Information System for Europe.

The main output of MoniFun will be a technical description of EFMMS, including recommendations for governance and funding. Financial support to third parties will be used to validate developed methods and analyse the possible of use of blockchain to augment information from existing public databases. MoniFun will share data, knowledge and tools with relevant related Horizon-projects. EFMMS will support the successful planning, implementation and evaluation of forest-related EU

policy objectives, including those of the New Forest Strategy, European Green Deal, Biodiversity Strategy, Bioeconomy Strategy, Fit for 55 Package, and Renewable Energy Directive.

Monitoring European forest condition in near real-time

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Climate-change induced forest decline is a major challenge for European forestry. In particular, recent extreme drought events as in 2018 and 2022 have resulted in widespread growth decline, tree die-back, and calamities. In order to timely react to emerging forest decline, foresters require up-to-date information on the condition of their forests. While ground-based forest inventories provide a high level of detail with regards to forest condition, the information typically comes at annual resolution with a delay of several months and is only representative for local sample plots. In contrast, remote sensing data deliver information on canopy reflectance in near real-time and across space, thus rendering a promising avenue for providing timely information on forests' condition.

Under this framework, we here present the European Forest Condition Monitor (EFCM). The EFCM is based on MODIS-NDVI and allows for visualizing and downloading information on the relative canopy greenness of any forest patch in Europe for any date since January 2001. The sensitivity of the EFCM to changes in forest condition is exemplified using case studies related to late-frost induced defoliation, drought-induced growth reduction, forest fire, and flood-induced dieback. Moreover, we show how EFCM data can be used to assess tree-species specific drought vulnerability providing valuable information for forest practitioners in context of managing the climate resilience of European forests.

Remaining methodological constraints of the EFCM are highlighted, resulting in a prospective for further refinement of existing and upcoming forest monitoring platforms. Here, particular emphasis is given to the implementation of freely available, high-resolution satellite images (e.g. Sentinel 2) and additional vegetation indices (e.g. NDMI, NDRE) that have rendered valuable for monitoring forest decline but also come along with computational challenges due to the vast amount of pixels that need to be processed on European scale. In conclusion, we present an existing and freely available European forest monitoring platform and provide suggestions for the further development of a pan-European forest condition monitoring.

Operational forest monitoring across Europe using Earth observation

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Forests cover more than 30% of Europe's land area and provide important services to society. Recent climate events have led to likely unprecedented episodes of natural disturbances, rising questions regarding the resilience of Europe's forests to climate change. Yet, there is a lack of comprehensive data on forest state and change across Europe, which has resulted in a call for developing a pan-European forest monitoring system. Within the Horizon Europe ForestPaths project we aim at approaching this ambitious goal by creating a (i) a new forest disturbance monitoring system and (ii) a set of base layers on forest structure and composition, both based on Earth observation data. The forest disturbance monitoring system is based on the analysis of annual Landsat time series processed consistently for all of Europe at 30 m spatial grain and covering all years since 1985. Different approaches for detecting disturbances are benchmarked with initial results showing substantial improvement compared to past datasets. A novel agent attribution approach further allows for attributing disturbances to either natural (i.e., wind, fire, bark beetle) or human (i.e., harvest) causes. Mapping base layers on forest structure and composition will be achieved by integrating dense time series from Sentinel-1 and Sentinel-2 with air- and spaceborne LiDAR data. Initial tests from Belgium suggest a high potential of this new approach for mapping key structural features (i.e., height, density, vertical diversity) and composition (e.g., leading species). Our approaches serve as a first step towards an operational Earth observation forest monitoring system across Europe.

Overview of the main challenges for comprehensive forest monitoring in Europe

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Comprehensive forest monitoring systems are crucial for supporting effective forest management and policy development and target setting. The new European Union (EU) Forest Strategy for 2030 calls for the development of an EU-wide integrated forest monitoring framework. This framework should address the patchiness of the current inventory systems, which includes national, EU, and international initiatives, expand the scope and overcome other challenges related to the systems currently in place. To identify the main challenges in developing a comprehensive forest monitoring for Europe, we reviewed more than 60 scientific papers, books, reports, and legislation and identified over a hundred issues that represent obstacles to harmonization and a holistic European system. Subsequently, we classified these issues into problem categories, which represent the main challenges for forest monitoring in Europe: (i) comparability: since most national forest inventory systems are developed independently, their definitions, time coverage, plot density, or resolution often differ in a way that data are not easily comparable, and datasets need harmonization to achieve the necessary comparability (ii) quality: assessment quality may differ between indicators within a forest inventory, or for the same indicator between forest inventories. This is influenced by differences in plot measurements, plot density or the number of plots over an area, and to which extent earth observation is included in the methodology (iii) transparency, accessibility, and dissemination: access to forest inventory data is mostly limited across European countries, including restrictions on in-situ plot data availability. The disseminated data is often expressed in a format that poses challenges in terms of usability and interpretation for different types of users (iv) indicator coverage: national forest information systems often lack a holistic approach and topics such as biodiversity and bioeconomy are not sufficiently covered. The development of comprehensive EU-wide forest monitoring and information system(s) has multiple motivations and is undoubtedly part of an ongoing political debate. Several ongoing projects are actively working towards addressing these obstacles. As the aforementioned problems differ in terms of their drivers, significance, and impacts, it is vital for the success of initiatives aimed at developing harmonization approaches to address solutions across all problem categories.

Pan-European, large-scale, long-term and harmonized – ICP Forests as a model for future international forest monitoring?

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Context. European forests represent an invaluable asset for wood production, biodiversity conservation and to combat climate change. While National Forest Inventories (NFIs) are important to periodically evaluate the condition of European forests, they may be limited in terms of international focus, temporal resolution, range of attributes covered, and data accessibility. These are exactly the areas where the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) has had its strengths for almost 40 years. By reviewing the main achievements of the program, here we show how it is relevant and useful to several European policy initiatives and discuss areas of future improvement.

Methods. Launched in 1985, ICP Forests includes now 42 Countries in Europe and beyond. It is based on a multi-level monitoring concept with a probabilistic component (ca. 6000 Level I plots) and an intensive, case-study oriented component (ca. 600 Level II plots). The two components are linked by a common set of attributes. Methods adopted by the ICP Forests are internationally standardized, regularly reviewed and updated, cover all ecosystem compartments, include comprehensive Quality Assurance/Quality Control, and permit annual reporting.

Main results and conclusion. Results can be considered in terms of scientific achievements and program's governance. In terms of science, ICP Forests was successful in detecting and reporting spatio-temporal changes in forest condition (in terms of forest health, growth, nutrition, biodiversity) and identifying their relationship with biotic (e.g. pests, diseases) and abiotic (e.g. climate, air pollution) drivers. In terms of governance, since its establishment ICP Forests adopted a model combining a bottom-up approach (with Expert Panels dealing with scientific evidence and methodologies) and a top-down decision-making mechanism (the Task Force, where all Countries are represented). Overall, this model was resilient during the dramatic political changes that happened in Europe since the 1990s, and was able to demonstrate over the past 40 years that harmonized international forest monitoring is possible and feasible. For the above reasons, while there are areas where considerable improvement is necessary, we consider ICP Forests as a useful model for future forest monitoring in Europe and beyond.

PathFinder:Towards an Integrated and Consistent European LULUCF Monitoring and Policy Pathway Assessment Framework

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: PathFinder will develop and demonstrate an integrated forest monitoring and pathway assessment system. This system will allow a consistent EU greenhouse gas reporting of the LULUCF sector, while at the same time, combine such monitoring capability with advanced pathway assessment to help plan the essential policy and implementation steps towards achieving the policy targets.

The PathFinder project is funded under Horizon Europe framework (no. 101056907) from 2022 to 2026. The PathFinder consortium consists of 24 partners including JRC and EEA, and is coordinated by NIBIO.

PathFinder combines the use of field and remotely sensed data for high-resolution mapping and precisely estimating forest attributes. The cooperation of the largest forest monitoring organizations operating in the EU, i.e., national forest inventories (NFIs) and the network installed under ICP Forests, provides a rich data base of harmonized ground truth information which will be complemented by a field survey of consistently assessed field monitoring sites. Advanced measurement devices will provide an audio-visual digital twin including genetic properties of the consistently monitored forest for maximum transparency and interoperability of new data. The analysis of combined databases will improve our understanding of fluxes among carbon pools and the development of biodiversity indicators.

The forest information of the monitoring system will feed into a scenario framework that forecasts outcomes of forest management alternatives. The scenario framework utilizes a wall-to-wall approach combining forest management, land-use, cross-sectoral demands, and climate impacts to forecast future forests. The scenarios facilitate trade-off analysis of forest ecosystem services and are potential alleys in the pathway assessment.

More information can be found under https://pathfinder-heu.eu/ and by following @EUPathFinder (twitter).

First results of the PathFinder project will be presented:
- The design of a consistent European field survey optimized for remote sensing applications.
- Advanced field plots that are assessed with various proximal sensors.
- Pan-European 10-meter-resolution forest attribute maps combining NFI and Copernicus satellite data.
- An estimation system that turns fine-resolution maps into relaible estimates.
- An analysis platform for communication the results.
- The forecasting system that supports today's decisions by predicting their future impact.

- Policy pathways that minimize trade-offs and maximize synergies among forest ecosystem services.

Potentials of National Forest Inventories for Annual Reporting: The case of Sweden

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Many national forest inventories (NFIs) in European countries rely on a combination of permanent and temporary field samples to gather information about the state and changes in forests. Normally the full sample is not measured each year. Rather, it is covered over intervals ranging between approximately 5 and 10 years. Estimates are typically reported as moving averages or average annual changes for the period between two consecutive measurements.

For current reporting on Land-Use, Land-Use Change and Forestry (LULUCF) in climate reporting for Sweden, a five-year re-inventory cycle is used. Data between consecutive measurements are interpolated and data for the most recent years are extrapolated for this reporting.

To fulfil upcoming requirements for forest accounts (FA) in Eurostat's proposal for amending Regulation (EU) 691/2011 on European environmental accounts, member states will need to supply annual estimates of standing stock, increment and drain for calendar years. These estimates can then be used for the interpolation of LULUCF climate reporting data and thus make for better cohesion in estimates reported within LULUCF and FA.

To meet the need for annual estimates, remote sensing (RS) data and different model-assumptions will be needed. We evaluate a solution involving:

1) Updating plot level information using normal growth models, applying ordinary mortality functions. Average annual growth multiplied by estimated annual growth index (from bore core measurements on temporary sample) is added to previous measurements per year since inventory.

2) Detecting harvesting activities, predicting harvested volumes and the remaining volumes on plots by continuous monitoring using Sentinel-2 satellite images with high temporal resolution.

This approach is expected to greatly reduce the bias when using the full five-year-panel, in comparison to ignoring the growth and harvest in estimating with full panel in spite of time difference. Potential improvements of sampling error by utilizing full sample means introducing model errors in growth and harvest volume predictions. These are also assessed. The possibility to combine the full sample with model assisted estimation may open up statistics production for both smaller areas and more narrow time-frames and will be compared to using only most recent inventory data.

Preserving European Forests: The Vital Role of Seed Monitoring in the Face of Climate Crisis

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: The 3 Billion Trees Pledge of the European Green Deal 2030 combined with an increase in disturbances and the trend for assisted migration results in high demand for tree seeds. Many of the required species show masting behaviour, intermittent seed production with high spatial synchrony. While this phenomenon is well understood in some species, we lack information on reproduction in many forest species. Monitoring their seed production will result in an increased understanding of their biology and the drivers underlying masting behaviour. In addition to increasing biological understanding, monitoring is important to plan seed harvesting and resource allocation within nurseries. Furthermore, it has effects on the number and diversity of seedlings available for forest managers, thus limiting their choices when reacting to disturbance events. Here, we discuss several monitoring concepts and investigate criteria that optimize the trade-off between effort and information gained. Monitoring of seed production within a coherent and consistent European framework would ultimately enable the prediction of annual seed production.

Project FORWARDS: The ForestWard Observatory to Secure the Resilience of European Forests

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Climate change has already had a harmful impact on forest ecosystems in various parts of the world. For this reason, the EU-funded FORWARDS project will prototype the ForestWard Observatory, a pan-European monitoring and evaluation tool that will help in demonstrating the impact of climate change on forests, guiding decision-making for practical forests management.

By developing the ForestWard Observatory and promoting Climate-Smart Forestry and biodiversity restoration, FORWARDS will reconcile the current divide between forest information obtained from the ground and from satellites incorporating timely and detailed information on European forests' vulnerability to data on climate change impacts.

The project will gather and apply information from existing networks and also establish a novel network of pilot sites testing climate-smart forestry and biodiversity restoration practices. The knowledge resulting from the research will be employed to inform relevant stakeholders of best practices, to secure the long-term resilience of European forests.

The European Forest Information Network (EFINET): toward a forest monitoring system based on remote sensing and ground data integration

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: Forests are a primary ecosystem in Europe and play a crucial role in citizen health and human wellbeing, representing a cornerstone to climate change adaptation and mitigation. However, Europe lacks a unified, and comprehensive forest monitoring system that integrate ground and remote sensing data sources. Currently, ground-based surveys from national forest inventories (NFIs) are the main data source for official statistics. Despite its valuable contribution, ground data alone presents some limitations due to cost, standardization issues, infrequent updates, and data access restrictions. Meanwhile, the increasing availability of remote sensing data combined with advances in cloud computing enables the use of sophisticated algorithms over large areas, opening new possibilities for generating comprehensive and up-to-date information on forest structures and dynamics in Europe.

To harness this potential, the European Forest Institute provided funding for the European Forest Information Network (EFINET) project, which aims to prototype a European forest monitoring system based on the integration of ground and remote sensing data. EFINET focused on the adaption of existing and the development of new methods in five representative large study areas: Bialowieza Forest (Poland), Tuscany (Italy), Canton of Grisons (Switzerland), Vindelaven Juhtatdahka biosphere reserve (Sweden), and the whole of Nederland. Airborne Laser Scanning derived metrics were used as reference data, due to their previously demonstrated strong correlation with several forest variables of interest, as canopy cover, diameter at breast height, tree height, basal area,

biomass, growing stock volume, carbon content, and their changes over time due to disturbances. Then, temporal patterns derived from Landsat data were employed to establish a comprehensive set of predictors for estimating forest 3D metrics. These predictors were then used to generate spatially-explicit estimates of forest disturbances and forest structure variables – complementary to NFI estimates.

Our results reveal that forest height metrics can be predicted through automatic analysis of remote sensing imagery with high accuracy, which is crucial from a European forest monitoring system perspective. Our approach provides indeed a core component of a fully integrated forest monitoring system, which will ultimately bring together the spatial consistency and temporal frequency of remote sensing with the fidelity of ground-based observations.

Towards a global forest map implementing the FAO FRA land-use definition

T5.34 The new age of forest monitoring: A common European forest monitoring system in a global perspective

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Abstract: The Food and Agriculture Organization of the United Nations (FAO) performs global Forest Resources Assessments (FRA) regularly at the request of and in collaboration with member countries since 1946. The most recent assessment (FRA 2020), examines forest resources, their management, and use in 236 countries and territories. Forest area and change is a key variable in FRA, particularly to support countries reporting on 'Life on Land' indicators - 15.1.1 and 15.2.1 of Sustainable Development Goals (SDGs) and the Nationally Determined Contributions (NDCs) to the Paris Agreement. For the FRA purpose, the FAO implements a harmonized definition of forest as land use, in contrast to common land-cover definitions. Moreover, the FRA forest land-use definition is implemented in the recent European Union Deforestation-Free Regulation (EUDR).

The FAO national reports provided by national correspondents for the FRA are mostly tabular data and aggregated estimates. A participatory global Remote Sensing Survey (FRA 2020 RSS) was conducted with the aim of improving estimates of forest area and change at global and regional levels by taking advantage of the increased availability of satellite imagery. The result is a unique dataset of satellite images consistently analyzed at 400 000 sample locations by more than 800 trained local experts from 126 countries and territories.

While the RSS provided quality interpretations at sample locations for regional and global analysis, the survey has not provided spatially explicit information on forest distribution. We will present here how Artificial Intelligence (AI) models trained on the RSS dataset can be leveraged to fill this gap. A first forest land-use map for different continents inferred from a model with over 90% overall accuracy will be showcased. The challenges paired with mimicking the human photointerpretation process with an AI model will be discussed, including accuracy assessment, feature selection, model architecture, and model training strategy. We will further present how these models trained and deployed on the FAO SEPAL cloud-computing platform can assist countries in developing their own forest maps using sample data.

T5.35 The next generation of forest decision support systems for tackling today’s and future challenges!

Accounting for economic and environmental impacts of farm afforestation

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: With the prevalence of often mis- or partially-informed political debates on the composition and management of future forests, there is an immediate need to provide policy, industry, and research/extension stakeholders with decision support systems (DSS) that go beyond traditional forest production to account for multifunctional outputs. As a largely agricultural country that provides substantial government subsidies to incentivise land use change to forestry, Ireland presents an interesting case-study of broadening an existing forest growth/economic DSS to facilitate life-cycle analysis of the economic (private) as well as environmental and social (public) impacts of different scenarios for land-use change in relation to both the long-term impact of new forest types and the potential to mitigate emissions from superseded agricultural enterprises, with regard to the provision of timber and non-timber life-cycle ecosystem services. Building on considerable cross-country modelling experience, the modelling approach adopted in this paper interacts timber and management considerations with soil type, policy subsidies and increasing carbon prices to provide quantitative values for the private (farmer's) life-cycle return to planting conifers and broadleaves in different agricultural contexts, but also quantifies the social/public (carbon) return for both land uses, along with bioeconomy inputs: roundwood and biomass production and flows to harvested wood products (HWP). The carbon impact is estimated using National Inventory Report methodologies and valued using government shadow prices for carbon. These economic and carbon values will be aggregated to develop life-cycle scorecards with different values for different soils, species types and management practices (e.g. thin/no-thin). An expert-based forest biodiversity scorecard will also be developed by the multi-disciplinary team, which will allow for the tabulation of quantitative economic and carbon impacts against tabulated qualitative forest biodiversity scores. As agricultural soils, land use and efficiencies vary widely and based on the dearth of micro-modelling of the agriculture/forestry land use change uvovered in a systematic review, farm/forest scale modelling is required to reflect the heterogeneity in land-use change decisions. Combining existing and new model components, the outputs of this challenging modelling framework should provide useful discussion points for other researchers, along with important topical information for a wide range of stakeholders.

A novel interactive multiobjective optimization method for group decision making in climate-smart forestry

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: Although storing carbon in forest trees, soils, and wood products is a straightforward way to mitigate climate change, decisions to do so depend on the preferences of the forest owners. For example, economic objectives typically conflict with environmental benefits and climate mitigation. Traditional forest management tools cannot support simultaneous consideration of climate and other environmental benefits and individual objectives (called climate-smart forestry). Climate-smart forestry can also be hindered by lack of awareness, communication, and collaboration between forest owners to have large enough areas for climate impact. Therefore, there is an acute need for a group decision support tool enabling climate-smart forest landscape planning where multiple forest owners can balance between various individual objective functions alongside some collective objective functions (e.g., climate and environmental ones), and different holding sizes are involved. The tool must be designed to increase the forest owners' awareness and support trade-off analyses and collaboration among them to find consensus plans for climate-smart forestry.

To address this crucial gap, in this study, we propose a novel interactive multiobjective optimization method enabling different forest owners to provide their preferences for both their individual and collective objective functions and support them in finding consensus plans that benefit both individual and collective objective functions. We demonstrate the usability of the proposed approach as a group decision support tool with a case study of climate-smart forest planning. We show in the pilot study how multiple forest owners with various holding sizes were supported in finding a consensus solution with the proposed method.

Adaptation strategies timeline for conservation and sustainable use of forest resources under uncertainty climate change.

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: The purpose of this research is to establish a timeline for implementing adaptation strategies that support the sustainable conservation and utilization of forest resources in the face of uncertain future conditions. By doing so, it seeks to determine the optimal timing for implementing adaptation measures and identify irreversible tipping points. The study focuses on a 250 km^2 area in northern Kyushu, Japan, including cities, rice paddies, and forests. Using climate scenarios and concentration pathways, the research projected forest stand growth and landslide risk for the 2030s, 2050s, and 2080s. Models estimated forest stand growth and the frequency of heavy rainfall events causing landslides. Based on the outcomes, five land-use maps were created: two for timber production and landslide reduction, two for balanced objectives, and one representing the current state. Modifying land use according to each map was considered as adaptation measure. However, implementing such measures faced limitations due to factors like the need to protect areas with high biodiversity, depletion of social and human resources resulting from population decline, and restricted transportation due to aging infrastructure. The evaluated the extent of achievement towards the optimal adaptation measures by considering these limiting factors and assessed the tipping point when the level of achievement dropped below 25%. The time period at which this tipping point occurred was recorded. The findings indicated that tree height growth patterns would change in various parts of the target area starting from the 2030s, but only a limited number of locations were expected to experience growth decline. On the other hand, landslide risks were projected to increase in certain areas of the target region from the 2050s onwards. As for both growth and landslide risk projections, the uncertainty associated with climate scenarios and RCPs amplified from the 2050s onwards. The decreasing effectiveness of adaptation measures and the growing uncertainty towards the later part of the period suggest that early implementation of adaptation measures may yield better results.

An interactive decision support tool for sustainable robust forest harvest planning

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: Sustainable forest management involves decision-making problems with multiple conflicting objective functions (e.g., economic, environmental, and social), multiple periods, and different sources of uncertainty. We have designed an interactive decision support tool prototype for sustainable, robust forest harvest scheduling in multiple periods. A novel multi-scenario multi-objective mixed-integer optimization problem has been formulated and solved, providing support for forest planners to study the existing trade-offs between demand satisfactions for multiple assortments in different planning periods. Besides, an intuitive robust analysis to study the outcomes variations caused by uncertainty and find a robust schedule in tactical forest planning problems has been proposed. The prototype's usability has been examined with a case study of forest harvest planning with 250 stands, three assortments (pine, spruce, deciduous trees), and a twelve-month harvest planning horizon.

Ecosystem-based Adaptation and Changemaking to Shape, Protect and Maintain the Resilience of Tomorrow's Forests

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: In the Horizon Europe project, *eco2adapt*, we will develop the Ecosystem-based Adaptation (EbA) framework, derived from Nature-Based Solutions (NBS), that harnesses biodiversity and ecosystem services to reduce vulnerability and build social-ecological resilience to climate change. We will work in Living Labs in Europe and China, located in climate hotspots, and adopt a cutting-edge Decision Theatre approach to investigate how forest managers integrate disturbance and vulnerability into decision-making. Scenarios of how disturbance affects forest dynamics and ecosystem services at a landscape scale will be derived through modelling, and in Living Labs, stakeholders will learn how their choices affect ecosystem services in neighbouring forests. We will combine interdisciplinary knowledge from scientists and stakeholders in Europe and China to understand perception and provide incentivization for adopting EbA solutions, through local capacity-building and national policy plans. Through the same Decision Theatre methodology, we will use a capacity building approach to create and promote innovative technical, economic and governance mechanisms at a regional level. Semantic technology will be applied to create a knowledge base for hosting FAIR data and creating a SmartPhone Application (named the OneForest ToolBox) that allows users to access and add data concerning climate-resilient species, provenances, mixtures, management techniques and ecosystem services, whilst taking into account future uncertainties about climate and societal changes. We also provide a suite of cutting-edge tools to monitor vulnerability and resilience (including invasive species and above-and belowground biodiversity), at all levels of society – from the citizen to the policy-maker. By including tailored communication to all levels of society, we will reach out to a broad audience that has the capacity to cause positive change.

Environmental, safety and economic benefits of two-stage trucking in harvesting operations, introducing a decision-supporting tool

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: The authors aimed to provide a decision support tool to optimise transportation and roading decisions by considering economic, social, and environmental factors. Two-stage trucking uses capable off-road vehicles to transport logs to roads that highway trucks can use. That solution is beneficial since it needs less roading and smaller landing sites and decreases erosion. The trade-off is the potentially higher cost due to the additional downloading and uploading of vehicles. Therefore, a multiattribute decision-supporting tool helps find the best solution by harvesting sites.
Based on semi-structured interviews with forest owners, forest management companies, harvesting crews and transportation companies, the key factors: terrain, existing road network, specific challenges of the roads, the total mass of logs from the harvest, erosion risk, multiple woodlots and harvests served by one super-skid, and the landing site distance from the all-season road.
Interviewees found economic and environmental benefits of two-stage trucking compared to one-stage trucking, mainly from the less roading and smaller landing sites. Generally, the steeper the terrain, the more benefits the two-stage trucking. Two-stage trucking can reduce roading by 30%. Sediment traps need to be emptied less frequently, which indicates less erosion from logging operations and infrastructure construction. The well-organised two-stage trucking operations reduced operation waste and improved safety. The number of incidents was significantly reduced reported by forest management companies.
Following the interviews, several time studies were conducted at harvesting sites to establish the logistic-economic model and identify the critical variables, distributions, and best-fitting regressions. Their probability distribution represented essential factors and outputs to make the model adaptable to various environments. The challenging terrain, lack of forestry roads, smaller woodlot, and longer transportation distance on an all-season road make two-stage trucking beneficial compared to one-stage trucking.
The designed integrated logistic-economic model asks for a reduced set of inputs (terrain -1-5 scale-, total wood mass, existing roads -yes/no-, distance from mill and distance from an all-season road) from the users.

Integrated Decision Support Systems for delivery of ecosystem services based on EU forest policies (DSS4ES): New COST Action CA22141 project

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: The role of digital technologies continuing to enhance the sustainability of value chains grounded in renewable resources has been well acknowledged. Within these technologies, the advanced DSS with embedded Operations Research techniques has proven to be indispensable tools for the long-term sustainable production of forest products and conservation of services. In this context, new COST Action has been started in 2023. The main aim of this Action is to establish a research network for facilitating the conceptualization and development of new methodological approaches of the next generation of DSS covering the relations between forest, forest landscape management and stakeholders of the landscape. The emphasis is on screening, evaluating, and proposing decision-making tools and methods. There are five focal points of the Action: 1) data and knowledge, for gathering and utilization of forest characterization; 2) models and methods, for design of DSS; 3) user perspective, for processes involving stakeholders; 4) DSS integration of various ES; 5) governance**,** for approaches of translating results into practice. The results of the Action will support holistic landscape planning approaches, which enhance sustainable forest management, considering a full range of ES, and address the policies and regulations across Europe. In this respect, an integrated DSS for sustainable provision of multiple ES at landscape scale includes support for the provision of resources for bio-based economic activities. The concept, structure and the process of the Action and opportunities for joining the network will be presented in interactive way for engaging the audience.

Modelling forests as social-ecological systems - A systematic comparison of agent-based approaches

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: Forests play a substantial role for a multitude of nature's contribution to people: in relation to biodiversity loss, climate change mitigation and adaptation, water availability, timber production, local ecological knowledge, and recreational values. This wide range calls for appropriately complex approaches to capture human behaviour in forest systems. Starting from a social-ecological system understanding, we perform a systematic comparison of agent-based models that can be used for understanding human-nature interactions in such systems. In contrast to traditional decision support system, agent-based approaches are developed to explicitly model heterogeneous agents. This study highlights strengths and areas for development of agent-based approaches as forest decision support systems. We find that out of 31 reviewed models, only 10 approaches include a direct representation of interactions between social actors and forests. Our comparison highlights three main angles for further development: i) calibration and validation of agent-based approaches include workshops, surveys, remote sensing and field measurements but robust methodological standards are still lacking, ii) agent learning and the dynamics of such feedback loops are emerging in computational science but are not yet fully implemented in social-ecological systems approaches, iii) coupling to ecological models such as dynamic vegetation models or species distribution models is only implemented in a few forerunner models. Based on this comparative overview, we present and discuss four agent-based model frameworks that are situated along these development frontiers: CRAFTY, FLAME, CORMAS, SOSIEL and PALM. These involve direct interaction among and between social and ecological systems, dynamic representation of processes, and a flexible design that allows for adjustments beyond their original purpose.

Key words: ABM, forest management, decision, model choice, complex adaptive system

Optimal Locations of Mass Timber Manufacturing Facilities within the Wood Supply Network in the United States

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: Mass timber building materials are becoming more popular worldwide due to their many benefits, including their low carbon footprint, potential lower construction costs, and ability to support sustainable development. Despite growing popularity, facilities manufacturing mass timber are still limited in the United States. Users mostly rely on imported mass timber, primarily from Europe, which is economically and environmentally inefficient. It is therefore crucial to establish a regional supply chain network of domestic mass timber industry. By integrating factors on demand and supply side of mass timber, such as regional mass timber demand forecasts, raw material availability, transportation networks, sawmill capacity, the cost of acquiring raw materials, and labor force availability, this study aims to identify optimal locations for new mass timber manufacturing facilities within the conterminous United States. Our GIS-integrated mathematical optimization foundation uses information about North American road networks, forest ownership, mill locations, and an estimate of mass timber demand based on city population densities to find optimal locations for both softwood and hardwood mass timber manufacturing facilities. Our study aims to create an ideal network between timber suppliers (sawmills), new mass timber manufacturing facilities, and timber growers by considering supply chain networks and the anticipated demand for mass timber in US regions. Findings will be useful in informing forestry stakeholders on the viability of mass timber manufacturing and regional development planners regarding ideal sites for strategic investment on mass timber industry.
Keywords: Mass Timber, Supply Chain Network, Manufacturing Facilities, Timber Supply, Softwood/Hardwood Sawmill

PixSim: Enhancing high-resolution large-scale forest simulations

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: PixSim is a flexible, cross-platform, open-source stand level forest growth simulator designed to operate at the pixel level using high-resolution wall-to-wall forest resource maps. It addresses the need to adapt forest growth simulators to modern remote sensing-based forest inventories, offering forest scientists and managers a powerful tool to enhance forest management strategies and decision-making processes. By operating at the pixel level, PixSim enables improved spatial resolution and captures intra-stand variability, which is often overlooked in stand-level simulators. Implemented in the R programming language, PixSim offers minimal package dependencies, provides flexibility and scalability, and has been optimized for high-resolution large-scale simulations, ensuring efficient computation. The simulator's flexibility and open-source nature facilitate the incorporation of management modules and the inclusion of climate change scenarios in simulations.

Potentials and limitations of adaptive management and the resilience concept for real-world decision making in forestry.

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: The transformation of our ecosystems due to global change is characterized by complexity and dynamics, subject to rapid change and disturbance. Foresters need to integrate deeper uncertainties and a wider scope of ecosystem services and stakeholder interests into their silvicultural considerations. A vast body of theoretical knowledge on adaptive management and the resilience concept with its different scopes for forest ecosystems already exist. Yet real-world examples for adaptive forest management and widely accepted implications of managing for resilience are not established yet. But what are the obstacles that prevent these theoretical concepts from becoming on-the-ground solutions for forest stewards and nature conservationists?

The trend in forest sciences goes towards viewing forests as complex, adaptive and open socio-ecological systems rather than something that can be steered with a command-and-control approach. Forest ecosystems are complex, have emergent properties and are capable of ecosystem learning and responding to impacts with resilience.

Nevertheless, little attention has been put on forester's perception of forest ecosystems and the bias in their decision-making in this complex and ontologically uncertain environment. Our hypothesis is that some of the needed prerequisites for adaptive management, namely experimenting, advanced monitoring and data availability and interregional networking as well as communication with stakeholders are hindered by structural limitations in the communication with science and superordinate hierarchical levels.

On my poster I will present some preliminary results from a series of qualitative interviews with German forest managers that specifically target their perception of uncertainty and their personal obstacles for incorporating adaptive management into their decision making. Findings will be presented in two categories: a more general, theoretical framework on the hierarchical, temporal and spatial environment that foresters centre their decisions around and more concrete problems like management tools or organisational institutions that foresters would need to improve for effective and future-oriented, uncertainty-sensitive decision making.

Supply and Demand of Local Forest Cultural Ecosystem Services based on Human Activity using Agent-Based Modelling

T5.35 The next generation of forest decision support systems for tackling today's and future challenges!

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Abstract: Efforts to quantify ecosystem services (ES) from supply and demand perspectives and incorporate them into environmental policies have been implemented. Among these efforts, the estimation of ES supply often reflects the features or capacities of the ecosystem related to the target ES, regardless of whether humans actually consume the ES. Demand is often estimated from a macro perspective using various data, such as social media and consumption patterns, assuming that humans consume ES supply. However, few studies have estimated ES at the micro spatial scale or individual level, considering the direct activities of humans. In particular, for cultural ecosystem services (ES), micro-scale human activities such as hiking and tourism play a significant role in determining supply and demand, compared to provisioning, regulating, and supporting ES. Therefore, if the existing macro-level methods are used to estimate cultural ES, there is a possibility of underestimation or overestimation. Thus, this study presents a new methodology to estimate cultural ES scores from the perspectives of supply and demand at an individual scale, considering individual human activities and assessing the mismatch. We utilized spatial data on mountain trails to estimate the supply ES score and conducted a viewshed analysis. We employed agent-based modeling (ABM) to simulate individual hiking activities and quantify their potential exposure to ES for the demand ES score. Our approach yielded a more detailed cultural ES supply score than traditional map-based approaches. By considering the number of hikers and their actual moving patterns, we achieved more accurate results for the supply-demand mismatch at an individual level. This methodology enables the examination of supply-demand mismatches in cultural services across various scenarios at an independent scale. The findings of this study offer implications for establishing effective policies that balance the supply and demand of cultural services in real-world contexts.

T5.36 Towards a global observatory of forest dynamics

A global map of disturbance patterns across the world's forests

T5.36 Towards a global observatory of forest dynamics

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Abstract: The patterns left by disturbances on forest landscapes are the result of a complex combination of factors, involving the causal agents, the pre-disturbance state of the forest and the broader environmental context. Characterising these patterns and understanding their distribution is therefore necessary for understanding the processes governing forest dynamics and how they can shape future forests. However, despite the increasing richness of ground and remotely sensed forest observations, we have limited knowledge on how forest disturbances differ structurally across the world. Here, we combine patch-level quantifications of disturbance structure, calculated from Landsat-derived tree cover loss data recorded between 2002 and 2014, to categorise and map forest disturbance patterns at the global scale. Based on metrics reflecting magnitude, shape complexity and spatiotemporal clustering, four patterns could be identified: i) small-isolated patches, the most abundant type, ii) clustered patches, prevailing in fragmented and sparsely treed forests, as well as in the dense intact forests of the Amazon, iii) complex patches, preponderant both in number and coverage, and iv) large-multi-year patches, the least abundant but most dominating spatially. In terms of counts, these patterns occurred in consistent proportions across all forested biomes. However, in terms of aggregated areas, the large-multiyear patterns were the most prominent in the fire-prone boreal and Mediterranean forests, while the complex patterns were as much dominating as the large-multiyear patterns in the heavily harvested forests across the Tropics and temperate regions. The disturbance patterns identified will provide a strong basis for elucidating the causal agents and for projecting potential trajectories of forest recovery.

Abundance of Northern Hemisphere tree species shrinks in the warm and arid regions of their climatic niche

T5.36 Towards a global observatory of forest dynamics

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Abstract: Long-term forest inventories provide an important data source due to their wide spatial extents covering large environmental gradients and detailed information on forest structure, composition and demography. These characteristics allow forest inventories to quantify a wide spectrum of indices from changes in forest dynamics to multifunctionality and give them a fundamental role in understanding the impacts of global change on forests. We analysed Northern Hemisphere forests with national forest inventories from Europe and North America, to quantify changes in tree species abundance across Northern Hemisphere forests in recent decades (1985-2019). For our analyses, we considered more than two million measured trees from 73 widely-distributed species on more than 126000 forest inventory plots. We found a generalised abundance decrease across the different regions of the species' climatic niche. However, when comparing changes in abundance within species, we observed that declines occur mainly in the warm and arid regions of their climatic niche, even adjusting for stand development. This result was also supported by quantifying the relationship between climate-driven abundance changes and species' climatic

niches. Our results imply an ongoing shift in abundance optimum of Northern Hemisphere tree species towards the cold and wet regions of their climatic niche but that might not be sufficient to track climate change for most species. We provide information on species-specific changes in abundance that must be taken into account when designing planting, management and conservation plans in the face of increasing climate change impacts.

AfriTRON: Challenges and Opportunities of Monitoring Africa's Closed-Canopy Tropical Forests

T5.36 Towards a global observatory of forest dynamics

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Abstract: Africa is home to the second largest block of closed-canopy tropical forest on Earth. Africa's forests play a major role in the global carbon cycle, being a major carbon sink in intact forests and a major source from deforestation and degradation. They distribute water to the Sahel and Nile headwaters contributing to maintaining agriculture that sustains 300 million rural people. In terms of biodiversity they are home to our closest living relatives, and are centres of mammal diversity. Yet we know very little about these forests and how they function in our rapidly changing Earth system. To help address this the African Tropical Rainforest Observatory Network, AfriTRON, has been established since 2009 (Lewis et al. 2009, Nature; www.afritron.net) to collect and collate standarised permanent plot inventory data across closed-canopy tropical forests in Africa, monitoring all trees >=10 cm diameter in plots, and periodically re-visiting them to assess tree growth, mortality and changes in carbon stocks. There are now ~500 locations with data across 14 countries spanning central, west and east Africa. Here we present the latest results from the AfriTRON network on the changing dynamics, carbon balance, and impacts of drought, temperature and elevated carbon dioxide concentrations on these forests. We then highlight the opportunities for understanding and better managing these forests, if the AfriTRON network obtains funds to continue recensuses and fill-in data gaps spatially, and the challenges faced by African scientists in doing science on the continent, including of making data not only open, but open and fair. We highlight that any 'global observatory' will be limited by the limitations of the most difficult to sample major forested regions of Earth. The world's second largest block of tropical forest is one of those, so a focus on Africa to build any global observatory is a must.

Building a global airborne laser scanning database to capture the 3D structure and dynamics of the world's forests

T5.36 Towards a global observatory of forest dynamics

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Abstract: Forest ecosystems vary enormously in the 3D structure of their canopies due to differences in the height, crown architecture, density and size distribution of their trees. Capturing this spectrum of structural diversity and complexity is essential to understanding the role that forests play in regulating both carbon and water cycling on land, as well as their ability to provide habitat for biodiversity and regulate local microclimatic conditions. When it comes to large-scale mapping forest canopy structure, airborne laser scanning (ALS, also known as LiDAR) is widely considered the gold standard due to its ability to generate accurate, high-resolution canopy height models (CHMs) and digital terrain models (DTMs) of entire landscapes. However, acquiring ALS data remains expensive and access to data is often limited to a small number of sites surveyed on a project-by-project basis. To overcome this hurdle, we compiled the first global ALS database of forests, including data acquired at >10,000 locations across the world and spanning all major forest types on Earth. The database will be hosted online, allowing users to explore the location of the individual ALS datasets on a map, query key aspect of their metadata (e.g., acquisition date, flight parameters, sensor specification, data contributors), and download analysis-ready CHMs and DEMs for those ALS datasets that are open access. In doing so these data will feed directly into numerous areas of ecological research, as well as providing crucial cal/val data for forest biomass mapping efforts, satellite data fusion and integration with land surface models – ushering in a new era of canopy science and discovery.

Building the AfriMont network to study Africa's montane forests

T5.36 Towards a global observatory of forest dynamics

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Abstract: Until recently, carbon stocks in African montane forests were poorly known, with insufficient data to generate an old-growth specific default value in the latest IPCC guidelines. To address this knowledge gap, we formed the AfriMont network, bringing together over fifty researchers who had established inventory plots in montane forests. We found that African montane forests on average stored 149 Mg C ha^{-1}, comparable to lowland African forests and greater than forests in tropical America. This ground-based data is especially valuable as remote sensing data related poorly to field measurements in our topographically complex mountain sites. We discuss experiences from building the network, and the challenges for sustaining it to monitor forest dynamics.

Ecological insights unveiled: half a century of research at Stillberg, a high-elevation afforestation in the Swiss Alps

T5.36 Towards a global observatory of forest dynamics

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Abstract: The catastrophic avalanche winter of 1950/51 devastated large areas of protective forests in Switzerland, raising questions about causes of such damage and the implementation of preventive measures for the future. Consequently, the high elevation afforestation Stillberg was established in the treeline ecotone near Davos in the eastern Swiss Alps. The experiment aimed to investigate methods for regrowing avalanche-damaged forests and developing sustainable measures to reduce avalanche risk. Since 2016, the site is integrated into the European Long-term Ecosystem Research network (eLTER).

In 1975, a total of 92’000 seedlings of *Larix decidua*, *Pinus mugo* ssp. *uncinata*, and *Pinus cembra* were planted along an altitudinal gradient at and above the current treeline (2075 to 2230 m a.s.l.). Annual monitoring of tree survival, growth, and vitality was conducted from 1975 to 1995, with additional assessments in 2005 and 2015. Meteorological parameters have also been continuously measured, alongside the documentation of microsite features such as solar radiation and snowmelt date.

During the initial 15 years after establishment, mortality rates were highest. Snowmelt date emerged as the most important factor influencing the mortality of all tree species, while elevation strongly affected growth during the first three decades. Pathogenic snow fungi were the primary agents of mortality of *P. cembra* saplings. Over time, the relative importance of different environmental variables for tree health and growth changed, leading to a *L. decidua*-dominated forest where competition and facilitation became crucial processes in recent years. Over the course of half a century of research at the Stillberg research site, a wealth of data has been collected, which have recently been made available as open research data. These datasets can contribute to transdisciplinary syntheses exploring ecosystem processes and the impact of climate change in mountain regions. In the face of climate change, new questions arise about suitable management strategies to adapt high-elevation forests to future climatic conditions without compromising the multiple ecosystem services they provide. As a result, the site is currently used as one of five demo sites in the EU-funded project FORWARDS, which aims at prototyping a future European observatory for climate change impacts on forests.

Land-use change effects on habitat availability and genetic diversity of tropical trees

T5.36 Towards a global observatory of forest dynamics

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Abstract: Land-use change presents major threats to biodiversity with impacts typically outpacing those from climate change. Habitat loss and fragmentation, key features of land-use change, can have direct and indirect consequences on plant species including reduced size and connectivity between populations, and reduction of genetic diversity. In Puerto Rico, for example, forest cover dramatically increased from ~6% in the early 1900's up to ~55% today. We quantified the impacts of land-use change on the area and configuration of suitable habitat patches for 267 native tree species in Puerto Rico to understand how land-use dynamics have affected their current geographic distributions, population sizes and genetic diversity.

We built species distribution models (SDMs) for all native tree species in Puerto Rico (N=267) based on current geographic distribution and abiotic conditions. We then combined SDMs with available data on land-use change (based on historical aerial photos from the 1930s, 1950s, and 1970s, combined with more recent satellite imagery) to estimate habitat availability through time. We used Plot based data from the Forest Inventory and Analysis (FIA) Program of the US Forest Service to estimate current population sizes and forest cover. Our results provide species-specific information on (i) the areal extent (km2) of climatically suitable habitat at different time points, (ii) fragmentation indices of suitable habitat at different time points and (iii) species responses to land-use change according to their life history strategies and phenotypic traits.

Overall, 223 species gained and 44 species lost suitable habitat during the time period analyzed. Species-specific responses varied and depended on species' life-history strategies, phenotypic traits, and general habitat association. To more comprehensively assess both the short- and long-term effects of land-use change, we will integrate this information with population genetic data. We will use a comparative genomics approach to determine how land-use change has influenced patterns of genetic diversity for a focal set of 20 tree species with diverse life-history strategies and climatic associations. This will allow a broader understanding of the implications of habitat recovery for forest genetic resources.

Monitoring tree growth and mortality in central Africa

T5.36 Towards a global observatory of forest dynamics

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Abstract: Tree growth and mortality are two central processes in mixed and structurally complex moist tropical forests. Accurate estimates of the variables needed to model them remain sparse and scattered though. It remains thus difficult to predict forest evolution at a local scale and build reliable management plans. To fill this gap, from 2009 and up to now, we have annually monitored up to 21,000 trees belonging to 42 species exploited for timber production in Central Africa. To this end, we set up a particular sampling scheme. We sampled tree individuals without establishing plots, while ensuring that at least 20 trees were measured per species, site and logging history. With this data, we successfully provided new species-specific estimates of diameter increments and mortality rates, and we could investigate the relationships between tree growth, tree size and logging history. The resulting estimates can be used to provide more accurate forest projections (e.g. with matrix population models) and draw up sustainable management plans. Yet, the within and between-site variability were substantial, and further long-term data should be collected in different sites to predict tree growth and especially tree mortality with accuracy under different ecological conditions. The pros and cons of our monitoring systems will next be discussed and compared to other approaches used to monitor forest dynamics.

Quantifying European forest harvest regimes – a realistic representation of forest management for large-scale models

T5.36 Towards a global observatory of forest dynamics

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Abstract: The majority of forests globally are impacted by human activities and Europe in particular has a long history of intensive forest use. Harvesting of wood is one of the key processes of forest management, altering forest dynamics from tree recruitment to growth and mortality. This makes accounting for it crucial in any large-scale analysis of forest ecosystems. Yet, the representation of harvests in large-scale models is typically far from realistic, as the true management regimes – a realization of decisions made by individual forest owners – are not well described by simple rules or even by formal management guidelines. Here, our goal was to use field-based forest inventories to characterize European forest harvest regimes, implement these in the demographic vegetation model LPJ-GUESS and assess the effect on carbon dynamics. We quantified harvest regimes in 11 countries based on forest inventory plots (in total over 180 000 plots). Harvest regimes were described in terms of frequency and intensity of harvest events, and their relationship with potential drivers of harvest were quantified, considering pre-harvest forest structure, growth conditions, natural disturbances and variables relating to the policy environment, harvest costs and management goals. The results reveal notable variation in harvest regimes across Europe, with differences

between the countries, but also finer-scale variation within country borders. The results were then used to implement empirically-based harvest regimes in LPJ-GUESS, deriving harvest probability and intensity from the patterns observed in the data. The quantification of the current harvesting regimes across Europe provides much needed detail and fidelity in our understanding of the contemporary forest management practices, and implementation in vegetation modelling brings the model simulations closer to what is happening in forests in reality. This enables both improved assessments of continental-scale carbon dynamics and a realistic reference to which potential future forest management regimes can be compared to.

The Power of Plots: tracking Earth's tropical forests one tree at a time

T5.36 Towards a global observatory of forest dynamics

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Abstract: Tropical forests, Earth's most precious ecosystems, are changing as never before. Meanwhile, careful, long-term measurements are essential to know how, where and why. The tropical forest carbon sink and its changing dynamics - which we only know about because of thousands of plot-level measurements - have consequences for policies intended to stabilize Earth's climate. Can we rely on tropical forests to keep on helping us? One thing is for sure, if we don't look, we won't know. Meanwhile, the people making the necessary measurements are among the most disadvantaged in global science. The large investments being made in remote sensing, machine learning, and open data initiatives have potential to help, but they also risk exacerbating the structural inequalities in global forest monitoring where thousands of key workers on the ground are already helping to make big data science possible, science that is largely led by others.

Our challenge is therefore huge - to unite researchers across the world to understand the ecology of tropical forests, their sensitivity to climate change and how they may help to slow it, while simultaneously making the research process much more equitable. ForestPlots.net aims to bring communities together to support sustainable, equitable and reliable long-term monitoring of Earth's most critical ecosystems and create a shared scientific picture of their health.

In this talk I will first briefly touch on the key findings from our tropical ground monitoring. I will then especially explore the scientific, practical and ethical challenges that we face, as we try to ensure that both the production and the use of forest data becomes more equitable, that the many less-visible colleagues who contribute vital work receive real recognition, and that we build fair, long-term collaboration across national, economic and cultural divides.

Towards a global understanding of tree mortality

T5.36 Towards a global observatory of forest dynamics

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Abstract: Rates of tree mortality are increasing in many regions, with implications for forests and climate. Yet how and why these trends vary globally remains unknown. Developing a comprehensive assessment of global tree mortality will require systematically integrating data from ground-based long-term forest monitoring with large-scale remote sensing. Here, we summarise data from more than half a million forest monitoring plots from 88 countries and five continents and discuss the potential to use these to estimate tree mortality trends globally. Our survey shows that the area monitored increased rapidly from 1960 and has remained steady since 2000. Our data also shows large regions with limited ground-based information on tree mortality, especially the tropics and Asia. The integration of existing forest inventories with remote sensing and modelling can potentially fill those gaps, but this requires development of methods and legally binding agreements enabling seamless flows of information from the field to global assessments of tree mortality. Finally, a truly global monitoring effort must promote fair collaborations, transferring funding to and empowering scientists from less wealthy regions. Increasing interest in forests as a natural climate solution, the advancement of new technologies and world-wide connectivity means that now a global monitoring system of tree mortality is not just urgently needed, but also possible.

Unity makes strength: accelerating tropical forest science and building capacity through a global alliance of research networks

T5.36 Towards a global observatory of forest dynamics

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Abstract: Tropical forests contribute to approximately 70% of the world's forest carbon sink and support more than half the known species on Earth. Despite their global significance, our empirical understanding of the structure and functioning of tropical forests remains hindered due to the limited availability of field-based observations across environmental, disturbance, and successional gradients. While several international research networks have made significant contributions to tropical forest science over the past decades, none of them offer a comprehensive pantropical perspective on the dynamics of these critical ecosystems.

Here, we introduce the Alliance for Tropical Forest Science (ATFS), a new pantropical partnership that aims to accelerate research and build the scientific capacity necessary to improve understanding of how tropical forests function and to predict their responses to future environmental changes. The ATFS brings together 12 international tropical forest plot networks that manage 11,680 forest plots across 57 countries. We present the main objectives of the alliance and share the experience from the Tropical Forest Mortality Working Group (ATFS–MWG). We discuss the main challenges and showcase recent advancements in multi-network data harmonization and capacity building, along with preliminary results from the first multi-network study aiming to identify the primary drivers of tree mortality and associated carbon losses across the world's tropical forests.

As climate changes, assembling the disciplinary expertise, data, and scientific capacity across tropical forests is critical to resolving the underlying drivers of forest dynamics as well as informing the policy initiatives necessary to stop further global temperature increases and biodiversity losses.

Using a tree ring network to detect tropical forest responses to global change

T5.36 Towards a global observatory of forest dynamics

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Abstract: Introduction. Tropical forests and woodlands are key components of the global carbon cycle, and have a large potential to help mitigating climate change. Their ability to sequester carbon is likely diminished by increasing droughts. Yet, little is known how droughts affect wood production at pantropical scale. A new tropical tree-ring network helps filling this gap.

Questions. We answered the following research questions. (1) To what extent is tree stem growth reduced during drought years, and does this differ across droughts caused by low precipitation, high vapour pressure deficit (VPD) or high climatic water deficit (CWD)? (2) Is there evidence for lagged effects of droughts on tree growth, and – if so – how strong or persistent are these? (3) To what extent is variation in drought effects explained by mean climate?

Methods. We used a pantropical network of 477 tree-ring chronologies (https://tropicaltreeringnetwork.org/) from (sub-)tropical latitudes, comprising 150 species, 35 plant families and > 10,000 trees. For each chronology, we used gridded climate data to identify the 10% driest years (since 1930) in terms of seasonal precipitation, VPD and CWD.

Results. (1) Tree-growth responses during drought years were highly variable, but mostly negative. At pantropical level, growth declines during drought years were very small: ~ -3% (dry season) and ~ -2% (wet season). These values were very similar across drought types. Growth declines during dry-season droughts were significantly larger for Gymnosperms than Angiosperms. (2) During the two years following droughts, pantropical growth anomalies returned to values close to zero (-1 to +1 %). Thus, we did not find evidence for lagged effects of droughts. (3) Growth declines during drought years were stronger in hotter and more arid areas, but ample local variation in responses remained.

Discussion. Tropical tree-growth sensitivity to droughts is highly variable, overall small in magnitude and short in duration. Nevertheless, mild drought responses in terms of tree growth may still cause elevated levels of tree mortality. Under climate change, we expect drought impacts on growth and mortality to aggravate due to warming, VPD rise and increasing drought frequency and intensity.