12th
IUFRO

Uneven-aged silviculture: insights into forest adaptation in times of global change

INTERNATIONAL CONFERENCE

Monday, September 18th – Wednesday, September 20th, 2023

Patronage: IUFRO working groups 1.05 and 1.09

Edited by Tomáš Vrška, Linda M. Nagel, Pavlína Pancová Šimková

Faculty of Forestry and Wood Technology and University Forest Enterprise Křtiny

IUFRO

Mendel University in Brno

MENDELU Faculty of Forestry and Wood Technology

MENDELU University Enterprise Masaryk Forest in Křtiny

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Content

Introduction

Dear Conference Attendees,

We are delighted to welcome you after 5 long years to the 12th IUFRO Unit 1.05 Uneven-aged Silviculture International Conference. This time we are happy to be hosting this meeting jointly with our friends from Unit 1.09 Ecology and Silviculture of Mixed Forests.

The Covid-19 pandemic temporarily prevented us from meeting in person. We have learned to use online communication effectively, including hosting scientific meetings, but there is no substitute for the benefits of personal contact and direct discussion. That's one reason for us to meet.

The second is even more serious. In parallel with the global pandemic, we are witnessing another „pandemic" - the impact of climate change on forests, which is the subject of our professional interests. Slowly but surely, natural forces are rapidly changing forests and, from the utilitarian point of view of humans, destroying long decades of cultivated stands. We now think about how to slow down this trend, and how to adapt forests to the new situation. But we are very well aware that we don't really know what the „new situation" will be. We prepare forests for conditions that we cannot define in the future, but can only estimate through the best models and projections we have today. The future of forestry will be very diverse and variable, and that is why we are joining forces together with the IUFRO Unit 1.09 Ecology and Silviculture of Mixed Forests. Time will tell how irregular forests will be (1.05) and how diverse (1.09), but we know that both attributes will be important for the future, and that they will intertwine.

And thirdly - we also have social reasons for our discussion. Modern society is very quickly changing its demands and expectations from the benefits forests provide. Today's priority of the urban population is not wood for heating, but recreational use of forests, and the many ecosystem services they provide, such as clean water, air, and shade. And in the era of vulnerable forests and large-scale disturbances, the public is growing concerned by the current situation and often blames today's forestry generation as being responsible.

We are meeting in the Czech Republic, which unfortunately today has a long tradition of planting even-aged conifer monocultures of the same age. It was also affected by a large-scale calamity in the years 2016-2021, while the problem of further disturbances and disintegration of these monocultures continues still across the landscape. We are therefore in the European center of gravity of today's problem of adaptation of forests to climate change. We recognize that more than ever, two-way communication between scientists and practicing foresters is essential. Therefore, we will also discuss how to train new knowledge in practice. It will be our greatest pleasure if our conference brings new insights for everyone, connects partial knowledge into a comprehensive understanding of the problem, and also establishes or refreshes already existing personal relationships.

Most sincerely,

Tomáš Vrška, Pavlína Pancová Šimková, Linda Nagel

Conference program

18TH SEPTEMBER 2023 - DAY 1

9:00 9:20 Opening Remarks

- **PART 1** **Moderator: Andrej Bončina**

9:20 10:00 **Keynote speaker: Linda Nagel**
Managing for Uncertainty through Adaptive Silviculture for Climate Change

10:00 10:20 Johannes Mohr
The impact of natural disturbances on uneven-aged forests in Central Europe - Are uneven-aged forests less affected by natural disturbances than even-aged forests?

10:20 10:40 Frank Krumm
Integrated forest management – promoting wood production and biodiversity

10:40 11:00 Coffee Break

11:00 11:20 Lucie Vítková
The concept and practice of ecological forestry in the context of central Europe

11:20 11:40 Hana Štraus
Assessing forest vulnerability to main disturbance agents as a basis for adaptation management: Experiences from Slovenia

11:40 12:00 Stefano Puccinelli
Climate smart and biodiversity-oriented forestry for European beech at rear edge. Preliminary outcomes from a systematic review

12:00 12:20 Closing Discussion of the Section

12:20 13:40 Lunch

- **PART 2** **Moderators: Olga Orman & Gauthier Ligot**

13:40 14:20 **Keynote Speaker: Toshiaki Owari**
Digital transformation of uneven-aged forest management and planning

		SECTION A	SECTION B
14:00	14:20	Miren del Río *Growth response to thinning in mixed and monospecific stands of Pinus sylvestris L. and Quercus petraea (Matt.) Liebl. across Europe*	Christian Rosset *Applicability of remote sensing data in uneven-aged forestry*
14:20	14:40	Mark J. Ducey *The Leak Distribution and its Application to Uneven-Aged and Irregular Stands*	Justin Crotteau *Transforming even-aged ponderosa pine to multi-aged stands in the northern Rocky Mountains*
14:40	15:00	Živa Bončina *Are homogenous European beech stands in Slovenia more uneven-sized and uneven-aged as anticipated?*	Bohdan Kolisnyk *Growth Dominance and Diversity: The Interplay of Stand Structure, Species Mixing and Growth Limiting Factors*
15:00	15:20	Closing Discussion of the Section	
15:20	15:40	Coffee Break	

- **PART 3** **Moderator: Tomáš Vrška**

15:40 17:30 Poster Session including short author's presentations

17:30 18:30 IUFRO 1.05 & 1.09 Business meeting

19TH SEPTEMBER 2023 - DAY 2

- **PART 4** **Moderators: Frank Krumm & John Devaney**

8:30 9:10 **Keynote speaker: Andres Bravo-Oviedo**
Increasing forest stand complexity in Southwest Europe

		SECTION A	SECTION B
9:10	9:30	Stanislav Kucbel *Five decades of structural changes in two old-growth mixed forests of the Western Carpathians*	Dorota Dobrowolska *The regeneration after the windthrow in the Piska forest: the role of large scale disturbances in Polish forestry*
9:30	9:50	Gauthier Ligot *Ungulates and succession dynamics reduce tree species richness in temperate oak-beech forests*	Vasilije Trifković *Assessing optimal and critical stand, site, and climatic conditions for recruitment of European beech, Norway spruce, and silver fir in uneven-aged forests*
9:50	10:10	Olga Orman *Variation in browsing intensity of beech and fir saplings in relation to their crown architecture and growth in natural mixed forests*	Pia Caroline Adamič *Growth response of European beech (Fagus sylvatica L.) and silver fir (Abies alba Mill.) on climate factors along the Carpathian massive*
10:10	10:30	Coffee Break	
10:30	10:50	Radek Pokorný *Adaptation measures in the Czech Forestry to GCC*	Mike Battaglia *Comparing the tree spatial patterns derived from various forest management treatments in ponderosa pine (Pinus ponderosa) forests of the Black Hills, USA*
10:50	11:10	Matjaž Čater *Light response of silver fir and European beech along Dinaric Mountains of the Balkans and the Carpathian Mountains*	Sonia Condés *Aridity is modulating the forest dynamics of the Scots pine – European beech mixtures in Spain*
11:10	11:30	Emira Hukić *Short term impacts of harvesting intensity*	Janusz Szmyt *Group-selection system as alternative management of Scots pine (Pinus sylvestris L.) forests facing climate change*

11:30	12:10	**Keynote Speaker: Petr Horáček** ***Climate change as a trigger to forest change in Central Europe - what lesson did we learn from biomonitoring of forest ecosystems?***
12:10	12:30	Tomaš Vrška *Silviculture for climate change and for new social expectations*
12:30	13:45	Lunch
13:45	14:20	Bus transport to the excursion
14:20	18:00	Excursion on the University Forest Enterprise
18:00	18:30	Return to Brno

20TH SEPTEMBER 2023 - DAY 3

- **PART 5** **Moderator: Sonia Condés Ruiz**

8:30 **9:10** **Keynote speaker: Arne Pommerening**
The trees, the people and the marteloscope – What human tree selection behaviour can tell us about CCF training requirements

9:10 9:30 Richard Deffee
The Irregular Silviculture Network (ISN) - Monitoring irregular stands and stands in transition from even-aged to uneven-aged structures in the UK and Ireland – early results from two ISN stands in Dorset, England

9:30 9:50 Gary Kerr
Forest Development Types: an essential tool for diversifying stands in Britain

9:50 10:10 Lenka Kuglerová
Can continuous cover forestry in wide riparian buffers improve their function and better protect Swedish streams?

10:10 10:30 Coffee Break

10:30 10:50 Srdjan Keren
Fine-scale spatial variability of stand structural features under active and passive forest management approaches

10:50 11:10 Keith W. Moser
Tree Response to Variations in Overstory Density and Climate in an Uneven-aged Ponderosa Pine Forest in the Southwestern US.

11:10 11:30 John Foppert
Implications of modern finance theory for the management of complex stands

11:30 11:50 Closing Discussion of the Section

11:50 13:00 Lunch

- **PART 6** **Moderator: Gary Kerr**

13:00 **13:40** **Keynote Speaker: Pablo Jorge Donoso**
More than one: Potential and challenges for mixed-species silviculture in South-American Temperate Forests

13:40 14:00 Satoshi N. Suzuki
Unexpected directional changes in relative dominance of deciduous broadleaves along an elevation gradient in a hemiboreal mixed forest zone in northern Japan

14:20 14:40 Mehdi Vakili
Resistance and resilience of Hyrcanian mixed forests under natural and anthropogenic disturbances

14:40 15:00 Daniel P. Soto
Selective harvest improves the stand structural complexity and productivity along precipitation gradient in temperate Patagonian old-growth forests

15:00 15:20 Closing Discussion of the Section

15:20 15:40 Closing Remarks of Keynote Speakers

15:40 16:10 Coffee Break

16:10 16:50 Bus transport to the Chateau Křtiny

16:50 17:30 Church Křtiny guided tour - excellent baroque building by J.B. Santini

17:30 18:00 Movies from University Forest Enterprise - knowledge of leading foresters with the transformation of forests from even-aged to uneven-aged stands

18:00 21:30 Dinner and social evening on the Chateau Křtiny

21:30 22:00 Return to Brno

Abstracts: Key-note speakers

Managing for Uncertainty through Adaptive Silviculture for Climate Change

• Author: Linda Nagel
• Key words: adaptation, diversity, heterogeneity, resilience, silviculture

Global climate change is expected to impact forest ecosystems worldwide, with growing emphasis on enhancing adaptive capacity of forests to maintain healthy and sustainable ecosystems. Climate-adaptation frameworks have emerged in response to this global challenge, aimed at guiding scientists and managers in developing adaptive forest management strategies. Approaches include close-to-nature silviculture, adaptive silviculture, ecological silviculture, climate-smart forestry, and nature-based solutions, among others.

In response to this need, a collaborative manager-scientist effort called the Adaptive Silviculture for Climate Change (ASCC) project was created to establish a series of experimental silvicultural trials in different forest ecosystems throughout the United States and Canada. Scientists, land managers, and a variety of partners have co-developed fourteen fully-replicated experimental sites as part of this international study to research long-term ecosystem response to a range of climate-focused adaptation approaches, enabling forest ecosystems to continue providing valuable ecosystem services into the future. Silvicultural treatments approximate a gradient of climate-adaptive management approaches: (1) resistance – maintaining relatively unchanged conditions over time; (2) resilience – allowing some change in current conditions, but encouraging an eventual return to reference conditions; (3) transition – actively facilitating change to encourage adaptive responses; and (4) no action control – allowing forests to respond to climate change without direct management intervention.

Site-specific treatments were collaboratively designed using local ecosystem vulnerability and socio-ecological contexts, and specifically address complex and changing disturbance regimes. The range of silvicultural treatments involve a combination of intermediate treatments, regeneration silviculture, forest assisted migration using natural and artificial regeneration, and increasing species and structural complexity and heterogeneity at the stand and landscape scales. This presentation will provide an overview of the ASCC Network, emergent trends across sites, key silvicultural considerations for achieving sustainable management of multiple species, forest structure and ecosystem services, and lessons learned from implementing adaptive silviculture treatments through this collaborative effort to steward forests into the future under climate uncertainty.

Digital transformation of uneven-aged forest management and planning

• Author: Toshiaki Owari
• Keywords: Stand-based silvicultural management system, GNSS, UAV

Digital transformation (DX) has recently been promoted in the Japanese forest and forestry sector. In northern Japan, the University of Tokyo Hokkaido (UTHF) manages uneven-aged mixed conifer-broadleaf forests using the stand-based silvicultural management system (SSMS) and has actively introduced geospatial information technologies and digital devices since the late 2000s. As a unique application of forest and forestry DX, this presentation introduces the latest technological advancements and prospects of the SSMS in the UTHF. Our forests are classified into several forest types according to stand characteristics and management objectives under the SSMS, and in-depth forest surveying is an essential technique for forest management planning under the SSMS. Since 2021, our forest survey has been using a low-cost dual-frequency RTK-GNSS (real-time kinematic global navigation satellite system) receiver, which exhibits high and stable positioning accuracy. Airborne LiDAR (light detection and ranging) data are currently available for the whole area of UTHF, and we take aerial photographs using RTK-UAV (unmanned aerial vehicle) prior to each forest management planning session. Forest types can be delineated while referring to various spatial information of the managed area. The survey field notebook is produced in-house using relational database software, and field notebook entry is performed on-site using tablet terminals. GNSS receivers are also used for our precision forestry activities, including tree marking under the selection system and post-harvest silvicultural treatments to recover logging gaps. It is possible to pinpoint the location of tree individuals and cut stumps using such technologies, and the information can be used to examine the long-term stand dynamics after recurrent selection cutting, to identify the sites with poor natural regeneration for restoration planning, and to manage high-value tree species on a single-tree basis.

Increasing forest stand complexity in Southwest Europe

• Author: Andrés Bravo-Oviedo
• Key words: mixed forests, complex structure, silvicultural systems,

Forestry faces important challenges in the decades ahead. The quick global change affecting the climate system, economy and biodiversity has put forests in the front line of mitigation and adaptation policies across the world with different approaches. In temperate regions forest researchers and practitioners have already understood that more structurally and compositionally diverse forest stands are essential to meet climate and bioeconomy targets. This presentation will show how southwest Europe is performing transformation of monospecific reforestation into mixed species to increase resilience and the creation of new mixed forest plantations to promote more diverse and stable production of raw materials for the bioeconomy.

Climate change as a trigger to forest change in Central Europe – What lesson did we learn from biomonitoring of forest ecosystems?

• Author: Petr Horáček
• Key words: Tree growth, physiological processes, ecosystem stability

One of the major potential effects of climate warming across terrestrial biomes is an increase in climate driven tree mortality, particularly mortality triggered by a combination of drought and hotter temperatures. Under rapidly changing climate, accelerated understanding of the diverse patterns and processes driving dynamic ecosystem responses is needed to effectively address the challenges of sustainably managing and restoring affected ecosystems. Forests, the terrestrial ecosystems with the highest water demand, will likely be the most influenced by the changing water regime. Water has a central role in all plant physiological processes and changes in its availability could drive structural and process shifts on the cell level up to the level of the whole tree. This is leading to consequences that range from reduced tree growth to large-scale disturbances of forest ecosystems. All these factors are contributing to severe economic losses for European forest lands. Hence, knowledge concerning the changing climate and its specific impact on trees across the elevation gradient is becoming very important for forestry planning and management in order to ensure optimal forest functioning as constrained by the growth environment.

Now we are not facing a question about how to increase productivity (including C-sequestration) per given forest area, but rather how to even ensure forest existence and how to restore forest ecosystem stability that has been drastically reduced within recent years. Here we propose to quantitatively assess both production and regulation function performance of forests and provide a new paradigm highlighting that high care is needed not only to sustain the production functions as was done up to now but emphasize how to maintain and enhance the regulation functions with the same or even higher priority as is done for the production function.

The trees, the people and the marteloscope – What human tree selection behaviour can tell us about CCF training requirements

• Author: Arne Pommerening
• Key words: Human tree selection behaviour, silvicultural training, climate change mitigation, between and within-person variability

Human professional and non-professional behaviour in forest ecosystems is still a very young research field offering many opportunities. For example, silvicultural prescriptions and guidelines are often based on growth-and-yield or other research, but little attention is paid to how they are implemented in practice or whether operational staff are able or willing to follow them. It is also largely unclear how the trees in the forest influence forestry staff when they walk through them and carry out thinnings. In simulations, tree models often assume best-practice or textbook behaviour of forestry operators, but our research has shown that human tree selection decisions vary much between people but also even within one and the same person in the same forest.

Understanding human tree selection behaviour in forests is important in the context of continuous cover forestry (CCF), one of many semi-synonyms of uneven-aged silviculture. CCF has recently been re-visited in many countries for its potential to mitigate climate change, to maintain biodiversity in forest ecosystems, to provide valuable tools for forest conservation and to enhance the appeal of woodlands used for recreation. It is comparatively easy to manage forest plantations, but managing CCF woodlands requires much more knowledge and long-term experience with the interaction between trees at a particular location, the corresponding environmental conditions and the likely tree response to human interventions. That is why silvicultural training is crucial when CCF is introduced. Knowledge and experience deficits can be addressed by specific courses and marteloscopes have been very effective in strengthening the transition between indoor training and practical implementation. In marteloscope exercises, course participants walk the forest and log down their tree selection preferences which are then analysed statistically. Instant feedback in the form of individual result sheets is made available to each trainee after completion and it is also possible to carry out research on the tree selection behaviour of trainees. These research results can provide important information on training requirements and are also crucial to the quality assurance of training programmes.

This presentation outlines what knowledge the international research community has so far gathered on human tree selection behaviour and what these results imply for CCF training. Recommendations are also made for how marteloscope training can be designed and optimised for different objectives of CCF management.

More than one: Potential and challenges for mixed-species silviculture in South-American Temperate Forests

• Author: Pablo J. Donoso
• Key words: mixed species forestry, resilience, *Nothofagus*

Temperate forests in South America are restricted to Chile (14 million ha) and Argentina (3,6 million ha). Of these, two-thirds in Chile are mixed forests, especially in the south-central part of the country (37-42°S; Valdivian Temperate Rainforests (VTR)); only 5% in Argentina, in northern Patagonia. VTR grow in a mild climate and on volcanic soils, and have a high diversity of tree species, mostly hardwoods, among which *Nothofagus* have the highest growth rates and reach the largest sizes. Forest dynamics in the Andes are dominated by large-scale disturbances that, in general, allow the continuous presence of pioneer long-lived *Nothofagus* species, while west of the Andes forest dynamics are dominated by small-scale disturbances. However, human disturbances (especially during the mid-20th century) have determined the occurrence of secondary forests throughout, which are now increasing their "old-growthness". Species richness in these forests can reach more than 20 tree species, many of high timber quality and value.

Silvicultural experiments in the VTR started in the 1980's. Thinnings have been practiced mostly in secondary *Nothofagus* and *Drimys winteri* forests. They have resulted in high growth rates (13-18 m^3 ha^{-1} yr^{-1}) and resilience, and have favored the development of understory species and vertical stratification. Mature and old-growth forests have been managed with even- and uneven-aged silvicultural methods. Even-aged cuts have resulted in rapid and homogeneous reorganization and growth in the Andean range, and heterogeneous and slower development in the Coastal Range, with a consistent pattern of dominant short-lived tree species (*Proteacea*) dominating the first two decades after interventions, followed by an increasing dominance of mid-tolerant species. Irregular shelterwood cuttings have resulted in slower growth rates than clearcuts in the Andes, but they have been more successful in the Coastal Range, i.e., less competition with bamboo resulting in more homogeneous regeneration. Several *Nothofagus* species are practically absent among regenerating species, unless soil scarification is practiced to expose mineral soils and occasionally eliminate bamboo rhyzomes, which is only recommended in the coarse soils of the Andes. Uneven-aged silviculture seems to be a viable option in forests with a great diversity of mid-tolerant and shade-tolerant species. Preliminary results have resulted in abundant and diverse regeneration and growth rates (4-10 m^3 ha^{-1} yr^{-1}) that suggest 10-15 year cutting cycles. Variable-density thinnings have also been used to increase old-growth attributes in secondary forests, resulting in diverse regeneration and rapid understory development, increased volumes of standing and dead wood, fast growth rates, and increased structural heterogeneity, while avian diversity and fitness appears to be mostly affected by tree composition. Finally, mixed-species plantation silviculture has also yielded good results, largely due to the facilitative effects of combining shade-intolerant and mid-tolerant *Nothofagus* species.

Overall, our results support the use of mixed-species silviculture to manage native forests and plantations in the VTR region for an array of objectives, including a) mitigation of climate change impacts via increasing functional redundancy, which is associated with greater resilience, b) biodiversity conservation, by increasing habitat heterogeneity for multiple taxonomic groups c) greater productivity in medium- to good-quality sites with structurally complex forests, and c) where multi-aged silviculture plays an important role to increase the diversity of timber products and ecosystem services.

Abstracts: Oral presentations

The impact of natural disturbances on uneven-aged forests in Central Europe - Are uneven-aged forests less affected by natural disturbances than even-aged forests?

• Authors: Johannes Mohr, Dominik Thom, Hubert Hasenauer, Rupert Seidl
• Key words: uneven-aged silviculture, natural disturbances

Natural disturbance activity has strongly increased in recent decades. Climate change will further intensify disturbance regimes in the future, threatening ecosystem services provided by forests. In order to adapt European forests to these changes, it is of high importance to understand the vulnerability of different silvicultural systems to natural disturbances. While previous studies suggest a high resilience of uneven-aged forests, comparisons about differences in disturbance impact in even- and uneven-aged forests remain scarce. The objective of our study was to quantify the difference in impacts by wind and bark beetle disturbances on even- and uneven-aged forests.

Our study is based on remote sensing data quantifying canopy disturbances over three decades across four topographically complex landscapes in Austria. To account for environmental factors, we used a paired landscape approach, matching uneven-aged and even-aged sub-landscapes with similar elevation, slope, northerness, topographic exposure and share of coniferous species. For each pair of sub-landscapes we then quantified differences in disturbance size, frequency and severity between uneven-aged and the even-aged forests.

Uneven-aged forests were disturbed less by wind and bark beetle disturbances compared to even-aged forests. Moreover, disturbances were of lower severity and had smaller disturbance patch sizes in uneven-aged forests. Yet, slope had a strong modulating effect on disturbance impact, with uneven-aged forests being more strongly affected than even-aged forests on steep slopes above 21.5°.

Overall, our results suggest that complex uneven-aged forests are more resistant to disturbances than homogenous even-aged forests. Therefore, forest managers should consider converting forests to uneven-aged systems and enhancing structural complexity in order to mitigate changes in future disturbances.

Integrated forest management – promoting wood production and biodiversity

• Authors: Frank Krumm, Andreas Rigling
• Key words: European scale, Net-Zero, climate change, close-to-nature

Climate change, the biodiversity crisis, and the need to produce renewable resource wood asks us to rethink and adapt forest management. Recent drought periods and subsequent large-scale disturbances demonstrate the increasing susceptibility of European forests, across forest types and species composition to climate change. At the same time, biodiversity is increasingly under pressure and action to conserve and restore it in the forests at a wide range of scales is urgently needed. In addition, the forests produce wood, one of the scarce renewable resources, and hence, might significantly contribute to the transition of our societies towards Net-Zero (drastic reductions of C emissions). The concept of Integrated Forest Management (IFM) aims to holistically manage our forested landscapes considering all demanded ecosystem services (ES) including biodiversity. Ecological and historical boundary conditions and societal framing need to be considered as part of pragmatic solutions. We will present and discuss a toolbox of management measures suited to balance forestry and biodiversity in European forests. Specifically, the role and potential challenges of close-to-nature forest management, including continuous cover forestry, will be elaborated, and put on discussion with the audience.

The Irregular Silviculture Network (ISN) - Monitoring irregular stands and stands in transition from even-aged to uneven-aged structures in the UK and Ireland – early results from two ISN stands in Dorset, England

• Author: Richard Deffee
• Key words: irregular silviculture, local research stands

Irregular silviculture, more commonly known as Continuous Cover Forestry (CCF) in the UK and Ireland, is still fairly new to the British Isles. Early adopters were inspired by visits to mainland Europe notably Switzerland, Slovenia, Germany, or France but these silvicultural systems, although growing in popularity, remain a novelty. Methods for measuring stand performance and structural change once the trajectory leaves the 'standard' (plantation) management approach are lacking, or as in the Check Method (complete stand enumeration) are too onerous or expensive to measure regularly.

The ISN was developed out of the French research network Association Futaie Irrégulière (AFI) in 2013. An abbreviated version of the AFI measurement protocol was developed to enable foresters to measure stand performance and structural change in irregular stands, and stands in transition from even-aged to permanently irregular structures, more widely and relatively cheaply. There are two scales of monitoring: Local Research Stand with 10 permanent sample plots giving detailed information at the stand level, and Whole Forest Inventory with a grid of sample plots measuring structural change over the whole Forest estate.

Early results from two Local Research stands in Dorset, England (one non-native P1965 Douglas fir and one native late 18th century oak dominated) will be presented. They indicate the value of stand measurement, and in this case specifically about the growth increment response following canopy release after long periods of closure.

It is too early to draw any conclusions about the effects of predicted climate warming on uneven-aged compared to even-aged stands, but long-term study of actual stand development, building a body of data across different stand types on different site types will provide vital clues to guide future management.

The concept and practice of ecological forestry in the context of central Europe

• Authors: Lucie Vítková, Petr Kjučukov
• Key words: biodiversity, biological legacies, variability

Although the theory of considering nature as a template for forest management has been discussed in the past few decades, its proper implementation into practice has been rather slow in central Europe. Therefore, the concept of ecological forestry that can be applied in the conditions of central European temperate forests is presented. Ecological forestry focuses on the application of forest management practices emulating natural dynamics that is primarily driven by natural disturbance regimes. The aim of ecological forestry is to enhance biodiversity via retention or restoration of biological legacies meanwhile producing timber generating a viable income. Case studies of ecological forestry based on practical experience are presented along with the necessary aspects of ecological forestry such as retention or creation of key structural and functional biological legacies. The use of traditional silvicultural practices requires a substantial alteration to reach the major aims of ecological forestry. This needs both a substantial revision in commonly used methods as well as changes in forestry professionals' mindsets since human decision-making is key when adopting novel practices, which is the case of ecological forestry in central Europe. Therefore, the willingness of foresters to adopt new management principles is described in order to highlight the necessity to have enthusiastic forestry professionals that are prepared to use novel forest management practices that are suitable for the challenging era of global climate change.

Assessing forest vulnerability to main disturbance agents as a basis for adaptation management: Experiences from Slovenia

• Authors: Andrej Bončina, Hana Štraus, Aleš Poljanec, Matjaž Guček, Andrej Rozman, Vasilije Trifković
• Key words: climate change, tree species, stand structure, adaptation

Due to climate change severe disturbances are becoming more frequent, causing huge damage toforest stands. They lead to economic losses of forest owners and decrease capacity of forests for providing essential ecosystem services. In the recent two decades the mutual impact of abiotic and biotic agents has caused substantial damages to forest stands in Slovenia. Increased forest risks and uncertainties require the understanding of higher vulnerability of forest stands, and the inclusion of adaptation strategies and measures into forest management. The main objectives of this research were 1) to analyse the changes in forest disturbances in Slovenia in the period of > 20 years, and 2) to examine which climate, site, stand, tree and management variables influence the susceptibility of trees to damages caused by six main agents: wind, snow, ice storm, insects, diseases and fire. We were especially interested to what extent species mixture and stand structure modify susceptibility to trees for damages caused by individual disturbance agents. The huge dataset Timber provided by Slovenia Forest Service, containing spatially explicit data of individual trees harvested in the period of 1995-2022 was used for the analyses. Almost 150 million trees (dbh, tree species, and cause of sanitary felling) are included in this dataset, more than one third was harvested as sanitary felling due to abiotic and biotic agents. In the observed period insects were the main disturbance agent, followed by wind, ice storm, disease, and snow. The results showing which tree, stand, and management variables reduce susceptibility of trees to damages caused by individual disturbance agents will be reported, and will serve as a basis for defining possible adaptation strategies.

Climate smart and biodiversity-oriented forestry for European beech at rear edge: Preliminary outcomes from a systematic review

• Authors: Stefano Puccinelli, Josef Brůna, Giorgio Vacchiano, Paola Mairota
• Key words: Habitat 9210, Mediterranean ecoregion, rear edge

Many studies carried out to find solutions to mitigate and adapt forest dynamics to climate change considered either climate smartness of forestry measures or the preservation of biodiversity, with great attention to the EU Natura 2000 Network. The aim of this review was the identification of forestry measures capable of concurrently fostering European beech (*Fagus sylvatica* L.) forests resilience in the context of climate change while maintaining their biodiversity level, with particular attention to the rear edge of the species range and on low altitude Natura 2000 Habitat type 9210* in the Mediterranean EU biogeographical region. Due to species vulnerability, these areas are of great interest for the identification of measures applicable elsewhere. The main article search was carried out on the Scopus database. The primary selection criterion was on studies about beech forest management that can fit the objectives of climate-smart forestry or increase biodiversity. Secondary selection criteria were the focus on uneven-aged silviculture, spatial structure, and on mixed forests as these are considered important management strategies. The initial dataset resulted in 1020 documents, of these 170 comply with the primary criterion. The application of secondary criteria to those yielded 9 showing enhanced biodiversity and decreasing competition pressure along with structure improvement, 44 on mixed forest with regard to growth, drought resistance, and carbon stocks and 7 relating uneven-aged silviculture to the improvement of stress resistance and recruitment, productivity, and stabilization. The latter two groups indicate contrasting effects on biodiversity. Untangling the causes of contrasting effects of climate smart and biodiversity-oriented measures, relating to context or to measure itself, is mandatory to find management solutions that can fit both objectives. The effectiveness of such harmonized measures will support future forest landscape modelling research.

Growth response to thinning in mixed and monospecific stands of *Pinus sylvestris* L. and *Quercus petraea* (Matt.) Liebl. across Europe

• Authors: Miren del Río, Hans Pretzsch, Kamil Bielak, Felipe Bravo, Marion Jourdan, Cristobal Ordoñez, Maciej Pach, Ricardo Ruiz-Peinado, Enno Uhl
• Key words: mixed stands, silviculture, thinning, growth reaction

The knowledge on the dynamics and productivity of mixed forest stands has significantly increased during the last decades. However, the advances on silviculture in mixed forests are still limited. Some previous studies indicate a more plastic growth response to thinning in mixed than in monospecific stands, but they are based on experiments not specifically designed to compare thinning reactions in mixed and monospecific stands. In this study, we aim to analyse the growth response to thinning in mixed and monospecific stands of Scots pine and sessile oak growing under similar conditions. For this, we used a set of eight pairs (thinned and unthinned) of triplets distributed across Europe. Each triplet was formed by one pine-oak mixed plot, and two monospecific plots of the respective species. The applied thinnings were heavy selective thinnings from above promoting.

Our results show that stand gross basal area increment was lower in thinned than unthinned plots (2-5 after thinning), but there were no significant differences between the different species compositions. At the species level, the difference between gross basal area growth in thinned and unthinned plots was significant for oak but not for pine. The gross basal area growth was greater in monospecific than in mixed stands for pine and lower for oak. When analysing the net basal area growth, i.e. removing mortality, the growth was similar in all stands. However, at the species level, it was greater in thinned and monospecific stands for pine. These findings indicate that the thinning responses are similar in mixed and monospecific stands for this mixture and that thinning avoids tree mortality, which was especially high for pine in mixed stands. This agrees with a recent study where it was found that a large part of the overyielding in mixed stands is lost by mortality, highlighting the need of thinning mixed stands to control species composition and better benefit from their greater productivity.

The Leak Distribution and its Application to Uneven-Aged and Irregular Stands

• Authors: Mark J. Ducey, Jeffrey H. Gove
• Key words: quantitative silviculture, rotated sigmoid

The q ratio (the ratio between numbers of trees in successive diameter classes) features prominently in many treatments of the diameter distribution of uneven-aged stands. While a constant q leads to the familiar exponential distribution, many authors (going back to de Liocourt) have recognized that q may vary, even in stands approaching a steady state. In a seminal paper from 1963, Bill Leak found that q was often well-approximated by a linear function of diameter at breast height D. However, to utilize Leak's results directly requires splitting the stand into diameter classes, and the results are sensitive to the center locations and class widths used. We present a new, continuous diameter distribution function that has the properties outlined by Leak, and we propose to name it in recognition of his original ideas and long service in a 68-year career in the forest sciences. An extended version, with 3 fitted parameters, can model not only J-shaped but rotated sigmoid and bimodal distributions. The distribution is tractable with left- or right-truncation (minimum or maximum values of D), and the same can be said of its size-biased distribution (e.g., the distribution of basal area by diameter). We outline considerations for computing the probability density function (pdf), cumulative distribution function (cdf), and quantiles, along with random number generation. We illustrate the distribution with hypothetical examples, along with distributions fit to data from the Bartlett Density Study (a six-decade individual tree selection study) and the College Woods Natural Area (an old-growth mixed pine-hardwood stand), both located in New Hampshire.

Are homogenous European beech stands in Slovenia more uneven-sized and uneven-aged as anticipated?

• Authors: Živa Bončina, Matija Klopčič
• Key words: beech, diameter distribution, tree size diversity

European beech (*Fagus sylvatica*) is the most widespread tree species in Slovenia. Beech forest types account for almost 70% of forest area in which homogeneous (even-sized and even-aged) stands predominate. The goal of our study was to analyse the structure of homogeneous pure beech stands on beech forest types from permanent sampling plot data gathered by Slovenia Forest Service (n = 4973, 500 m^2 each). Stands were defined as homogeneous based on classification with the Gini index being <0.33. The three-parameter Weibull distribution was fitted to the empirical diameter distribution on each plot, whereas the parameters were estimated i) for all trees in the plot and ii) for the dominant trees only. Our results showed that diameter distributions were not just unimodal as is expected for uneven-aged stands. The values of the shape parameter of the Weibull distribution, relations between different mean diameters, and the histograms of the diameter distributions indicate a noticeable share of bi- and multimodal and J-shaped distributions. This is probably a consequence of practicing the rather small-scale continuous-cover irregular shelterwood system as well as the small size of the sampling plots. Furthermore, we were interested in whether the sampled stands are even- or uneven-aged. The tree age was calculated based on the average diameter increment per diameter class for the mid- and understorey and the dominant canopy trees separately. Uneven-agedness of stands was detected in a noticeable share of observed plots. Our results demonstrated that although stands look like and are classified as homogenous even-sized and even-aged stands, they can still be uneven-sized and uneven-aged if originate from the rather small-scale continuous cover silvicultural systems.

Applicability of remote sensing data in uneven-aged forestry

• Authors: Christian Rosset, Andrej Bončina, Gaspard Dumollard, Vasilije Trifković, Manuel Kurt, Hannes Ole Horneber
• Key words: remote sensing, LiDAR, uneven-aged silviculture

Transformation from even-aged to uneven-aged forest management is a challenging and long-lasting task. Remote sensing data, especially LiDAR with its high spatial resolution, are useful to monitor horizontal and vertical structure of forests in space and time. It can be used for the delineation and description of forest stands, which is an important part of forest planning and management.

TBk is a toolkit developed at BFH to automate stand map creation based on remote sensing data. The delimitation process underlying TBk is rule-based and consists of building networks of dominant trees of similar size. The rules basically mimic the way stand delineation is done in the field to obtain stands that are clearly recognisable in the forest. In addition to stand delineation, stand description data are provided about dominant trees (top height) as well as about horizontal and vertical structure. TBk is already in use in Switzerland in several cantons as well as in Slovenia with several hundred thousand hectares already mapped. Both countries have a long tradition in close-to-nature silviculture with clear cut forbidden resulting in heterogenous mosaic of forest stands, which is demanding for stand mapping. TBk was basically designed for even-aged forests.

Based on selected sites in Switzerland and Slovenia, we investigated the applicability of TBk for mapping forest areas under uneven-aged forest management including the transformation to uneven-aged. We applied the concept of transformation stages after Schütz (differentiation, promoting regeneration, structuration and structure achievement) and extended it to encompass young even-aged stands (preparation before transformation) and situations where demographic equilibrium is likely to be lost or has already been lost.

First results are encouraging. By using TBk, it is possible to assign the transformation stage to each single stand. Possible improvements of the algorithm are discussed.

Transforming even-aged ponderosa pine to multi-aged stands in the northern Rocky Mountains

• Authors: Justin Crotteau, Neil Williams, Shelagh Fox, Cheri Hartless, Sharon Hood
• Key words: management guide, public land, fire resilience

Across much of its range, ponderosa pine (*Pinus ponderosa*) stands are thought to have been predominantly multi-aged – i.e., a structure containing two or more cohorts – before Euro-American settlement. Most of the first true silviculture of ponderosa pine-dominated stands also used multi-aged approaches, including the Munger's Maturity Selection and Pearson's Improvement Selection systems. Large areas of pure and mixed ponderosa pine forests are now managed as plantations using even-aged methods to maximize economics, simplicity, and low fire hazard. In a multi-objective setting, however, multi-aged structures, including those representative of pre-settlement conditions, may provide a broader range of benefits and/or reduce risks. Transformation of existing even-aged stands to one of many alternative multi-aged structures may be desirable, but there are obstacles to making this transition. Examples include uncertainty and inexperience with the application of multi-aged methods in ponderosa pine forests and of the steps involved in silvicultural transformation, pragmatic concerns over the feasibility of complex multi-aged approaches, challenges in internal reporting of management actions, and concerns of high fire hazard associated with multiple canopy layers. We aim to address these barriers through the (ongoing) development of a practitioner-oriented management guide. In this guide we walk through two case studies of transformation: the Lick Creek irregular shelterwood study and the Lubrecht Fire and Fire Surrogate study. This presentation highlights rationale behind production of this management guide and shares the approach to second-entry transformations in these two ponderosa pine study areas. Transformation in the study areas focused on basal area targets, tree vigor, and creation of canopy gaps, demonstrating loose and successive efforts to develop multiple canopy layers and improve ecosystem resiliency to drought, mountain pine beetle, and wildfire.

Growth Dominance and Diversity: The Interplay of Stand Structure, Species Mixing and Growth Limiting Factors

• Authors: Bohdan Kolisnyk, Stanisław Drozdowski, Kamil Bielak
• Key words: growth dominance, structural diversity, *Abies alba*

This study aims to investigate how growth dominance changes with stand structural diversity and species mixing and to disentangle the mediation effects of growth limiting factors. Our study areas are Zagnansk forest district in central Poland, where belowground resources (water and nutrition) are the main limiting factors, and Inzell forest district in Germany, where aboveground factors such as competition for light and duration of the vegetation season play a more significant role.

We hypothesize that dominant trees, not limited by nutrition and water availability, can use the maximum growing season and compensate for the "loss" in the number of growth contributors with increasing structural diversity by asymmetrically accelerating the growth rate due to better access to light. Therefore, light-limited systems may have a strong positive growth dominance (with dominant trees contributing most to the stand growth), while belowground resource scarcity results in size-symmetric growth and less prominent positive or even negative growth dominance.

To answer the formulated question and achieve our objectives, we established 35 circular plots (0.05 ha) in each location in Silver fir (*Abies alba* Mill.) dominated stands, covering the stand diversity (even-aged, two-aged, uneven-aged) and mixing gradients (mainly with European beech). We recorded tree positions, performed standard dendrometric measurements, and cored at least 3-4 trees from different social strata closest to the center of each plot. We then developed an individual tree-based spatial model to reconstruct the growth of all trees within the plot and describe the growth dominance.

We expect the results of our study to provide valuable insights into the relationship between growth dominance, stand structural and species diversity, and the role of growth limiting factors in forest ecosystems. Understanding this can help enhance forest management strategies aimed at maximizing carbon sequestration.

Five decades of structural changes in two old-growth mixed forests of the Western Carpathians

• Authors: Stanislav Kucbel, Róbert Sedmák, Milan Saniga, Ján Pittner, Jaroslav Vencurik, Pavel Ďurica, Ladislav Šumichrast, Peter Jaloviar
• Key words: old-growth forest, beech, fir, spruce, long-term dynamics

The objects of the study are two old-growth mixed forest remnants located in Central Slovakia. Old-growth forests Badín and Dobroč have been under strict legal protection since 1913 and represent the oldest forest reserves in Slovak Republic. National Nature Reserve Badín is dominated by a fir-beech forest on the area of 30 ha. National Nature Reserve Dobroč belongs to the spruce-beech-fir forests, with the size of the core zone reaching 50 ha. With the first measurements conducted in the late 1950s, the regular research on the series of permanent plots started in the 1970s. Moreover, since the late 1970s every decade the registration of all stems with dbh > 8 cm using the method of full callipering has been conducted on the entire areas of both reserves. The long-term data from five finished measurement campaigns provided the possibility to analyse the large-scale dynamics of tree species composition, structural and dimensional variability regarding ongoing climate change. The analysis confirmed the general trend towards increasing dominance of European beech at the expense of the conifer species (silver fir in Badín or silver fir and Norway spruce in Dobroč), the significant increment of overall stand volume and the problems with natural regeneration survival of the majority of tree species, with the exception of beech, especially due to the excessive densities of ungulates.

Ungulates and succession dynamics reduce tree species richness in temperate oak-beech forests

• Authors: Gauthier Ligot, Romain Candaele, Alain Licoppe, Julien Lievens, Violaine Fichefet, Mathieu Jonard, Frédéric André, Philippe Lejeune
• Key words: continuous cover forestry, regeneration, deer, seedling

Wild ungulate populations have increased throughout the northern hemisphere exacerbating the impact of browsing on understory vegetation. Ungulates could thus become an important driver of future forest diversity with cascading effects on forest resistance to future climatic conditions, forest resilience and provision of ecosystem services. Such an observation would be of particular concern in forests that are managed under continuous cover silviculture relying on natural regeneration that can hardly be protected against browsing. To better understand the impact of ungulates on future forest diversity, we conducted a large experiment with 734 pairs of fenced and unfenced 6-m² plots set across a broad gradient of red deer abundance in oak-beech forests managed though continuous cover forestry, in Belgium. Height of the dominant seedlings, seedling density, and vegetation cover were monitored annually from 2016 to 2021. Species diversity and ecological affinity for light, temperature, and atmospheric humidity conditions were inferred from these measures and the literature. Ungulates were found to strongly reduce seedling growth, density and cover of understory vegetation. Among the species studied, the early successional species (*Betula pendula* and *Sorbus aucuparia*) were the most affected. These species failed to grow in height when unprotected from ungulates but grew faster than the other species in fenced plots. In contrast, without protection against browsing, the late successional species (*Fagus sylvatica* and *Picea abies*) rapidly dominated the other admixed species. In contrast to the two previous species groups, oak (*Quercus petraea* and *Quercus robur*) was rapidly dominated in both treatments (fenced and unfenced). Ungulates can thus be a key factor in oak-beech forest succession, seriously impeding the regeneration of several species, including those most adapted to the warmer and drier conditions to come.

Variation in browsing intensity of beech and fir saplings in relation to their crown architecture and growth in natural mixed forests

• Authors: Olga Orman, Janusz Szewczyk
• Key words: European beech, silver fir, crown length, diameter, height

Mixed forests composed of European beech and silver fir are valuable from both ecological and socioeconomical perspectives, but they have been experiencing increasing anthropogenic changes such as enhanced ungulate populations. In 2018-2021 we studied the relation between the browsing occurrence/ browsing intensity and crown architecture and growth of young beech and fir saplings in three natural mixed forests located in Swinia Gora forest reserve (345 m a.s.l.), Swiety Krzyz forest reserve (560 m a.s.l.) and in Gorce National Park (883-1052 m a.s.l.). We used generalized linear models and multinomial log-linear models to check for an occurrence of terminal leader shoot browsing and intensity of herbivory (0-5 browsing categories). The preliminary results showed that an occurrence of browsing in leader shoot varied between species, sites, years and crown architectural and growth characteristics. Beech was more likely to have browsed the leader shoot compared with fir, especially in Swinia Gora and Gorce National Park. The intensity of browsing varied between sites. In Gorce National Park most of saplings did not have any signs of browsing or showed very light browsing evidence, while in Swinia Gora beech showed no browsing or light browsing signs, while most firs showed light to intense browsing signs.

The regeneration after the windthrow in the Piska forest: the role of large scale disturbances in Polish forestry

• Authors: Dorota Dobrowolska, Bogdan Pawlak, Leszek Bolibok
• Key words: disturbance, wind, regeneration

In July 2002, a hurricane of considerable force damaged 33,000 ha of forests in northeastern Poland. In the Pisz forest district (the most damaged), the hurricane blew down 12,000 ha of pine dominated forest stands. The wood was harvested as soon as possible, and the areas were replanted. In the Pisz forest district, an area of 475 ha was left without any intervention in order to observe the natural processes (Szast protection forest). The study of post-disturbance regeneration has been conducted on 65 permanent observation plots since 2005. The aim of the study was to determine the role of large-scale disturbance in forest regeneration. We divided natural regeneration into three phases: seedlings, saplings, and recruits. It was found that the most important tree species that regenerated in the Szast protection forest were Scots pine, silver birch, pedunculate oak, and Norway spruce. We investigated the influence of the severity of disturbance and the year (time since disturbance) on the density of seedlings, saplings and recruits of the main tree species. Seedling density of pine and oak depended on disturbance severity and year (pine), with the best conditions for pine seedlings in moderately disturbed stands. The intensity of disturbance influenced the occurrence of birch, oak, pine, and spruce saplings. For pine and birch saplings and recruits, the year of survey was also important. The vitality of natural regeneration of the major tree species changed within years and depended on the severity of disturbance. We found that the structure of the forest after disturbance was uneven-aged and diverse. However, the main problem for the future persistence of the forest is the density of herbivores, especially moose. The results of the study will be useful for foresters and policy makers to change the approach to large-scale disturbance in Polish forestry.

Assessing optimal and critical stand, site, and climatic conditions for recruitment of European beech, Norway spruce, and silver fir in uneven-aged forests

• Authors: Vasilije Trifković, Andrej Bončina, Andrej Ficko
• Key words: Tobit model, recruitment potential, ingrowth

Tree recruitment models are crucial for predicting the dynamics of uneven-aged forests. The factors that determine the optimal and suboptimal environmental conditions for recruitment of European beech, Norway spruce and silver fir remain poorly explained. In this study we 1) examined the influence of stand, site, and climatic factors, and their interactions, on the recruitment of trees in uneven-aged forests; 2) determined the optimal and critical ranges of influential factors, including stand basal area, number of trees, proportion of tree species, shade casting, soil pH, site productivity, temperature, and precipitation; and 3) estimated the maximum expected response of recruitment to changes in stand density while controlling for the impact of other limiting factors. To account for the fact that the observed range of the number of recruited trees is censored at zero, a Tobit censored regression model was utilized using 30,963 forest inventory plots (200 m^2 each) in uneven-aged forests in Slovenia. Stand structure was the most critical factor, with stand basal area and the proportion of the studied species having the most significant effect. Site factors, such as soil pH and rockiness, were found to be important for fir recruitment. The number of recruited beech and spruce was positively influenced by decadal precipitation. Shade casting was found to be important for beech; recruitment of beech was higher when shade was imposed by tree species other than beech. The optimal and critical ranges of limiting factors varied between species. The maximum predicted response of the studied species to changes in stand basal area shows that stand density control is efficient for regulating recruitment of spruce and beech, but not for fir. The suggested sensitivities and threshold values can be useful in individual tree growth models or simulation-optimization studies to support forest management decisions.

Growth response of European beech (*Fagus sylvatica* L.) and silver fir (*Abies alba* Mill.) on climate factors along the Carpathian massive

• Authors: Pia Caroline Adamič, Tomislav Levanič, Mihail Hanzu, Matjaž Čater
• Key words: climate change, dendrochronology, radial growth response

European forests are increasingly threatened by climate change and more frequent droughts. The likely response of species to climate change will vary, affecting their competitiveness, their existence, and consequently forest management decisions and measures. We investigated the influence of climate on radial growth of beech and fir along the Carpathian Mountains to identify commonalities and key differences between the two species. Along the Carpathian Mountains, 7 sites with mature fir-beech stands above 800 m a.s.l. were selected and analyzed. Our study confirmed different responses according to species and site. A more pronounced response of tree growth to climate was observed on the eastern side of the Carpathians, while it was less pronounced or absent at the southern sites. Both beech and fir show better radial growth with higher precipitation in July and slower growth with higher average and maximum temperatures in June of the current year. Fir shows a positive correlation between radial growth and temperature in winter, while beech shows a negative correlation between radial growth and temperature in summer. In 1950, average tree ring widths for fir and beech were greatest at southern sites compared to other sites, but after 2016, the increase is smallest at southern sites while it is greatest at northern sites. Both species respond differently to climate and are likely to follow different competitive paths in the future.

Adaptation measures in the Czech Forestry to GCC

• Author: Radek Pokorný
• Key words: adaptation, silviculture, climate change, risks

Due to recent approaches to afforestation, forest establishment and/or regeneration; inappropriate tending of forest stands; maintaining labile forest structures (even-aged coniferous monocultures); changing and extremely varying environmental conditions; high population densities of wild game; mass outbreaks of insect pests and severe epidemics of (mainly fungal) pathogens, forests are at high risk not only in the Czech Republic but worldwide, and forestry has to cope with these risks as best as possible. After risk identification, appropriate measures should be taken into consideration, sorted, and then applied in forestry practice as soon as possible. Selecting tree species to appropriate sites according to the species' ecological characteristics and stress tolerance are the key elements to avoid risks in forestry. To be well prepared for risky situations, it is necessary to know history and still have actual information from monitoring systems and educational materials. Therefore, the main recommendations could be: to keep more or less permanent forest cover; to avoid climatic extremes; to maintain three (in similar proportion) or more tree species in a stand to use their different ecological demands and tolerance; to keep a diversified forest structure not only in tree species and their genetic composition, but also in their size and age, in vertical and horizontal scale, support particularly also regeneration; to consider micro-site conditions in silviculture; to manage and tend a forest in order to facilitate its resistance and resilience (tend early, frequently and with high intensity; maintain diversity and species mixtures); to restore labile forest stands as soon as possible; to keep the various abiotic and biotic disturbance and damaging factors carefully in mind, and consequently, monitor forest stands regularly for important damaging factors in order to be able to react as timely as possible.

Light response of silver fir and European beech along Dinaric Mountains of the Balkans and the Carpathian Mountains

• Author: Matjaž Čater
• Key words: silver fir, beech, light response, geographical gradient

The response of trees to different light intensities was intensively studied during three consecutive growing seasons in the Dinaric Balkan Mountains and along the Carpathian Mountains. Eleven permanent observation plots were established in uneven-aged Dinaric beech and fir forests above 800 m from northwestern sites in Slovenia, to southern, warmer, and drier sites in Macedonia. In the Carpathian arc, response was studied in uneven-aged forests on eight permanent plots with the same criteria from the Czech Republic to Romania.

Along both geographic gradients, physiological and morphological responses were measured in predefined light intensity categories. Radial growth was analysed on all plots and compared with precipitation, temperature, and drought.

Based on tree responses, optimal locations for beech and fir were determined for each studied site and studied gradient. Physiological and morphological responses to light were compared with meteorological data.

Short term impacts of harvesting intensity on soil organic matter in the Dinaric Karst uneven-aged fir-beech forests

• Authors: Emira Hukić, Matjaž Čater, Aleksander Marinšek, Mitja Ferlan, Milan Kobal, Daniel Žlindra, Primož Simončič
• Key words: close-to-nature silviculture, Calcic Cambisol, forest soil

This study deals with the short-term effects of the different harvesting intensities under close-to-nature selective management on the soil organic C and N in the upper soil layers in Slovenian and Bosnian Dinaric karst fir-beech forests. Different harvesting intensities coincided with a single-tree and irregular shelterwood approaches, which are commonly applied in the region. The effect of harvesting intensities (0, 20, 50 and 100%) on the upper soil layers (Ol, Of, Ol and 0-10cm mineral soil) were assessed. In both experimental sites, Slovenia and Bosnia used identical sampling methodology and equal laboratory analysis were applied. Results of the assessment of the mean value differences, pointed to a significant impact of harvesting intensity on the decreases in SOC, TN concentrations, weights and C stock values in the organic layers and increases in the BD and SOC stocks in the 0-10 cm mineral soil. The highest relative decrease in Ol, Of, Oh SOC stocks appeared in 50% (-10 and -38 %) and 100% (-16 and -49 %) harvesting intensity plots. Negligible relative differences in both the organic and 0-10 cm mineral layers were found for < 20% harvesting intensity in the region. Change in the canopy openness in the forest relative to the applied harvesting intensity explained significant variation in the upper soil layer properties. The repercussions of the short-term losses in SOC stocks, in regard to general soil productivity, may depend on the regeneration dynamic and amelioration methods.

Comparing the tree spatial patterns derived from various forest management treatments in ponderosa pine (*Pinus ponderosa*) forests of the Black Hills, USA

• Authors: Mike Battaglia, Terrie Jain, Chad Hoffman, Scott Ritter, Wade Tinkham, Lance Asherin
• Key words: ponderosa pine, restoration, spatial complexity

Ponderosa pine (*Pinus ponderosa*) forests are a dominant ecosystem across the Western United States. Historically, this ecosystem experienced frequent fire that created and maintained a mosaic of diverse forest structure across the landscape. However, a century of fire exclusion and harvesting has increased the tree density and canopy cover of these open woodland forests, and increased the prevalence of undesirable outcomes during contemporary wildfires. For over 50 years, ponderosa pine forests in the Black Hills of South Dakota, USA have been managed as even-aged shelterwood systems resulting in homogeneous forest structures. In an attempt to develop multi-aged, spatially horizontal and vertical heterogeneous forest structures, we implemented a range of mechanical thinning treatments.

Overstory thinning treatments ranged from typical spaced-based commercial thinning to an irregular selection system that attempted to create tree groups, individual trees, and treeless openings. To enhance vertical heterogeneity, advanced regeneration was thinned based on two different approaches. The first approach thinned the advanced regeneration to a 4 x 4 m spacing, ignoring the overstory trees. The second approach included the overstory trees in the 4 x 4 m spacing for thinning the advanced regeneration. This presentation will demonstrate the differences in horizontal and vertical structure of these treatments and provide future research directions.

Aridity is modulating the forest dynamics of the Scots pine – European beech mixtures in Spain

• Authors: Sonia Condés, Miren del Río
• Key words: climate, diameter distribution, inter-specific competition

Scots pine (*Pinus sylvestris* L.) and European beech (*Fagus sylvatica* L.) compose mixed forest that are widely distributed through Europe, the north of the Iberian Peninsula being the southernmost location of this mixture. The socio-economic importance of mixed forests is well known as they supply many ecosystem services and are more resilient to disturbances and extreme climate events than monospecific forests. However, because of climate change, these mixtures are exposed to the effects of warming and drought, which could affect the ingrowth, mortality, and growth of each species in a different way or with different intensity. Thus, it could influence the dynamics of pine-beech mixtures by promoting one of the species and endangering the stability of these mixtures.

In this study, we aimed to analyse species size distribution dynamics under different climate conditions. We developed a matrix model based on about 9500 tree data from three surveys of the Spanish National Forest Inventory together with the historical climate data provide by CRU-TS downscaled according to spatial coordinates and elevation of the plots. We simulated different scenarios of starting diameter distributions to explore how the future climate projections modifies species size dominances and proportions.

Our preliminary results showed that, within the biological indices tested, the Martonne aridity index is one of the most explanatory when modelling growth processes of Scots pine and European beech mixtures in Spain. Increasing aridity seems to affect Scots pine more than European beech by reducing the growth of the former species and therefore its competition effects, although aridity also reduces the beech recruitment.

Group-selection system as alternative management of Scots pine (*Pinus sylvestris* L.) forests facing climate change

• Authors: Janusz Szmyt, Monika Dering
• Key words: Pinus sylvestris, forest structure, forest dynamics

Scots pine (*Pinus sylvestris* L.) is the most important forest tree species in Poland. Pine stands have been managed according to even-aged silviculture, which leads to a simplification of their structure and increased vulnerability to many biotic (insects, fungi) and abiotic (wind, fire, snow) threats. In 1992, an experiment with an alternative management system for pine stands was established in the Gubin Forest District (western Poland). Forty-nine permanent circular measurement plots of 500 m^2 each were laid out over an approximately 30 ha Scots pine stand. On each measurement plot, all living trees are measured (dbh, total tree height, tree status). The exact position (x, y coordinates) of each living tree is measured. Measurements and observations were taken in 1992 and 2019. Different structural indices describing different structural aspects (size structure, species composition, stand profile) were calculated. It allowed us to analyze the dynamics of stand structure over 27 years of forest development and answer the question whether group-selection silviculture can be an effective alternative to even-aged silviculture under the changing climate. Results showed that group-selection cuttings led to a more diverse stand structure. Most structural indices confirmed the positive effects of group-selection cuttings on structure differentiation in the case of Scots pine. Average values of the size diversity indices increased significantly compared to the state in 1992. The only exception were indices describing the species composition and species mixing. The results concluded that group-selection cuttings can be an alternative way for managing Scots pine forests in Poland and they can lead to structured forests. Therefore, this alternative can be recommended for Scots pine forest management aimed at strengthening the forest for unexpected threats associated with climate change.

Silviculture for climate change and for new social expectations

• Author: Tomáš Vrška
• Key words: transformation, silviculture, irregularity, variability

Due to the speed with which global climate change is acting, it is bringing fundamental questions to forestry. The inertia of the models used so far and the impossibility of changing the tree species composition of stands and their structure with the increasing age of stands places extreme demands on practical foresters. Scientific knowledge helps to redefine forestry models, but it is difficult to find a practical application in the operational mode of ordinary forestry. The University Forest Enterprise is an example of long-term efforts to apply new scientific knowledge in the practice of forestry. We have defined and are implementing 23 silvicultural models for climate change, some of them already 50 years old, others in the initial stages. In the contribution, we will show using real data how the individual models are defined, how to define the landscape mosaic of the selected cultivation models and how to carry out the transformation from even-aged to uneven-aged models in order to find a balance between the economic, ecological and social role of contemporary forestry. 10,400 ha of university forests are a laboratory that offers new solutions.

Combining simulations of forest dynamics with field marteloscope exercises to raise awareness of the effects of silviculture on ecosystem services

• Authors: Benoit Courbaud, L. Thill, Francois De Coligny, Laurent Larrieu, Mathieu Fortin, Gauthier Ligot, Johann Housset, Daniel Vallauri, Luce-Eline Darteyron, Emmanuel Ripout, Elodie Vanhal, A. Martin, Eric Lacombe
• Key words: marking, education, tradeoffs, biodiversity

Marteloscopes are forest plots used to teach tree marking and to discuss silvicultural strategies. They are popular with forestry professionals, students and the general public as tools that make silvicultural concepts concrete and stimulate discussion among participants. This is particularly the case in mixed continuous cover forestry and in situations of trade-offs between ecosystem services. Several computational tools have been developed to represent the forest plot before and after harvesting and to compare the markings of different groups of participants. We present here a complete processing chain that allows to simulate in the field with the Samsara2 simulator on the Capsis platform not only the proposed field marking, but also successive silvicultural interventions consistent with the field marking, and the stand evolution over 50 years. We present an application of this process on a marteloscope designed to raise awareness of the effects of silviculture on wood product supply, biodiversity conservation and carbon sequestration. We also show the economic consequences of different strategies for the forest owner, which could provide a basis for thinking about payments for ecosystem services. We discuss initial feedback from participants on the educational value of this approach and future developments towards the inclusion of other ecosystem services and the evaluation of silvicultural strategies in relation to climate change.

Forest Development Types: an essential tool for diversifying stands in Britain

• Authors: Gary Kerr, Jens Haufe, Victoria Stokes, Stephen Bathgate
• Key words: uneven-aged silviculture, mixed-species stand

The aim of this article is to introduce the concept of Forest Development Types to forest managers and policy makers in Britain and summarise a recent project to develop and test this concept. A Forest Development Type is a long-term vision of how the species composition and structure of a forest stand is intended to develop. The concept encourages the greater use of mixed-species stands and a wider variety of stand structures than presently deployed in British forests. During a period of change in British forestry, FDTs could be a useful planning and management tool that will help consecutive managers achieve greater resilience to meet the challenges of climate change and forest health.

Can continuous cover forestry in wide riparian buffers improve their function and better protect Swedish streams?

• Authors: Eliza Maher Hasselquist, Lenka Kuglerová, Therese Löfroth, Robert Spitzer, Anneli Ågren, Irina Mancheva, Francisco Aguilar, Hjalmar Laudon
• Key words: continuous cover forestry, streams, riparian buffers

Streams are an inseparable part of our forests and are some of the most degraded ecosystems, due to their poor management in the past and in today's forestry operations. Riparian buffers, strips of forest typically left unharvested adjacent to clear cuts, are the primary tool in forest management for protecting the habitat structure and function of streams. They help protect against biogeochemical perturbation, filter sediments and nutrients, prevent erosion, contribute food to aquatic organisms, regulate light and water temperature, contribute deadwood, and preserve biodiversity. In the even-aged management system with ~100 year rotation times as practiced in Sweden, understory trees have usually been cleared right up to the stream's edge during thinning operations done more than 30 years ago. This, in combination with a lack of natural disturbance, has created riparian zones dominated by single-storied, single-species forests. When the adjacent forest is cut, thin conifer-dominated riparian buffers are typically left but their width rarely exceeds 5-7 m on each side of the stream. For riparian buffers to maximize their crucial ecosystem services, buffer widths of > 30 m have been recommended by scientists, but such wide buffers along all streams would represent an economic loss for forest owners and would not optimize services because they are monocultures. We argue that if riparian buffers are managed for multi-layered, mixed-species forests with continuous cover forestry (CCF), it could be a viable way to increase buffer width while reducing the economic costs, while simultaneously enhancing the ecological function of riparian zones over the long-term. In this project we aim to investigate the options for CCF management in wide riparian buffers along streams in Sweden though harvest trials, modelling, and socio-economic and policy analyses.

Fine-scale spatial variability of stand structural features under active and passive forest management approaches

• Authors: Srdjan Keren, Wojciech Ochał, Vojislav Dukić
• Key words: spatial structure, silvicultural systems, old-growth

Background: It is generally known that structural variability is higher in old-growth forests than in managed forests, but the information on the extent of differences between them is rather scarce, so we focused on quantifying and explaining it with regard to fine spatial scales. Additionally, we investigated if there is a positive autocorrelation among neighboring patches in different stands regarding tree density and basal area. Material and methods: Data on tree positions and their diameters were collected at six 1.5 ha plots of which four were located in shelterwood even-aged stands (50, 65, 80 and 110 years old, respectively), one in a selection (plenter) stand, and one in an old-growth stand. We built variation models at scales ranging from 0.01 ha to 0.36 ha to observe for the degree of differences among examined stands. Spatial correlation of tree density and basal area was examined by applying detailed experimental semivariograms. Results: Small-scale structural diversity and basal area variability between neighboring patches was generally lowest in shelterwood stands, intermediate in selection stand, and highest in the old-growth stand. Older shelterwood stands were more structurally complex than the younger ones. The analysis of semivariance did not detect a positive spatial autocorrelation of basal area regardless of the management approach, while adjacent and nearby plots appeared to be more similar (autocorrelated) regarding tree density in differently managed stands. Conclusions: The stand managed with selection system differed least from old-growth structure, while consecutive thinnings made the oldest shelterwood stand look more similar to the old-growth stand than to younger shelterwood stands. This outcome indicates large variability of structural features among shelterwood stands of different age at fine spatial scales, which potentially may serve forest managers to diversify forest structure at a landscape level.

Tree Response to Variations in Overstory Density and Climate in an Uneven-aged Ponderosa Pine Forest in the Southwestern US.

• Authors: W. Keith Moser, Andrew J. Sanchez Meador, Zdeněk Vacek, Stanislav Vacek, Josef Gallo, Jan Cukor, Vilém Podrázský
• Key words: uneven-aged, density, climate response, long-term study

A long-term method of cutting study of *Pinus ponderosa* stands in the Southwest US was initiated in the Fort Valley Experimental Forest, north of Flagstaff, Arizona, USA, in the 1920s. In the 1960s, the emphasis on a portion of the area was changed to a study of uneven-aged management, with the first cut to convert to a group selection system initiated in 1968.

In 2017, a team of scientists from the US Forest Service and the Czech Agricultural University in Prague (CZU) completely inventoried 8 randomly-chosen 1-hectare blocks. Each living and dead tree was mapped, and the allometric measurements (height, base of the live crown, diameter at breast height, crown spread) were recorded. A randomly selected subset of trees was chosen for coring and dendrochronological analysis. This paper will primarily focus on that aspect of the study.

The eight 1-ha blocks represent a wide range of densities. Trees per ha ranged from 208 to 803 tph. Basal area ranged from 19.2 to 38.2 m^2 ha^{-1}. The average annual ring increment followed patterns one might expect, with larger increments for those trees in the low-density stands and smaller increments for trees in the higher density stands. An item of note was that, during the severe drought years of 1996 and 2002, the average annual increment of all trees, regardless of stand density, approached 0. After the drought year, when precipitation approached the long-term average, each stand reverted to its previous non-drought increment. During years of mild drought (2007, 2013, and 2016), there was some reordering of the tree response, suggesting that some densities were more sensitive to variations in available soil moisture than others. These results have implications for managers seeking to balance stand resiliency under changing climate conditions, habitat considerations for species of special concern, and other economic and ecosystem benefits of ponderosa pine stands in the Southwest USA.

Implications of modern finance theory for the management of complex stands

• Author: John Foppert
• Key words: irregular silviculture, asset pricing theory

Careful analysis of complex forest stands requires economic tools and concepts that differ from those developed for “pure” stands. Modern finance theory offers several key concepts relevant to the study of irregular silviculture, but these ideas fall largely outside the scope of standard forest economics and are unfamiliar to many forestry researchers. These include the principles of the capital asset pricing model, option pricing (including real options valuation and contingent claims analysis), and liquidity preference theory. The tools of modern finance were developed to valuate assets with dynamic cashflows and complex risk profiles. As such, they are also well suited to the analysis of mixed-species, multi-aged stands and can help inform the development of optimal silvicultural strategies for such stands when real option value, systemic risk exposure, and liquidity preferences are properly accounted for. This paper aims to introduce these concepts to a wider audience and explore some of their implications in the context of complex, irregular stands.

Unexpected directional changes in relative dominance of deciduous broadleaves along an elevation gradient in a hemiboreal mixed forest zone in northern Japan

• Author: Satoshi N. Suzuki
• Key words: hemiboreal forest, environmental changes, long-term dynamics

Under the current climate warming, forest tree communities are predicted to shift upward along an elevation gradient. To test this prediction, I analysed data from long-term permanent plots where trees have been measured since the 1960s or 1970s. The plots were located along an elevation gradient of 480-1290 m in the Maeyama Forest Reserve in the University of Tokyo Hokkaido Forest in northern Japan. The study area is dominated by cool-temperate broadleaves at lower elevations, boreal evergreen conifers at mid-elevations, and boreal deciduous broadleaves at higher elevations. Therefore, the relative dominance of deciduous broadleaves is lowest at mid-elevation around 800 m a.s.l. Given these situations, we expected the relative dominance of deciduous broadleaves (DBs) to increase at lower elevations and decrease at higher elevations under current climate warming. However, we observed unexpected changes; the relative dominance of DBs increased regardless of elevation. This suggests that not only climate warming but also other environmental changes, such as atmospheric CO_2 concentration, might have contributed to the increase in DBs. As increase of DBs in hemiboreal forests has been observed globally, a mechanistic understanding of the increase of DBs is necessary for developing effective management strategies to maintain the diversity and sustainability of hemiboreal mixed forests in the face of ongoing global changes.

Resistance and resilience of Hyrcanian mixed forests under natural and anthropogenic disturbances

• Author: Mehdi Vakili
• Key words: Hyrcanian forest, LANDIS-II, resilience, resistance

Biological disturbances are integral to forest ecosystems and have pronounced effects on forest resistance, resilience, and diversity. The Hyrcanian mixed forest, in northern Iran, is at risk of declining resistance, resilience, and diversity due to ongoing pressure from land use change, harvesting, and biological disturbances. We analyzed the resistance and resilience of this area under two biological disturbances (i.e., oak charcoal fungus, *Biscogniauxia mediterranea*, and alder leaf beetle, *Galerucella lineola*) and in concert with proposed harvesting. We used a simulation modeling approach whereby we simulated 12 combinations of biological disturbances and harvesting scenarios using the LANDIS-II landscape change model. We estimated the correlation between forest resistance and resilience and tree species diversity to harvesting and biological disturbance. We analyzed the full species composition and age class for 30 and 100 years after disturbances in order to assess resistance as the change in species composition over time. We considered resilience as the ability to recover from a disturbance back to a similar initial state. Results indicate a positive effect of biological disturbances and harvesting on diversity. Our simulations resulted in a negative relationship between diversity-resistance and diversity-resilience within high diversity areas. Our simulation of the Hyrcanian forest reveals that harvesting and biological disturbances, as tested, fulfill the goal of maintaining forest diversity. However, increasing diversity does not always follow by increasing forest resistance and resilience. Scenarios with oak charcoal fungus, both with and without harvesting indicate the lowest decrease in resilience and resistance.

Selective harvest improves the stand structural complexity and productivity along precipitation gradient in temperate Patagonian old-growth forests

• Authors: Daniel P. Soto, Pablo J. Donoso, Ángela Hernández-Moreno, Dominik Seidel
• Key words: Nothofagus, terrestrial laser scanning, enhanced vegetation index, stand structural complexity index, irregular forest structure

Forest management to increase forest structural complexity is becoming a new forestry paradigm worldwide because the resulting forests are hypothesized to be more adaptive to novel disturbances triggered by global change. However, the lack of empirical quantification may cloud its implementation. Here, we present results obtained from 40 1-ha permanent plots (20 treated with selective cuts and 20 unharvested) along a precipitation gradient (i.e., 320-2500 mm of MAP) in temperate deciduous old-growth forests in the Chilean Patagonia. All harvested plots were treated at least 30 years ago with selective cuttings – a partial overstory disturbance that removed 5 to 20 m^2 ha^{-1} of basal area. The terrestrial laser scanner (TLS) was used to calculate the stand structural complexity index (SSCI), and sentinel images were processed to obtain the Enhanced Vegetation Index (EVI: a proxy of aboveground primary productivity), which were related to precipitation (continuous variable) and management (binary variable: 1 as treated and 0 as unharvested plots) through a generalized mixed-effect model (glmm). The results show an interaction between precipitation and management, where management improves SSCI and productivity in mesic and wet sites and vice versa in dry sites. These results highlight no recovery trends at the drier conditions (i.e. < ~650mm), and stronger recovery trends in mesic and wet sites, creating more complex forest structures and productive forests (i.e., dense vertical canopy packing). These results provide important insights to implement management that increase complexity with low- to medium-intensity partial overstory disturbances, such as single-tree selection and irregular shelterwood cuttings. Last, precipitation should be considered as a prime variable to refine site-specific management operations to provide more resilient and productive forests to tackle global change.

Abstracts: Poster presentations

Effects of bark stripping by sika deer on forest stand dynamics with elevational gradient in subalpine mixed forests, central Japan

• Author: Takuo Nagaike
• Key words: sika deer, *Abies*, wild game damages

In order to understand the effects of bark stripping by sika deer (*Cervus nippon*) on the stand dynamics of subalpine mixed forests, the forests at different elevations were studied for 12 years. In 2008, 13 survey plots of 10 x 40 m were established at altitudes of 2000-2737 m at Mt. Kitadake, in the Minami-Alps Biosphere Reserve. Plots with lower elevation were dominated by evergreen conifers, while those with higher elevation were dominated by deciduous trees (*Betula ermanii*). All living trees ≥ 3 cm in diameter at breast height (DBH; where breast height is defined as 1.3 m) in each plot were identified to species and their DBH measured. The extent of visible bark stripping on each tree was recorded as the proportion of the tree circumference that had been stripped, in increments of 10%. Same surveys were conducted in 2012, 2016 and 2020. The number of living trees decreased year by year. The percentage of the number of bark stripped trees by sika deer to the total number of trees increased, particularly for *Abies veitchii* and *A. mariesii*. Also, the ratio of the number of the bark stripped trees to the total number of the dead trees during each survey period also increased year by year, particularly for the lower elevation plots where *A. veitchii* and *A. mariesii* were dominated. Therefore, the bark stripping by sika deer could decrease with living trees and significantly affect the stand dynamics of the plots, in which the preferred tree species for bark stripping dominated.

Seedlings of different ages in the same year respond differently to the root severance afforestation

• Author: Chang Xiaochao
• Key words: afforestation, seedling size, root severance

With the development of the seedling industry, industrialized, large-scale production has become the norm. In order to meet the demand for a large number of seedlings and the economical cost of production in the modern seedling factory model, seedling producers now produce multiple quantities of seedlings per year. Due to varying lengths of the growing period, various batches of seedlings will develop different seedling sizes and root structures in the same year. This has a significant impact on the identification of seedling quality and evaluation of silvicultural effects. During the course of a single year, our research concentrated on evaluating different seedling lots of the Chinese endemic species *Populus tremula* for different root severance intensities:

In the early stage of planting, larger-aged seedlings showed more severe dryness and dieback, with more than 50% dieback due to the maximum intensity of root break, whereas middle-aged and smaller seedlings were much less affected and the survival rate in the first year was stable until the fourth year; tree height and diameter at breast height (DBH) showed a trend close to the same survival rate, except for DBH, which maintained a clear advantage. In the remaining years, height and DBH were predictive of survival. In the other years, height and diameter were nearly eclipsed by seedlings with lower stature. This direction is supported by our calculated volume per hectare in conjunction with survival rate and volume per plant, which maintains an economic advantage of approximately 149% over conventional seedling size and root break strength. When added to the costs of pre-sowing management, this advantage becomes even more substantial.

Four years after planting, the survival and establishment of younger seedlings is superior to that of older seedlings, and this advantage has an effect on the economic production value, which is crucial for fast-growing poplars with a very brief rotation period.

Community forest management in Nepal

• Author: Binod Khatiwada
• Key words: forest management, governance, sustainable forest management

Interactive effect of salt stress and *Fusarium solani* on dieback in an important timber species *Dalbergia sissoo*

• Authors: Muhammad Zohaib Anjum, Asif Javed Muhammad, Imran Ul Haq, Fahad Rashed
• Key words: climate change, salinity, fungal pathogens, dieback interaction

Dalbergia sissoo is a native tree species of the Indo-Pak subcontinent. It is one of the most common timber-producing species used in the agroforestry, fuelwood, and furniture industries. Abiotic stress, such as salinity, is known to affect the establishment of *Dalbergia sissoo* plantations in Pakistan. This research aimed to determine the pathogenicity of *Fusarium solani* on *D. sissoo* under three levels of salinity (EC2, EC4, and EC6 dS m^{-1}). The seedlings were inoculated either simultaneously or predisposed to salt stress for two weeks before being subjected to fungal inoculation. High disease incidence was observed in seedlings predisposed to salinity following fungal inoculations. Controlled seedlings did not show dieback symptoms thus establishing the role of salinity predisposition in causing shisham dieback. Reduced plant growth rate and increased lesion growth were attributed to low leaf osmotic and water potential as a result of combined stresses. Photosynthetic pigments such as chlorophyll a, chlorophyll b, and carotenoids, were negatively affected. A marked increase in CAT and POD was observed which effectively lower H_2O_2 levels in stressed seedlings. It was concluded that abiotic stress may predispose shisham to the fungal pathogen that causes tree dieback. Therefore, it is suggested that abiotic stress remediation or the selection of the genotypes tolerant to abiotic factors would help manage shisham dieback effectively.

How climate change affects ecosystem services in mixed forests? Case study: mountains of the Iberian northwest

• Author: Ignacio Javier Diaz-Maroto
• Key words: land-use, socioeconomic model, local demand

The interaction between society and environment plays a key role in landscape patterns, mainly in those subject to human impacts. A few ecosystem services, e.g. biodiversity conservation, are often greater in mountain cultural landscapes than in natural landscapes, depending on the heterogeneity created by nature and anthropological actions and behaviours. Traditional practices of land-use in the mountains of the Iberian northwest have shaped a system planned by seasonal cycles and spatial patterns of human activities. The exploitation system is an agricultural-silvicultural-pastoral model adjusted to the heterogeneity of the highland environment. This socioeconomic pattern has shaped the current cultural landscapes, characterized by exceptional biodiversity and wide-ranging ecosystem services. In spite of the discrepancies between the local demand and political guidelines with respect to conservation objectives, there is an urgent need to implement a 'real' strategy for maintaining and enhancing biodiversity. The study focuses on a temperate mountainous region with an outstanding biodiversity, Mountain ranges of 'Os Ancares' and 'O Courel', located in the Autonomous Community of Galicia, in the northwest of the Iberian Peninsula. Our objectives are to know: i) the state of biodiversity and ecosystem services in cultural landscapes, ii) existing threats and risks, notably as climate change is affecting ecosystem services, and iii) the demand and local use of natural resources. Through these goals, we will be able to show how biodiversity and ecosystem services are embedded in cultural landscapes. Also, how the landscape quality influences biodiversity and ecosystems, as well as how landscape planning and management could create options for biodiversity conservation and to ensure ecosystem services. The results will provide a basis for conservation management of temperate mountain cultural landscapes, both from a scientific viewpoint and for land-use policymakers.

Socioeconomic changes in mixed forests in north-western Spain: ecosystem services, resilience and sustainable management

• Author: Ignacio Javier Diaz-Maroto
• Key words: *Quercus* forests, disturbances, human pressure

Current ecosystems are the result of a blend of anthropological influence and vegetation dynamics in the last Quaternary glacial-interglacial cycle, and their development can be well-defined by different methods (dendrochronology, isotope dating, palynology...). In the north-western Iberian there is data of *Quercus* species presence since the Cretaceous and their expansion in the Tertiary. The decline of broadleaf mixed forests began in prehistoric times, coinciding with the expansion of human activity and the establishment of crops and pastures; agriculture and livestock began between 4000-5000 BC. Other causes were the expansion of the naval industry, extraction of wood and firewood for domestic/industrial use and forest fires. These activities meant a diminution in the area occupied by woodlands until the middle of the 19th century, without carrying out any measure of suitable management to promote their resilience. On the contrary, forests were not managed at all and unsuitable silvicultural treatments were applied, such as pollarding and felling of the best trees. In the second half of the 20th century there was an increase in the area occupied by broadleaf species because of the abandonment of certain activities such as firewood use, agriculture and extensive livestock breeding, and shipbuilding decline. Much of smallholder farms have disappeared and have been replaced by protector repopulations, afforestation with fast growing species and unproductive land. As a result, in the last decades, there has been an important increase in the area occupied by mixed forests. Some authors have shown that the sustainability, and so the ecosystem services of these forests, depend on the maintenance of traditional activities, i.e., extensive agropastoral exploitation and forest suitable management. It is worth noting several observations indicate a substantial resilience of ecosystems to historical disturbances.

Transformation to continuous cover forestry in Ireland: the effect of gap size on growth of underplanted trees in Sitka spruce plantations

• Authors: Laura Harris, Áine Ní Dhubháin, Ian Short, John Devaney
• Key words: underplanting, continuous cover forestry, Sitka spruce

Most Irish forests are even-aged plantations managed under the clear-felling silviculture system. National and European forest policy promotes the transition to more environmentally sustainable forest management systems such as Continuous Cover Forestry (CCF), which typically relies on natural regeneration to restock trees. In cases where natural regeneration is unsuccessful or management aims to introduce new species, underplanting represents a viable method to introduce greater tree species richness. However, there are currently no established guidelines in Ireland on the appropriate levels of overstory canopy retention to ensure the success of underplanted tree species. The ContinuFor project aims to address this knowledge gap through a multi-species underplanting study. This aim of this study is to assess the relationship between canopy openness in stands of Sitka spruce and the survival, growth, and health of underplanted trees.

Two Sitka spruce plantations in the Dublin mountains which underwent one selective thinning intervention in 2020 are being used for this study. Each site was planted with 20 coupes in gaps of varying canopy openness (2% - 42%) of broadleaves or conifers. The broadleaf coupes contained *Quercus petraea* and *Fagus sylvatica*, while conifer coupes included *Pseudotsuga menziesii* and *Thuja plicata*. Trees were protected with metal mesh tree guards to protect from deer browsing and planted 1.5 m apart. Tree survival, height and root collar diameter are being monitored for the duration of the experiment. In addition, the maximum quantum yield of chlorophyll fluorescence is being monitored to directly assess the impact of light intensity on the photosynthetic health of underplanted seedlings.

Determining the levels of canopy openness that promote optimal growth and survival of these underplanted trees will offer valuable insights into the use of underplanting to enhance the resilience in Sitka spruce stands in the face of climate change.

Post-war restoration of windbreak systems with innovative agroforestry

• Authors: Vasyl Yukhnovskyi, Olga Tupchii
• Key words: damaged wood, design, felling, silvoarable agroforestry

The war in Ukraine caused significant damage to the woods. Three million hectares of forests were damaged by Russian aggression and need to be restored. The windbreaks protecting the fields also suffered great destruction. As a result of intensive military operations unprecedented destructive processes took place in the East and South because windbreaks within these forestless areas are almost the only shelter for military equipment and troops. The area of the damaged windbreaks will be approximately 2.7 thousand hectares.

Restoration of heavily damaged, thinned, ineffective plantations is recommended to be carried out by reconstructive felling. Since the edges are usually more damaged during military operations, it is advisable to remove the outer rows of trees and bushes. During the implementation of such measures, it is advisable to transform the windbreaks into silvoarable agroforestry with the formation of two- or three-row windbreaks.

First, the width of a windbreak will decrease sharply, which will make it possible to free up significant areas for agriculture. Secondly, an effective design of the windbreak will be formed. Third, the windbreaks will be supplemented with new, more valuable tree species, adapted to climate change with a wide range of ecosystem services.

Restoration of windbreaks with innovative agroforestry is carried out by planting seedlings, saplings or sowing seeds of tree species and bushes, as well as natural restoration on the spot of destroyed plantations after their felling.

Thus, the destruction of both wood and windbreak systems as a result of the war in Ukraine should lead to revisions in forest management that will help forest ecosystems better cope with climate change, maintain biodiversity, and strengthen ecosystem services. A more diverse mosaic of agroforestry systems should replace the damaged windbreaks. New agroforestry systems will be less vulnerable to intense fires, more stable, with high amelioration properties.

The perspective of pure silver fir forests in Croatia concerning climate change and different management models

• Authors: Eva Dafčik Močnik, Vid Šarić, Karlo Beljan, Krunoslav Teslak
• Key words: climate change, ForClim, management, silver fir

Silver fir forests are a significant natural resource of the Republic of Croatia with a share of about 13% of the forest area. About 90% of the areaare mixed beech-fir forests on limestone and the rest are pure silver fir forests on a silicate geological base. The area of silver fir in Croatia forms the southern edge of its distribution. All mentioned above, along with other characteristics of the habitat, makes silver fir forests in Croatia quite sensitive to climate change.

This paper investigates the future development of pure silver fir forests using the Forclim simulator with the application of theoretical management through three climate scenarios: optimistic, pessimistic and conservative. In the defined projection period of 150 years, climate scenarios are determined by different increases in temperature, amount of precipitation and air humidity. The optimistic scenario represents the lower limit of temperature increase as a result of the maximum reduction in the use of hydrocarbons. The pessimistic scenario outcome is from a maximum increase in temperature with a failure to reduce the use of hydrocarbons. Further, the conservative scenario is determined by unchanged climatic conditions. Research was conducted on a selected pure silver fir forest stand with a minimum possible proportion of common beech (number of trees 379 pcs/ha, base area 35 m^2/ha, wood stock 410 m^3/ha, share of deciduous trees max 20% of growing stock) for which it is assumed that the habitat is more suitable for silver fir and will be able to withstand the expected dynamics of climate change for a longer time.

Results indicate a great impact of climate change on the ecological niche of silver fir. All scenarios predict a significant increase in the proportion of deciduous tree species and poor rejuvenationof silver fir. Results point to extreme challenges for future forest management planning, especially in the context of the requirement to increase archived carbon in forests.

Role of disturbance legacies and browsing on forest recovery across a severity gradient caused by compounded disturbance

• Authors: Matteo Cerioni, Dušan Roženbergar, Matija Klopčič, Thomas A. Nagel
• Key words: disturbance legacies, mixed forests, resilience

In February 2014, an extremely severe ice storm caused damage to forests across Slovenia. This event was followed by a severe bark beetle outbreak, which caused widespread mortality to spruce trees, which were subsequently salvage logged. This sequence of disturbances created a heterogenous mosaic of forest patches with different degrees of damage and disturbance legacies, drawing attention to the role of species and structural diversity on forest resilience to compounded disturbances. Further abiotic and biotic drivers, including browsing and competition with ground vegetation, interacted in affecting the density and composition of post-disturbances tree regeneration. We examined a forested landscape in central Slovenia characterized by a disturbance severity gradient ranging from undamaged areas to complete canopy removal in areas comprised of pure spruce stands prior to disturbance. We collected field data on the remaining tree structure and growth of surviving adult trees across the disturbance severity gradient, on tree regeneration in patches with complete canopy removal across multiple inventories, and regeneration in fenced areas to quantify the impact of ungulates browsing. Preliminary results on the role of structural and species diversity in forest recovery after compounded severe disturbances will be presented, together with temporal trends of post-disturbances regeneration density, composition and ecological drivers.

Testing methods for assessing the performance of natural regeneration and artificial afforestation using verifiable criteria

• Authors: Blaž Fricelj, Jurij Diaci, Gal Fidej, Tim Pirc, Dušan Roženbergar
• Key words: planting, densities, mortality, methods, silviculture

The intensity and frequency of extreme weather events has increased worldwide in recent decades. At the same time, the resilience of forests is decreasing due to changes in their structure, pollution, lack of maintenance, non-management and the resulting ageing of forests. More than one third of annual logging in Europe and Slovenia is due to sanitary reasons. Improved methods for restoring forests after disturbance are needed to prevent increasing ecological and economic damage and the decline of ecosystem services. Studies indicate a high regeneration potential of ecologically and economically interesting light-demanding species, whose proportion is decreasing due to competition from ground vegetation, lack of management, and excessive wildlife. In Slovenia, decisions on supplementing natural regeneration with planting are not based on an objective assessment of the success of natural regeneration, while in most European countries minimum requirements for natural regeneration have been included in forestry legislation. As artificial reforestation declined, so did the production of forest nursery stock and seed. As a result, the success of artificial reforestation has not been satisfactory. In Slovenia, there is currently no system for verifying the success of reforestation, which applies to both natural and artificial forests. However, some other Central European countries have developed such systems, e.g. Switzerland (Canton Aargau) and Germany (Bavaria). To assess the success of regeneration, we have developed three methods for evaluating the performance of young trees in natural and artificial regeneration plots: (I) a method based on comparison with planting density for uniform stands, (II) a method based on a combined assessment of density and cover, (III) a method based on mortality, and (IV) a method for evaluating the success of regeneration of forests in the pole development stage.

The influence of species diversity, stand structure and competition on stem quality of different species

• Author: Luka Krajnc
• Key words: stem quality, assortment grade, beech, spruce, oaks

This study presents the results of stem quality assessment data collected last year on a subset of Slovenian National Forest Inventory plots. Stem quality was assessed using a relatively objective approach, and we present here the results on how different external factors influence tree stem quality on individual plots. The effects of stand horizontal and vertical structure, competition, and species diversity on stem quality will be evaluated and presented in this study. Stem quality was objectively evaluated based on the length of the stem usable for assortment production, the height of the first living and dead branch, and other quantitative assessments for each tree. Using the developed methodology, each tree was divided into three different sections, and for each section, the most prominent depreciating factor was recorded in relation to the assortment grade requirements. By combining the recorded stem quality data with taper equations for each tree species, the proportion of the total tree volume by individual assortment grade was calculated. The volume proportion of each grade was then used as a proxy for stem quality in subsequent analysis. A total of 2260 individual trees were measured and included in the analysis, distributed across 344 sample plots.

Extreme climate events force spruce trees to choose between growth and defense

• Authors: Denisa Sedmáková, Róbert Sedmák, Peter Jaloviar, Pavel Ďurica, Milan Saniga, Stanislav Kucbel.
• Key words: *Picea abies*, growth trends, single tree mortality

Low temperature and the short length of the growing period are the predisposing factors limiting the long-term tree growth in timberline or lower treeline zones of the Western Carpathians. Recent climate warming has relaxed growing conditions and resulted in observed enhanced productivity and growth rates of trees. In contrast to average growth of all trees, the sub-group of trees may express different long-term growth trends, the so-called growth divergence. Mechanisms leading to long-term divergence of secondary growth of neighbouring trees in high mountain conditions are largely unknown. To improve the understanding of this phenomenon we sampled groups of visually healthy and declining Norway spruce trees of comparable size and social status. One of our hypotheses was that health status and morphology of tree crowns can differentiate and define the long-term growth-specific subsamples of trees within the population. We also hypothesized that an individual extreme climatic event could affect the growth dynamics in the longer term and consequently cause a decrease in trees' resilience and their dieback. We found that the single-year extreme negative growth deviations (below 25% of the previous short-term growth) recorded on more than 50% of trees induced a long-term growth decline in size and subsequent dieback of trees. Identified years showed significant drops in temperature and increased rainfall (not exclusively) in summer during the same and/or the previous season with likely influence of winter weather as well. Our findings bring some light into issues on the uncertainty of climate change impacts and vulnerability of high mountain spruce forest stands and are relevant for single-tree or group selection silvicultural systems. We point out that extreme weather events - likely to accelerate in the near future- constitute serious risk factors that alter the stability and functionality of trees as well as patterns of stand dynamics.

Analysis of dry episodes in the spurce stands of the Orava region during 2015-2021

• Authors: Jozef Rozkošný, Gabriela Ivaňáková, Ivana Krčová, Maroš Turňa, Jakub Ridzoň
• Key words: drought, forest ecosystem, spruce, drought intensity, Orava region.

The aim of this work was the analysis of the occurrence of drought, which was determined by the deficit of precipitation and the deficit of soil moisture in the time period 2015 till 2021 in the Orava region. Dry episodes were compared with the extent of the occurrence of important biotic pests on the adult forests, which had been registered by the foresters of the state corporation Slovak Forests. The Orava region was chosen because of the long-term spruce forests decline and the occurrence of more severe drought, which had been rare in the past there. The biotic factors Armilaria sp. were chosen for their high frequency in Orava area and for their predisposition to continue in the process of the degradation of woods, as the secondary pest beside the drought. The soil water deficit correlates with deficit of precipitation. The drought damage on spruce stands was observed approximately 1 - 2 month from the beginning of deficit of soil moisture. The highest drought damage was found in summer. It was registered, that the occurrence of important biotic pests in the dry periods is more frequent and the warnings and precautions are inevitable.

Continuous Cover Forestry: Which sampling method should be used to ensure sustainable management?

• Authors: Mathias Leiter, Hubert Hasenauer
• Key words: continuous cover forestry; forest sampling, sustainability

Even-aged forests in Central Europe are threatened by climate change and increasing forest disturbances. To address this issue, forest stands are being transformed into more resistant and resilient mixed continuous cover forests, through changes in forest management. This creates a new challenge that is often ignored: The transition towards more diverse stands implies a reevaluation of forest sampling designs. In our study we compare the two most commonly used terrestrial sampling methods in forestry, the fixed area plot sample and the angle-count-sample, for their suitability in continuous cover forestry. To address the challenge of transition from homogenous to structurally diverse stands on a forest inventory level, we virtually simulated these methods in real-world plenter forest stands in Switzerland. We analyse the error components and variability of each sampling method and different sampling sizes in deriving forest parameters, such as stand density, basal area and annual basal area increment. We calculated the needed sample size to stay within a 10% error from the mean: Our results suggest that for angle-count-samples with a basal area factor of 4 m^2/ha, 244 samples are needed for stand density, 35 for basal area, and 88 for annual basal area increment. For a fixed area plot sample with an area of 300 m^2 the respective sample sizes are 65, 61, and 51. These findings can guide forest practitioners in designing inventory strategies for structurally diverse stands.

Long stand development in floodplain forest on locality Mochov (East Bohemia)

• Author: Jiří Souček
• Key words: floodplain forest, multi-aged stand, development

A development of mixed floodplain forests on locality Mochov (East Bohemia, around river Dedina, altitude 250 m asl.) is realized from 1958 to today. The stands (oak with European ash in upper canopy, mainly lime in understorey) were actively managed as multi-storeyed forest for 50 years (until 1970s), with mainly sanitary cuttings carried out at present time. Diameter distributions are permanently shaped like an inverted J curve. Share of lime on stand characteristics successively increased.

Effective beech stand management in the conditions of climate change

• Authors: Zdeněk Adamec, Lumír Dobrovolný, Tomáš Pospíšil
• Key words: beech health, effective thinning, value increment silviculture

In many parts of Europe, problems with the dieback of beech (*Fagus sylvatica* L.) have occurred in the context of climate change and other factors. Specifically, in the southeastern part of the Czech Republic in our research area "Moravian Karst", however, we are recording a gradual disintegration of old beech stands growing on dry sites. These stands were managed by conventional way based on weak thinning interventions and a long rotation period for over 100 years. The goal of our research was to find a more efficient and safer model of beech management. For this purpose, two decades ago, research plots were established in the University Forest Enterprise Křtiny to compare variants of beech silviculture. The method of target trees was used with the release of the most prospective (valuable) individuals in the crown space. With high-intensity thinning (HIT), all direct competitors were always uncompromisingly harvested in the vicinity of the target trees (using 4-5 measures), while with zero-intensity - i.e. self-thinning (ZIT) no competitors were removed. At the level of individual trees, the released trees from HIT reacted with a significantly higher volume increment compared to ZIT. This also shows a good vitality of these trees as a prerequisite for future resistance. They will also reach target dimension earlier compared with conventional silviculture, which will prevent the risk of disintegration and wood depreciation (including reduction of red core). At the stand level, the total volume production of both variants HIT and ZIT was identical, and therefore there is no production loss in the HIT. In HIT with the occurrence of natural regeneration in gaps, there was found also a wider diversity of diameters and heights which again leads to higher resistance of the ecosystem. The conversion of even-aged management to a value increment silviculture could be one of the most effective and operationally usable ways to adapt European beech stands to climate change.

Quantifying Changes in Tree Species Diversity and Stand Structure in Three Sub-Areas of Training Forest Enterprise Křtiny (Czech Republic) using data from permanent inventory plots

• Authors: Michal Kneifl, Jan Kadavý, Robert Knott, Martin Kománek
• Key words: structure indices, continuous cover forestry, conversion

The article reports the findings of a study that analysed the changes in the Gini index (indicating stand thickness structure), Shannon index (indicating tree species diversity), and Artenprofile index over time, based on data collected from permanent inventory plots located in three sub-regions of the Křtiny Training Forest Enterprise. These sub-regions underwent conversion from an even-aged forest to a forest with permanent cover for varying durations. The analysis revealed significant spatial heterogeneity in the structural indices and highlighted that even in areas where the conversion to a forest with permanent cover was not implemented in the long term, heterogeneous forest stands could still be identified and serve as a foundation for future forest management.

Young beech plantation – “stepchild” of close-to-nature forestry

• Authors: Antonín Martiník, Petr Sýkora, Jiří Krásenský, Jan Žákovský
• Key words: beech, thinning, climatic change, strategy

We discuss the topic of how to manage young beech stands established following clearing in a time of climate change. In the present, European beech is the most common broadleaf species for reforestation in the Czech Republic. About 24% of all areas were artificially established by this species in the Czech Republic last year. According to bionomic strategy, beech is a competitive and stress tolerant species. Slow growth in youth, high tolerance to shade and specific reproduction ecology favor shelterwood or selection system for this species. On the contrary, beech cultivated on clearing show low quality of stems.

Two experimental plots with four thinning regimes were established in the Training Forest Enterprise Křtiny. These stands grow in the oak-beech vegetation zone and are at the age of 19 and 18 years. Only one, low intensive cleaning was performed in these stands several years ago. We performed these silvicultural treatments following different management strategies: 1. Conservative strategy; 2. Close-to-nature strategy; 3. Climatic strategy I (thinning interval 4-5 years); 4. Climatic strategy II (thinning interval 2 years).

The conservative strategy follows traditional treatments of beech stands; proper thinning regime is suitable for naturally regenerated stands. Thus, utilization of these treatments for beech plantations is questionable. Close-to-nature strategies follow natural processes. There are questions about how much space should be left for nature at the plantation forests. The climatic strategy stems from presumption that growing conditions for beech in target regions are getting worse. Strong positive thinning led to shorter rotation periods for target trees. There are expected longer crowns and lower stand productivity but higher tolerance to climatic extremes of individual (target) trees. Shorter thinning frequency means better utilization of growing space and sources, but also require more practical efforts.

EXCELLENTIA - Center for Climate-Diversity-Pathogen Interactions in Central European Forests

• Douglas Godbold, Boris Rewald, Libor Jankovský, Pavlína Pancová Šimková
• Keywords: interactions, biodiversity, soil, ecosystem

The new interdisciplinary EXCELLENTIA Centre for Forest Ecosystem Research, recently established at the Faculty of Forestry and Wood Technology (LDF) of the Mendel University in Brno, will research forest ecosystem functioning in climate-vulnerable Central European forests. Specifically, the centre will investigate the impact of projected climate scenarios for Central European forests on the relationships between biodiversity and ecosystem functioning (BEF). A particular focus will be on the under-explored 'hidden half' of forest ecosystems - the soil with its biotic interactions between bacteria, fungal pathogens, symbionts and decomposers, soil fauna and plant roots, and as affected by management, including harvesting. Building on the large and long-term data sets available, timely experimental research programmes will be established at the University Forest Enterprise Masaryk Forest Křtiny, complemented by forest education activities such as science days and guided tours for children to interested adults. The multidisciplinary team will focus in particular on the effects of climate change on differently diverse/mixed forest stands, with the Masaryk Forest offering unique opportunities due to its mixed old-growth stands, many of which have been permanent research plots since 1973, compared to more recently established tree diversity experiments worldwide. Species-, genotype- and management-specific drought effects, susceptibility or resistance of tree root systems to pathogen attack, and above- and below-ground carbon dynamics as shaped by (soil) diversity are other important issues the project will address. The new centre is establishing research programmes for the coming years and encouraging forest scientists worldwide to collaborate in research and communication activities - building a true "EXCELLENTIA" centre for Central European forestry, drawing on the multidisciplinary expertise of global experts.

In-conference excursion

Adaptive Forest Management to Climate Change in the University Forest Enterprise

EXCURSION GUIDE

On the occasion of the IUFRO 1.05 & 1.09 Conference in Brno and the 100th anniversary of University Forest Enterprise

Introduction

In 2019 Mendel University in Brno (MENDELU) observed the 100th anniversary of its foundation, and again in 2023 it is commemorating 100 years since the establishment of one of its organizational units - University Forest Enterprise Masaryk Forest in Křtiny (UFE). The Czechoslovak State purchased the property of the Liechtenstein family in winter 1922/23 and donated it to the university for research and practical teaching of students and practitioners. The honorary title Masaryk Forest was awarded by the Ministry of Agriculture on April 14th, 1932, with the consent of the first president of Czechoslovakia, T. G. Masaryk.

UFE fulfills three main functions:

- Provides practical experience to MENDELU students within teaching and research activities, particularly through curricula of Faculty of Forestry and Wood Technology (FFWT), and creates conditions for university teachers to solve teaching, research and verification tasks,
- Exemplary and multifunctional forestry management that is adapting forests to climate change (including care for recreational infrastructure and forest aesthetics).

University forest lands are situated in an area of 10,200 ha, and form a continuous complex from the northern edge of the South Moravian capital of Brno to the town of Blansko. Forests are located at an altitude of 210-574 m above sea level and belong mostly to the forest region 30 - Drahany Highlands. The average annual temperature reaches 7.5 °C, and is limited by an average annual rainfall of only 610 mm. Fertile sites (63%) predominate, and the remainder are acidic (10%) and exposed (27%) sites. Regarding potential vegetation *Querceto-Fagetum* is prevailing. The terrain is very heterogeneous, with distinctive deep valleys, especially the Svitava and Křtiny Rivers. The bedrock is formed by granodiorites, culm greywacke and limestone, with a third of the enterprise located in the protected area of Moravian Karst (Natura 2000 localities reach over 40% of total area).

The forest lands are predominantly mixed stands, characterized by a great range of natural conditions, with 35% coniferous tree species and 65% deciduous tree species. The main coniferous species are spruce (14%), pine (7%) and larch (9%), and the main deciduous species are beech (40%), oak (12%) and hornbeam (6%). The average growing stock reaches 234 m^3/ha with average volume increment of 8.6 m^3/ha/year. The annual harvest reaches around 74,000 m^3.

Forest business activities are performed on three UFE forest districts (Vranov u Brna, Habrůvka, Bílovice nad Svitavou) and include silviculture and harvesting work, forest protection and other activities. The sawmill in Olomučany, with 2 band saws and 1 frame saw, 3 lumber dryings, steaming chamber and assortment line, and processes its own harvested timber, including timber sales and the subsequent implementation of the fuel programme. A modernized forest nursery produces a suitable

planting stock for reforestation and greenery. Forest machinery develops and manufactures forestry equipment - winches, rill planters, nursery machines, soil scarificators and especially several models of forest cableways, "LARIX". In a renovated chateau Křtiny, redesigned to a modern educational center with accommodation, provides complete services for professional, cultural and social events. Game management in the hunting grounds of MENDELU, managed by UFE, is own-accounted - hunting rights execution is not rented, but operated by the holder of the hunting ground. Right of hunting is practiced by employees of MENDELU (UFE, faculties), students of the Hunting club FFWT and holders of permits to hunt. A total of 4 hunting ground areas (Křtiny, Hády, Pheasantry Rajhrad, Game reserve Sokolnice) is used for practical education of hunting for MENDELU students, including solving professional theses. The main game in UFE are roe deer, boar and mouflon, and is also home to red deer, fallow deer, hare and pheasant.

UFE has been a holder of ecological certifications - FSC since 1997, PEFC since 2003, and in 2011 was declared a Forest Park Masaryk Forest Křtiny. Main reasons for these designations include forest management methods, aesthetic treatment of forests, many purpose-built demonstration facilities, advanced manufacturing, a database of research results, and UFE is a destination for domestic and foreign excursions, practical placements of students, foresters and other visitors. UFE is an important subject of educational activities and scientific research of students.

Forest aesthetics has a long-term tradition at UFE. For studying and relaxation there are three arboreta with valuable collections of trees. We also manage around 60 aesthetic meadows with plantations of exotic trees, 90 memorials of important Czech foresters and 50 water springs. Everything serves not only the needs of the university, but also the general public, pedestrians and cyclists.

With regard to the risks, safety and sustainability of forest management on our property, we consider the global warming trend and increasingly frequent droughts as a major factor – see Fig. 1.

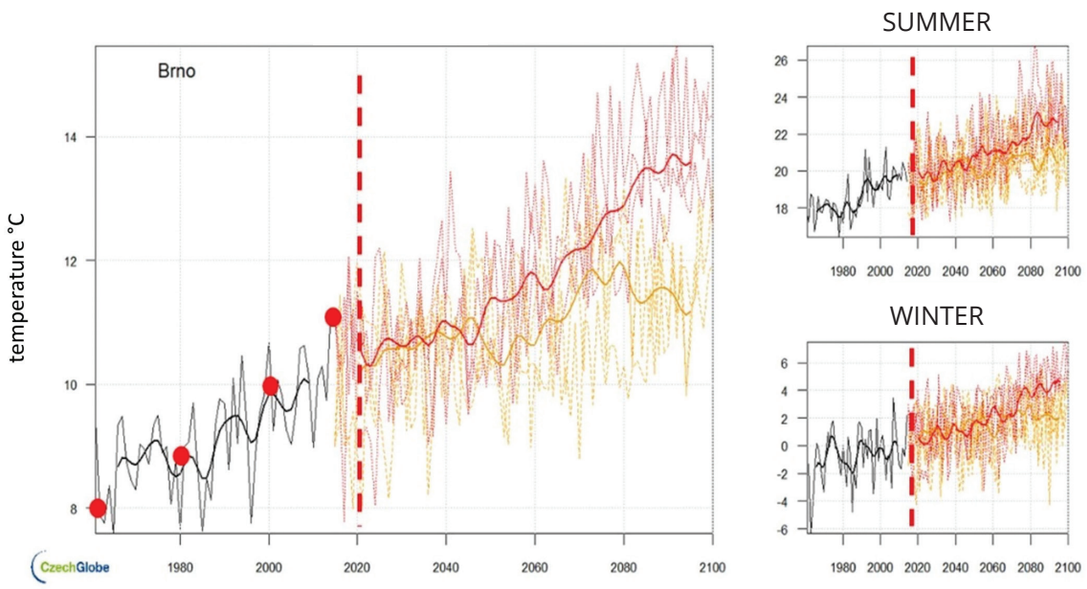


Fig. 1: Temperature trends for the period 1960 - 2020 and 2 prediction scenarios to 2100 - Brno region (source: CZECHGLOBE).

The recent drought period between 2015 – 2019 caused bark beetle (Ips typographus, I. chalcographus, I. duplicatus) outbreaks and dying of a certain proportion of Norway spruce – including young stands from the age of 30 years, and in the southern part Scots pine (I. acuminatus) and European larch (I. cembrae) were attacked. However, this was not "end of story". Since 2019 until now dying of deciduous species has started - mainly old beeches and oaks growing on limestone sites, steep slopes and forest edges (see Fig. 2, 3).

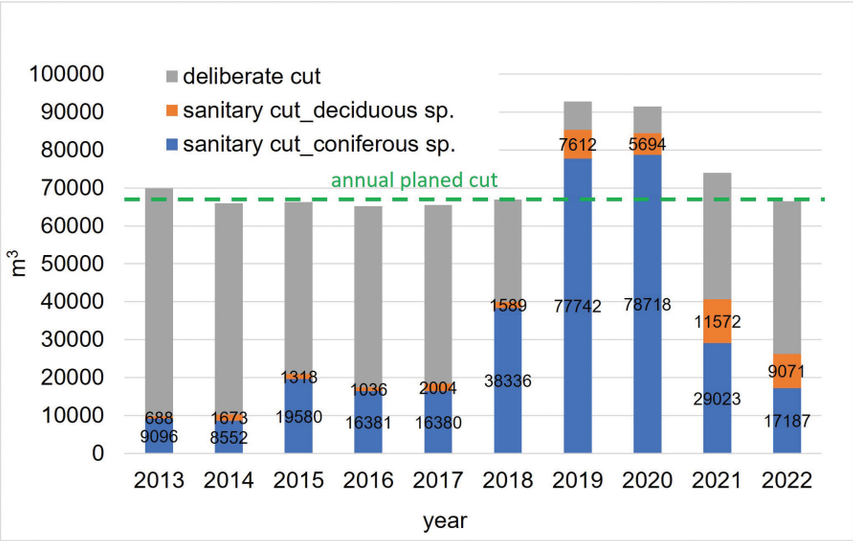


Fig. 2: Development of harvesting on UFE in decennium 2013 – 2022.

Fig. 3: Examples of dry beech (mainly from the top of crown) and marks of Taphrorychus bicolor on bark

Based on these facts we re-evaluated traditional shelterwood even-aged forest management on UFE towards low-intensity thinned dense stands (i.e. too high competition for resources – water) and trees with small crowns and root systems managed in too long of a rotation over 110 years. Forests and individual trees grown in this way are not adapted to predicted climate change and are more vulnerable to disturbances and therefore to economic losses. In cooperation with scientists from Mendel University, we have therefore developed and put into practice the concept of adaptive forest management, "Diverse forests for climate change".

Within the concept, we have introduced 9 key adaptation measures: 1) Forestry measures aimed at forest diversity (species, age, spatial, genetic) and the use of different types of management (or silvicultural models). 2) Closer-to-nature silvicultural techniques focused on the use of selective harvesting principles (with an increase in the value of volume growth) and use of natural processes in forest management. 3) The search for optimum standing volume stock and volume increment. 4) Forest tending aimed at individual tree stability and overall forest diversity. 5) Optimization of forest access

and harvesting technologies for sustainable harvesting and approaching of timber. 6) Maintenance of balanced game density - systematic monitoring of the ecosystem for derivation of a hunting plan. 7) Retaining habitat trees and dead wood. 8) Implementation of water retention measures in forests. 9) Qualified forest staff (foresters and workers).

With respect to point 1), we apply a total of 23 growing models within the forest estate. Some have been implemented for a long time (e.g. even-aged shelterwood, conversion to selection forests or forest reserves), others have been introduced recently – see Fig. 4.

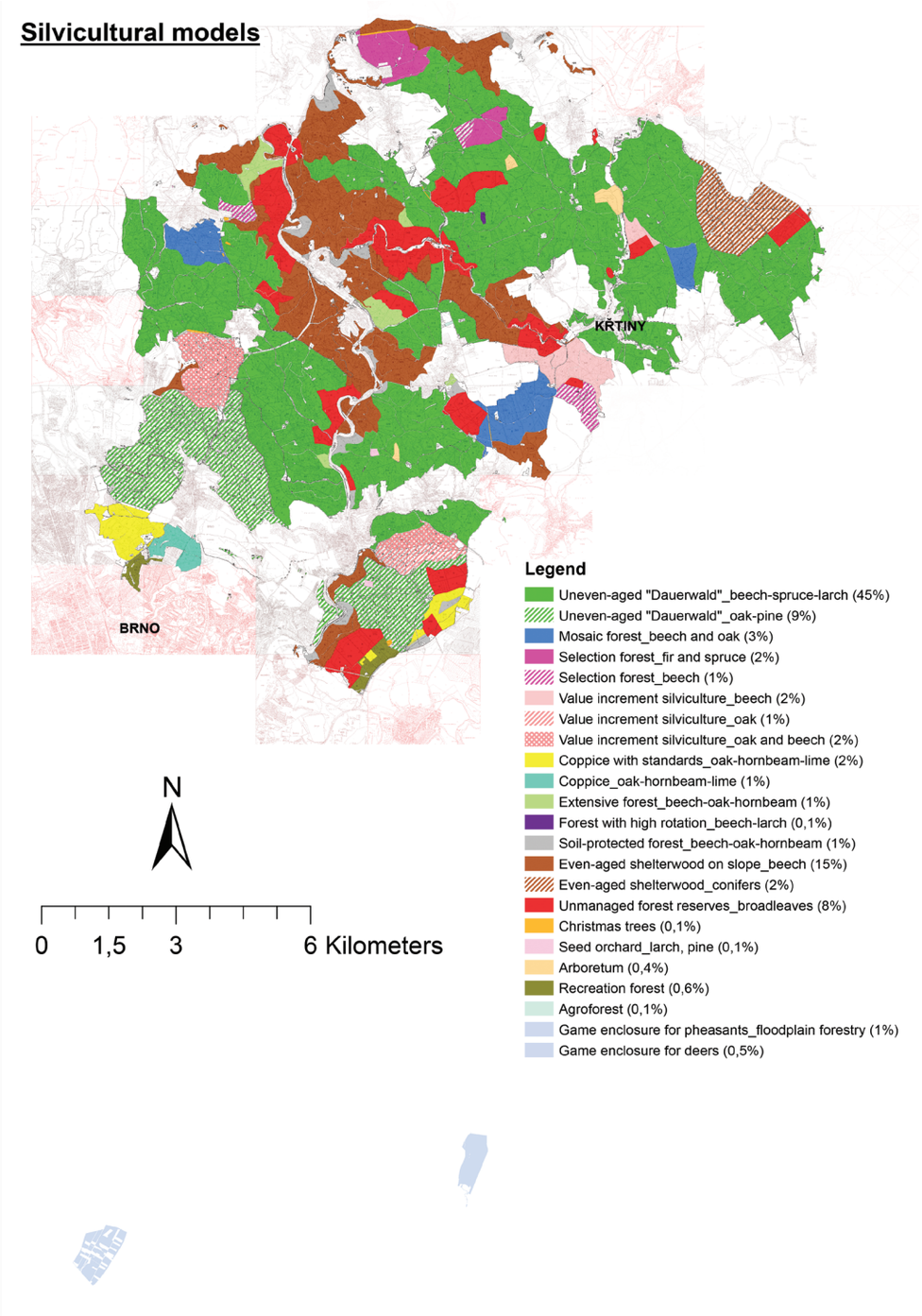


Fig. 4.: Silvicultural models at UFE

EXAMPLE 1: Mixed even-aged forest as a starting point of conversion to diverse forest

On the UFE there is over a 200 year tradition in management of mixed forest stands with high species diversity. This so called "Liechtenstein mixture" mostly consists of European beech and admixture of oaks, maples, limes, hornbeams, cherries, ..., Norway spruces, European larches, Scots pines, Douglas firs, ... all in one stand – see Tab. 1.

species	share %	volume m^3/ha
European beech	45	129
European larch	30	136
Douglas fir	15	79
sessile oak	5	13
hornbeam	3	4
Scots pine	1	4
Norway spruce	1	5
total	100	370

Tab. 1: Example of "Liechtenstein mixture" with 7 species in the age of 60 years (forest unit: 347A4/3a)

Under the Liechtenstein forest administration, these mixed stands were established by a combination of natural regeneration of deciduous trees and artificial introduction (by sowing and planting) of conifers using an even-aged shelterwood system. Even today, natural regeneration (70%) dominates in UFE forest regeneration, and the missing species are planted to create more valuable mixtures and increase tree biodiversity. Artificial regeneration prevails in calamity clearings, where we prefer group (patch) mixing - planting 1 tree species within a group (patch) up to a maximum of 0.2 ha, i.e. no plantations. Here, too, an admixture of trees from natural regeneration, including pioneer species, is welcome. For the formation of mixed stands, the subsequent thinning of the forest is also important, whereby all economically valuable admixed tree species are supported to grow.

Although we can be satisfied with such a mixed forest (in the future generation, however, maximum efforts will be made to increase the share of Sessile oak), its spatial structure - both vertical and horizontal is too homogeneous and even-aged, which is a consequence of the earlier use of the shelterwood model, with subsequent poor thinning (small crowns) and with the assumption of a high rotation period of 110 years. In view of the effects of climate change, it will be necessary to accelerate the felling maturity, and improve its spatial patch mosaic. Conversion to more diverse forest can be achieved in various ways - see below.

Example 2: Conversion to mosaic forest using value increment silviculture with target trees

Start: Even-aged (56 years old) beech stand (forest unit: 347B3b)
Model: Mosaic forest using value increment silviculture
Silviculture:

• Step 1 (current phase at UFE): selection and systematic intensive crown release of approximately 50 best quality target trees per ha. When selecting target trees, preference is always given to economically valuable and rare admixed species - typically oak, maple, cherry, larch,..., finally beech. We start the release when the lower length of the trunk without branches reaches about 10 m, i.e. when the upper height of the tree is about 15 m and the DBH is about 15 cm. The aim is to reach the target DBH of around 50 cm as quickly as possible, increase the value increment and to reduce the risk of disturbance of older stands, including the development of a red core. Once the stands have been thinned on high intensity level (around 25 - 30% of standing volume), natural regeneration takes place.

• Step 2 (future): use of irregular shelterwood - harvesting of target trees in groups (size around 0.2 ha). From a technological point of view, proper stand segmentation, sufficient density of truck lines and gentle harvesting in winter are required. After harvesting, the need for artificial regeneration of the missing valuable trees will be considered according to the situation with natural regeneration.

• Questions from practice: is the number of 50 target trees per ha sufficient? Will there be no loss in total volume production with intensive release?

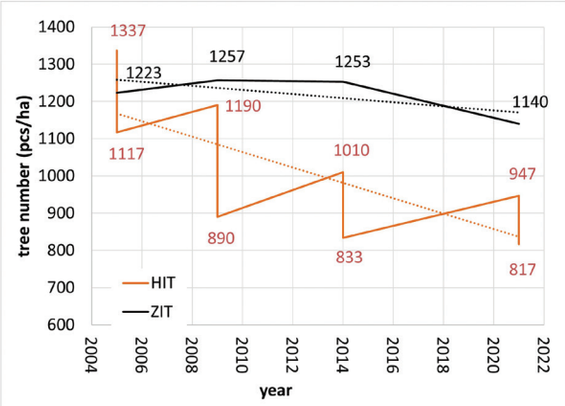
• Results from a 20-year research experiment (established by Prof. Heinrich Spiecker) of European beech production: Two extremes of thinned variants in two beech stands were tested. With high-intensity thinning (HIT), all direct competitors in crown space of the 47 target trees per ha (using 4 measures – once per 5 years) were always uncompromisingly harvested, while with zero-intensity - i.e. self-thinning (ZIT) no competitors were removed.

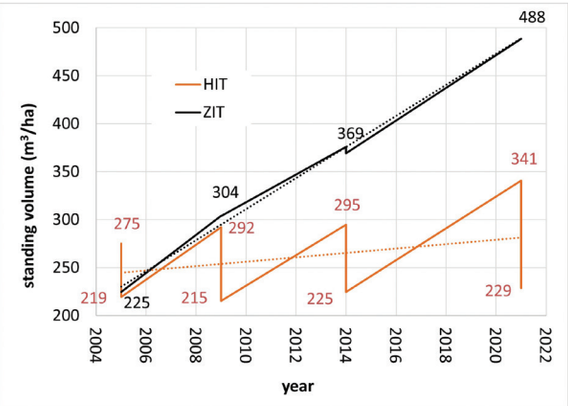
At the stand level, the total volume production in period 2005 - 2021 of both variants HIT and ZIT was identical (around 265 m³/ha), and therefore there is no production loss in the HIT – see Tab. 2 and Fig. 5. In HIT with the occurrence of natural regeneration in gaps, there was found also a wider diversity of diameters and heights which leads to higher resistance of the ecosystem.

Tab. 2: Values of European beech for HIT and ZIT variants at stand level

Variant	**HIT**						**ZIT**	
Year of (forest age - years)	Standing volume before harvest m³/ha	Harvest m³/ha	Standing volume after harvest m³/ha	Harvest intensity %	Volume increment m³/ha/year	Volume production_cumulative m³/ha	Volume increment m³/ha/year	Volume production_cumulative m³/ha
2005 (38)	275	56	219	24		275		225
2009 (42)	292	77	215		17,9	348	19,7	304
2014 (47)	295	70	225	32	15,5	428	14,4	376
2021 (54)	341	112	229		16,3	544	17,0	488
Volume production_2005 - 2021 m³/ha						**269**		**263**

Fig. 5.: Development of European beech tree number and standing volume for HIT and ZIT variants

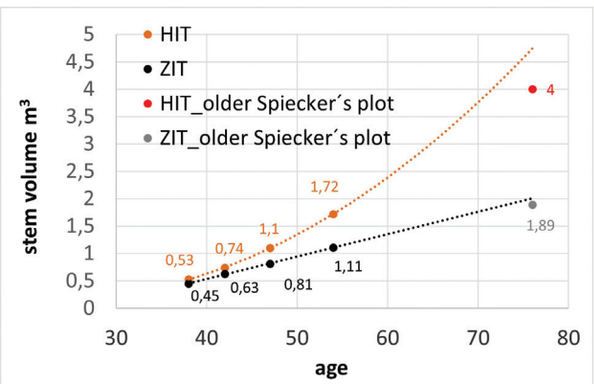




At the tree level the released trees from HIT reacted with a significantly higher diameter and volume increment compared to ZIT – see Tab. 3., Fig. 6. This also shows a good vitality of these trees as a prerequisite for future resistance. They will also reach target dimension earlier compared to conventional silviculture, which will prevent the risk of disintegration and wood depreciation (including reduction of red core).

Tab. 3: Average values of HIT and ZIT variants at target beech tree (47 trees per ha for both variants) level

Variant	**HIT**				
Year (age)	DBH cm	Stem volume m^3	Diameter increment cm/year	Stem volume m^3	Diameter increment cm/year
2005 (38)	23,9	0,53		0,45	
2009 (42)	27,4	0,74	0,90	0,63	0,86
2014 (47)	32,6	1,10	1,03	0,81	0,57
2021 (54)	38,1	1,72	0,79	1,11	0,39
2021 (76) – second older Spiecker´s plots	52,8	**4,00**	0,59	**1,89**	0,28



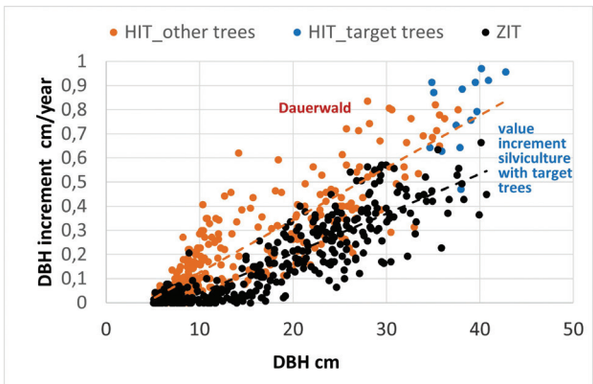


Fig. 6.: Beech target trees stem volume development according to age in HIT and ZIT variants / DBH vs. DBH increment relation of beech trees in HIT and ZIT variants.

These principles of the target tree thinning method can also be used in other related management models - e.g. continuous Dauerwald - to achieve individual stability and increase growth potential. Here, however, we use a larger number of target trees (around 80 trees per ha) at different DBH level and a lower release intensity.

Source: L. Dobrovolný, Z. Adamec, T. Pospíšil, et al. Beech dominated silviculture for the future - production, quality, stability. (in prep).

EXAMPLE 3: Conversion to Dauerwald using irregular shelterwood „free-style“

Start: High-value mature even-aged mixed beech stand with admixture of larch, spruce, fir, Douglas-fir and ash (forest unit: 141A4/1).
Model: Uneven-aged mixed forest “Dauerwald”.
Dauerwald principles:

- uneven-aged diverse (in species, diameters, layers) forest – stem by stem or in patches (up to 0.1 ha)
- continual canopy and soil cover, balanced microclimate, no clear-cuts
- balanced growing stock (around 300 m^3/ha) and volume increment (around 10 m^3/ha/year)
- harvest method: “free-style technique” - single and group selection (up to the value of volume increment) – salvage cut / removing the worst trees and competitors, cut of target DBH (approx. 45 – 55 cm), support of all perspective (high-quality and valuable) trees or rare species, optimal DBH structure
- prevailing natural regeneration with some planting of missed species (incl. exotic drought-resistant species)
- use of the control method of forest inventory (statistical grid of permanent plots) for harvest estimation (based on volume increment) and planning
- high resistance and resilience of forest ecosystem

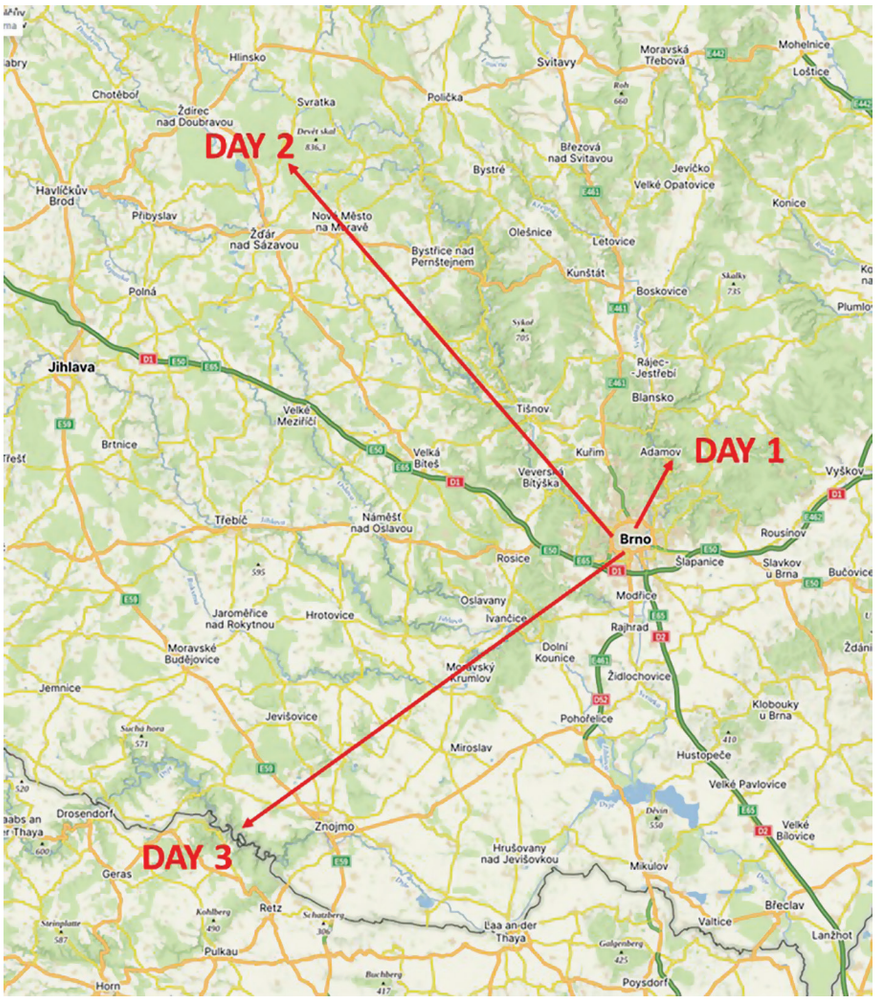
Silviculture: Originally, the stand was to be felled using regular shelterwood in strips with final felling of the mother stand during the following 20 – 30 years. Instead, irregular shelterwood using selection principles was used. In this way, a total of 1,117 m^3 was harvested in 2019 on an area of 9.9 ha from a total standing volume of approximately 5,300 m^3 (intensity 21%, 113 m^3/ha respecting the potential of the volume increment during 10 years). Single and group selection (called “free-style” silvicultural technique) have been combined. Group selection has created 21 gaps with an average area of 1,073 m^2 - see Fig. 8. These gaps serve to regenerate and support qualitative tree morphology and growth, especially of beech, and to increase biodiversity (regeneration of light demanding tree species, including pioneer species, etc.). Single selection has taken place between the groups.

The next felling intervention in 10 years (in 2029) will again take place in the form of single selection combined with a weaker expansion of the gaps created. The aim is a conversion into the model “Dauerwald” in this stand generation. In case of deterioration of the health of the converted stand, a faster regeneration will be proceeded with, and the conversion will be moved into the new stand generation, which will be well prepared for this purpose.

Fig. 8: Forestry map and situation after felling.

Legend
white: clear-cuts or roads
blue: gaps after harvesting
DBH classes:
yellow: 0 – 6 cm
red: 7 – 12 cm
green: 13 – 30 cm
brown: 31+ cm

Post-conference field trip



Locations visited during the post-conference field trip

Day 1 / Thursday, September 21st

University Forest Enterprise Křtiny

EXAMPLE 1: Conversion to selection forest using single tree selection

Start: Adult even-aged spruce-fir-beech stand – Stand A (forest unit: 113A4/1b), Stand B (forest unit 114D4/3b/1)
Model: Uneven-aged selection forest

Main differences of selection forest compared to Dauerwald:
- tree harvest method – single selection only (no groups, free-style, etc)
- higher spatial and age diversity – stem by stem or in very small patches
- lower species diversity – suitable only for shade-tolerant species – especially for silver fir

Silviculture:
Conversion using single selection since 1993 (Stand A) and since 1973 (Stand B) – see Fig. 9, 10, 11 and Tab. 4. Deliberate cut by single selection takes place here regularly once every 10 years. In the lower layers, the key tree species Silver fir is being promoted by thinning / tending at the expense of beech (natural strong competitor). The support of fir is also consistent with appropriate game management.

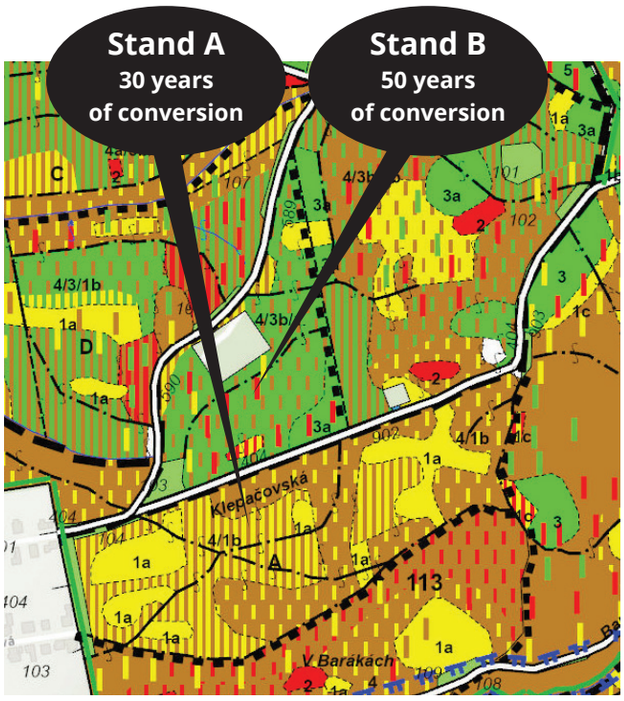
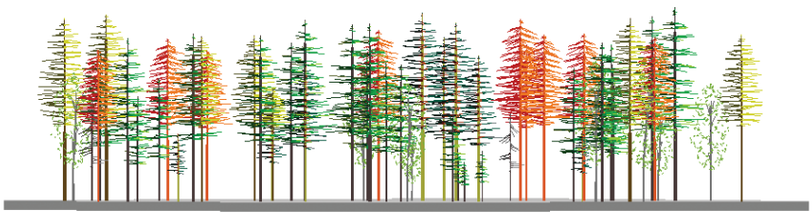
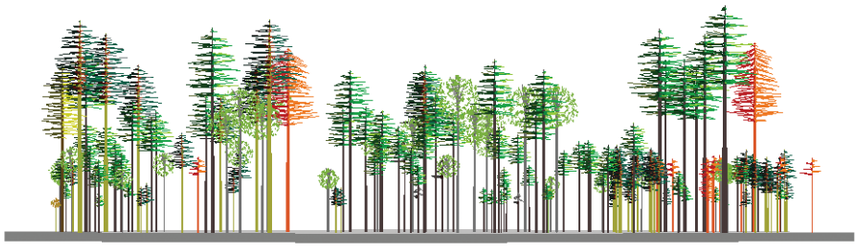


Fig. 9. Forestry map - Stands A, B in different time phase of conversion.

Stand A (30 years of conversion)



Stand B (50 years of conversion)



Visualisation of vertical structure of Stands A, B in different phase of conversion (visualised tress with DBH above 7 cm).

Fig. 10. Vertical structure of Stands A, B in different time phase of conversion.

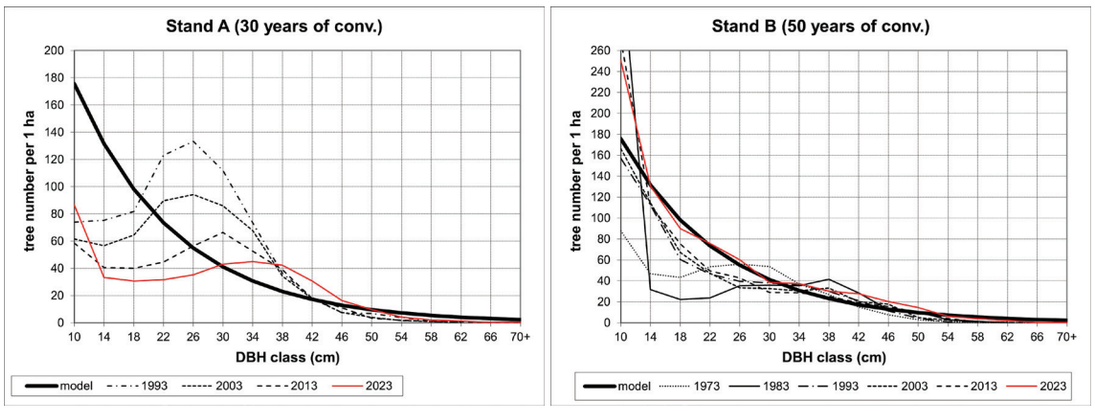


Fig. 11. Development of DBH structure of Stands A, B in different time phase of conversion.

Year	Stand A	Stand B	target
1973		231	363
1983		248	363
1993	418	271	363
2003	330	237	363
2013	346	250	363
2023	322	395	363

Tab. 4. Development of standing volume - Stands A, B (m3/ha)

EXAMPLE 2: Silvicultural Training Plot (Marteloscope)

Try to mark the silvicultural intervention using selection principles – see protocol.

EXAMPLE 3: Conversion to Dauerwald after windstorm

Start: Young (age 13 years) mixed stand resulting from the combined regeneration of a calamitous area (forest unit: 146E1a,1b).
Model: Uneven-aged mixed forest "Dauerwald"
Story: On June 12th, 2010, the entire UFE area was hit by the large-scale windstorm "Antonin". Not only spruce, but also deciduous stands were uprooted. In total, over 60,000 m^3 of calamity timber was processed on an area of over 70 ha, mainly using harvestor technology. The negative consequences of the resulting clearings for forestry on the one hand, have created an opportunity to change the species and spatial structure on the other. In the autumn of 2010, the resulting areas were reforested mainly with a group mixture of spruce and beech.

In the mentioned location (see Fig. 12) about 5.5 ha of calamity clear-cuts were created. The biomass after harvesting was mostly removed from the areas and used for wood chips. Subsequently, groups of spruce (total 2.3 ha, in spacing 1.5 x 1.5 m) and beech (total 3.2 ha, in spacing 1.2 x 0.8 m) were planted. At the same time, there was also a natural regeneration of successional species - especially birch, larch and pine. The resulting varied mix of trees, albeit in a uniform age arrangement, provides good conditions for conversion to the Dauerwald with proper thinning.

Silviculture: The aim is now to carry out structuring interventions leading to diversity in DBH and height and to reach the highest possible species diversity with all species, including pioneer species (as a safeguard for the future). The first such intervention took place here in November 2020.

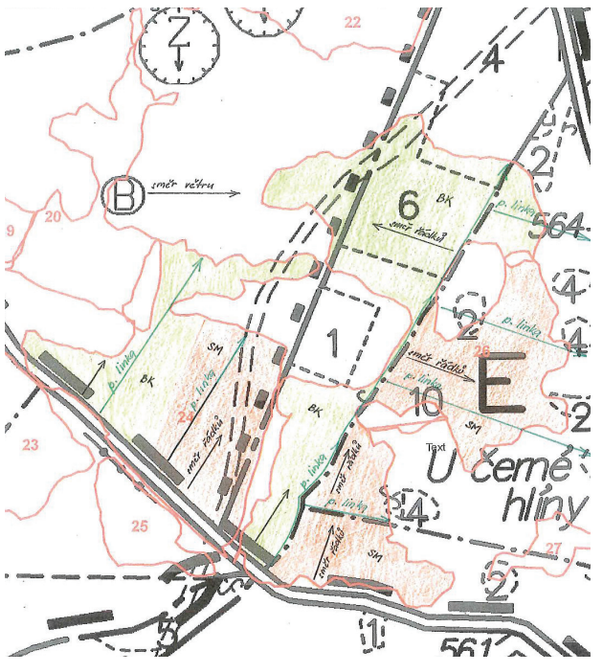


Fig. 12. Forestry map with situation of afforestation of calamity areas in 2010.

Legend
red lines: windthrow areas
green polygons: planting of spruce
red polygons: planting of beech

EXAMPLE 4: Conversion to Dauerwald after bark beetle outbreaks: close-to-nature experiment with secondary succession

Start: Middle-aged (30 – 50 years) even-aged spruce stands with admixture of deciduous species hit by bark beetle calamity (forest units 19, 20).
Model: Uneven-aged mixed forest "Dauerwald"
Story: This is an area of about 120 ha, where in the 1970s the old declining mixed stands (fir - oak - beech) were cleared and the resulting areas were planted mainly with spruce. In spruce outplantings, thanks to stump sprouting capacity, an admixture of oak and hornbeam has fortunately appeared, and in some places larch from natural regeneration. Even so, habitat-unsuitable unstable coniferous stands of the same age were created. During the large-scale bark beetle calamity in 2019, a large number of spruce areas (ca. 30 ha) died. At that time we were faced with the decision whether to use the conventional way, i.e. to harvest all the dead spruce area-wide and to carry out expensive artificial regeneration with aftercare on the groves. Instead, we opted for an experiment with the highest possible use of natural processes (especially secondary succession) to optimally move towards a diversified Dauerwald model and reduce economic inputs.

Silviculture: The whole area was divided into parts with different types of management.

Parts with monocultures of dead spruce – see Fig. 13. Logging took place in strips - alternating between clearings and standing dead spruce trees. The planting on the clearings was mainly oak, possibly also Douglass fir, beech or maples. Retained spruce parts with secondary succession and smouldering wood serve as islands of biodiversity and for maintaining the microclimate.

Parts with mixed vegetation (dead spruce with deciduous trees): no logging was carried out here. The dead spruce serves as a means of ensuring the mechanical stability of the deciduous trees (removal of the spruce would threaten to uproot, bend and break the deciduous trees). Again, these are to be islands of biodiversity with the expected natural regeneration of standing deciduous trees combined with secondary succession.

Parts with a predominance of deciduous trees: here commercial forest management will be carried out using the method of target trees.

Fig. 13. Orthophoto of the location (year 2021) after incidental logging of spruce. The picture shows a mosaic of parts with dead spruces, clear-cuts and living trees.

Due to the expected extremely interesting forest development, we have established in 2021 a statistical net of permanent plots with random distribution for monitoring forest regeneration (a total of 128 circular plots with radius 2 m, where the number of individuals of different tree species in 3 height categories 0.1 - 0.5 m, 0.5 - 1.3 m, 1.3 m - 6.9 cm in dbh) is collected. We repeated the survey in 2023. The first results show an overall progress of total regeneration after 2 years - see Table 5. The regeneration by secondary succession only (on clear areas and under standing dead spruces) is very poor at this point – here a longer time horizon will be needed for evaluation of these processes.

Tab. 5. Development of density (pcs per 1 ha) of forest regeneration (natural / artificial) in years 2021 and 2023

Year	**2021**					**2023**				
	natural regeneration			planted		natural regeneration			planted	**SUM**
	clear areas	*under dead spruces*	*all variants*			*clear areas*	*under dead spruces*	*all variants*		
Fagus	*261*	*25*	2002	466		*274*	*6*	1722	305	**2027**
Pinus	*0*	*0*	0	25	**25**			0	6	**6**
Betula	*0*	*0*	0	6	**6**			0	0	**0**
Sorbus torminalis	*0*	*0*	0	25	**25**	*0*	*0*	0	25	**25**
Quercus	*19*	*6*	180	162	**342**	*224*	*12*	2617	137	**2754**
Pseudotsuga	*0*	*6*	44	25	**68**	*0*	*0*	25	25	**50**
Carpinus	*180*	*0*	1181	19		*193*	*0*	1784	0	**1784**
Abies	*19*	*0*	50	0	**50**	*6*	*0*	12	0	**12**
Ulmus	*0*	*0*	0	12	**12**	*0*	*0*	6	19	**25**
Sorbus aria	*0*	*0*	174	0	**174**	*0*	*0*	124	0	**124**
Fraxinus	*6*	*0*	193	25	**218**	*6*	*0*	199	0	**199**
Acer	*12*	*0*	727	261	**989**	*218*	*0*	1641	124	**1766**
Tilia	*0*	*0*	25	44	**68**	*0*	*0*	62	37	**99**
Larix	*6*	*0*	19	12	**31**	*0*	*6*	19	0	**19**
Populus tremula	*6*	*81*	131	0	**131**	*0*	*12*	62	0	**62**
Picea abies	*131*	*62*	292	218	**510**	*81*	*0*	398	12	**410**
Prunus avium	*12*	*6*	286	12	**298**	*12*	*0*	566	0	**566**
Salix	*0*	*0*	0	0	**0**	*37*	*12*	75	12	**87**
SUM	*653*	*187*	5303	1312		*1051*	*50*	9313	703	**10016**

Example 5: Conversion to coppice and coppice with standards

Start: Start: Adult (age 110 years) oak stand with an admixture of hornbeam and pine on dry sites (forest unit: (85A1, 79B4, C4, 80C4a/1).
Model: coppice and coppice with standards
Silviculture:
These are dry habitats where we use coppicing with already established root systems of parent trees. The cut stumps are well replaced by new shoots - mainly oak, hornbeam, lime, maple, etc. They, especially at the beginning, show a fast and high biomass production. Clearings with an area of about 0.5 ha are created in a mosaic over the area in a 30-year rotation period. The planned use of the timber will befor the production of wood chips, pulpmill or as firewood.

We are also testing a conversion model with a combination of coppice (trees coming from vegetative regeneration) with standards (trees coming from generative regeneration). This model is closer to the Dauerwald principles. Standards are generative trees (mainly oaks) grown in 4 age (or DBH) cohorts of 30 years - 60 years - 90 years - 120 years and are used for the production of valuable assortments (joinery timber). The lowest coppicing cohort is again removed by clear cutting in groups of 0.5 ha with a 30-year rotation period, with the difference (compared to pure coppicing) that quality generative individuals (standards) are selected and kept in the next cohorts. Conversion in this initial phase consists of releasing the crowns of all promising trees in given age / DBH cohorts. The understorey has been removed across the board to allow the stumps to regenerate.

Day 2 / Friday, September 22nd
Kinský estate Žďár nad Sázavou

General characteristics

Forest range (FR) Žákovice is a part of management-plan area (MPA) Kinský Žďár belonging to Kinský family. The total area of the MPA is 5,790 ha. It is located in the Vysočina region, close to city Žďár nad Sázavou, about 90 km northwest of Brno. Current area of the forest range is 932 ha. River Svratka rises on the FR. The highest peak is Žákova hora with height of 810 m above sea level. National Nature Reserve is of the same name. On the contrary, the lowest point is a place, where River Svratka leaves the range, 647 m above sea level. The whole FR is a part of Protected Landscape Area (PLA) Žďárské vrchy.

Natural conditions

The bedrock is mostly acidic with neutral rocks such as orthorhombic rocks. Due to the predominance of acidic bedrock, and also due to the altitude, rainfall and acidic needle fall of the Norway spruce, mainly crypto-podzols are formed. The humus form is mostly composed of mor or moder. On water-affected sites, gleys or peat gleys are formed.

Within the typological division, we have 5 and 6 forest vegetation stages. Among the most represented forest type groups (hereinafter FTG) there are 6K - acid spruce beech, 6P - gleyd acid spruce fir.

The average annual temperature is around 5 °C. The average annual rainfall is about 850 mm. In 2020, when it rained a lot throughout the Czech Republic, the rainfall reached 1120 mm (measured by the author). The number of tropical days has been increasing in recent years. For example, in 2022 there were a total of 7 days when the temperature was around 30 °C. In addition, rainfall during the growing season is decreasing. Similarly, the number of icy days in winter is decreasing (T max < 0). On the other hand, at the turn of 2022 and 2023 the temperature during the day was above 10 °C. Unfortunately, these days are becoming more and more frequent (observed by the author).

Tree composition

The current tree composition is significantly altered from the original one. The human factor in the past had a great influence. Due to the industrial revolution, the tree composition was gradually transforming until the end of the last millennium, when fir, beech and maple trees disappeared from the stands. At the beginning of the 19th century, the recorded original distribution of tree species was 37% spruce, 28% fir, 19% beech and 16% other tree species. These were gradually replaced by non-native spruce - see table below.

Tree composition on FR Žákovice according to area

Tree species	Distribution (%)
Picea abies	88.76
Abies alba	0.8
Larix europea	1.05
Pseudotsuga	0.05
Pinus sylvestris	0.08

Fagus sylvatica	6.59
Fraxinus excelsior	0.02
Acer pseudoplatanus	0.8
Alnus glutinosa	1.85

Moreover, the current tree species composition does not fully reflect ongoing climate change. The stands are dominated by Norway spruce. It is also present in the older age classes (8 and 9). This creates a predisposition to threats from abiotic and biotic factors. The age distribution of spruce stands is a consequence of the devastating snow calamity of October 1930, when heavy wet snow fell overnight and began to freeze in the canopy, with disastrous consequences. By July 1931, almost 500,000 m^3 of spruce timber had been processed on the territory of the Kinský estate (approximately 5,600 ha of forest). Subsequent clearings were reforested with spruce, and reforestation of the clearings continued until the post-war years.

In view of this direct experience with spruce stands, forest managers proceeded to change forest management after the restitution of the property to the Kinský family (February 1993), with the long-term application of the shelterwood system with a significant use of selection principles towards uneven-aged stand management. The furthest is the conversion of the Žákovice FR, where the Kocanda Demonstration Facility - an uneven-aged stand management facility for Silva Bohemica was established.

1st stop

Stand 203A09/01c – What might that look like?

203A09	Stand area	Age	Tree species	Distribution (%)	Forest type set	Wood stock on 1 ha
	8.52	88	Spruce	95	6K	500
			Larch	5		25
						525

203A09/01c	Stand area	Age	Tree species	Distribution (%)	Forest type set	Top height
	1.05	15	Spruce	100	6K	2

After the property was returned to the Kinský family (around 1993), there was a change in management. Gradually, the replanting of the stands, which were mostly too dense and damaged by game, began. The aim was and still is to introduce other tree species such as fir and beech well in advance of the onset of natural regeneration of spruce. At the same time, the ecological requirements of the introduced trees must be respected. The choice of tree species depends on the habitat. Different lengths of shelterwood felling with different intensities are used for the insertion of the restoration elements so that the beech and fir trees grow back and at the same time the spruce does not rejuvenate. The size of one restoration element varies from 0.08 ha to 0.12 ha. We were able to change species on approximately 10% of the area by this process. Gradually, additional regeneration elements were added over the years to avoid creating the same age stands again. So we try to work in stands older than 60 years. We will show how we work in younger stands at the next stops.

Challenges for future management

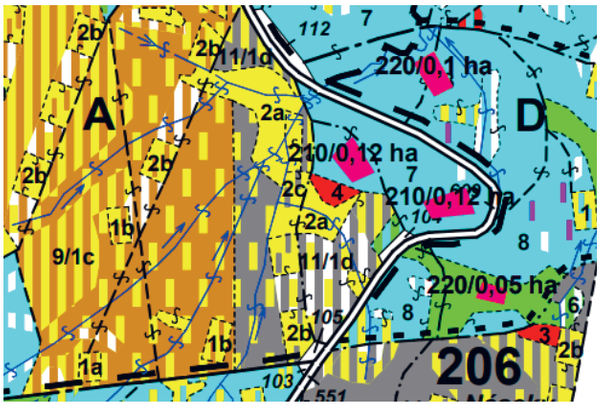
- tackle even more game
- make the vegetation more accessible
- efforts to optimise stocking

2nd stop

Stand 205A02a – When shall we start?

	Stand area	Age	Tree species	Distribution (%)	Forest type set	Top height
205A02a	1.15	19	Spruce	95	6G	4
			Sycamore maple	5		

In this stand, the effort was to rebuild using the same procedures as the previous stop. However, in January 2007, due to hurricane Kyril, the upper story was damaged and subsequently had to be harvested. This resulted in a stand that was not covered by the parent stand and thus auto-reduction processes could not occur. Therefore, a schematic educational intervention was made in 2015, during which approximately 2-m wide strips were cut. This resulted in a reduction from the higher tens of thousands to the lower tens of thousands (approximately 40,000 to 60,000 individuals were removed in the strip). This created space for the formation of new natural regeneration in the cut strips and increased stability in the individuals that remained standing in the rows. In 2022, further intervention was marked across the area to encourage other tree species such as beech and crane, while individuals with an already well-formed crown were selected and encouraged by removing competing individuals at the general level of the upper canopy. Approximately 6,000 individuals per hectare were removed in this way. The purpose of the interventions is to gradually increase the stability of individual trees by forming long crowns.



Challenges for future management

- access to the vegetation
- select target trees and their branching
- protect against game

3rd stop

Primeval forest of Žákova hora - textbook of a forester

The original primeval forest reserve, which ceased to be managed in 1929 by the decision of the then owner Eleonora Kinská (born Clam- Gallas). The current area is 39 ha. It consists of two parts - the core part (about 17 ha) and the extended part (22 ha). The reserve is dominated by beech. Unfortunately, the fir is missing. Thus, until recently, planting operations were carried out in the extended part to introduce silver fir.

Reservation is the best textbook for a forester. When one walks through it and observes individual situations and has the opportunity to see the time gap, it is the best experience for growing a forest.

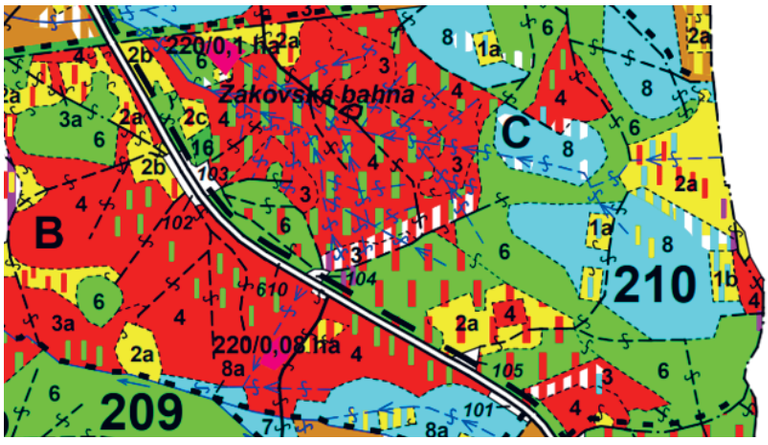
4th stop

Stands 210C03;04;06

Extensive damaged stands of the same age - a possible opportunity

	Stand area	Tree species	Distribution (%)	Forest type set	Wood stock on 1 ha
210C03	1.97	Spruce	85	6G	170
		Larch	5		10
		Alder	5		5
		Beech	5		5
					190

	Stand area	Tree species	Distribution (%)	Forest type set	Wood stock on 1 ha
210C04	5.86	Spruce	85	6G	267
		Beech	10		14
		Douglas fir	5		13
					294



This area is a set of several equally old spruce stands on the plateau between the peaks of Žákova hora and Fryšavský kopec. The stands were created after previous large-scale clear-cutting. The current stands have been and are being damaged by deer - by peeling and biting. In 2017, my predecessor's effort was to insert a hardening cut (barrier) into such large stands. However, in the winter of 2019, heavy wet snow caused extensive damage across the entire area. As a result, a total of about 680 m³ was harvested over an area of about 8 ha. The damage to the stand is uneven. During the random harvesting, target trees (200 trees/ha) were marked at the same time and a core

road was gradually completed to divide the stands. Due to damage to the stand by deer and subsequent stem rot, I decided to start restoration. I chose the tree species fir, which we sowed in several patches. The aim is to gradually introduce other tree species into the stand, similar to the first stop, and thus prevent the spruce from rejuvenating the whole stand. My effort will be to maintain the target trees as long as possible given the long regeneration period of the fir.

The sowing of fir seeds took place in the autumn of 2022 and spring of 2023. Approximately 10 kg/ha were sown. Sowing was primarily around old stumps. The area sown with fir is around 0.24 ha.

For the target trees, long crowns is again the goal.

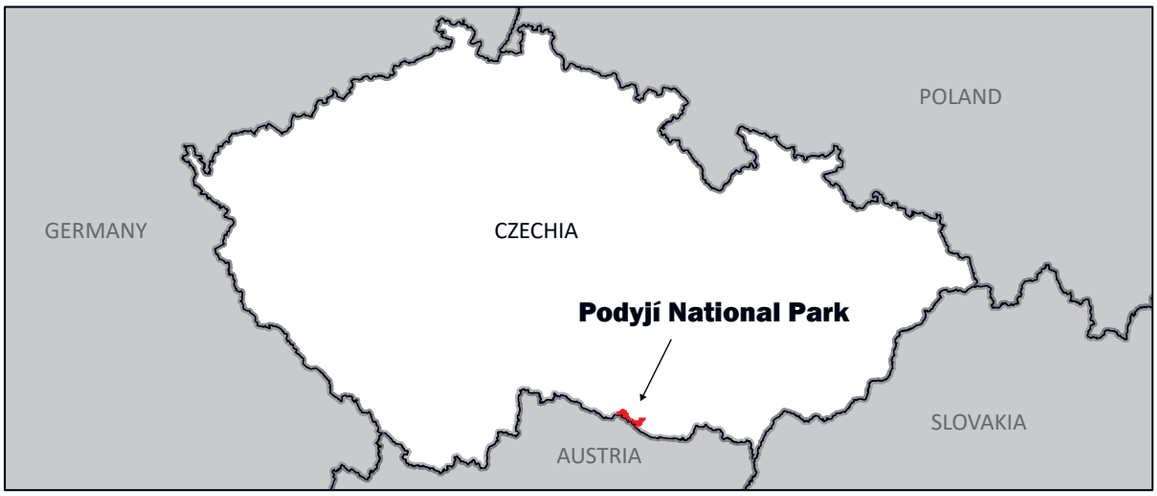
The remainder of this large complex was then structurally thinned.

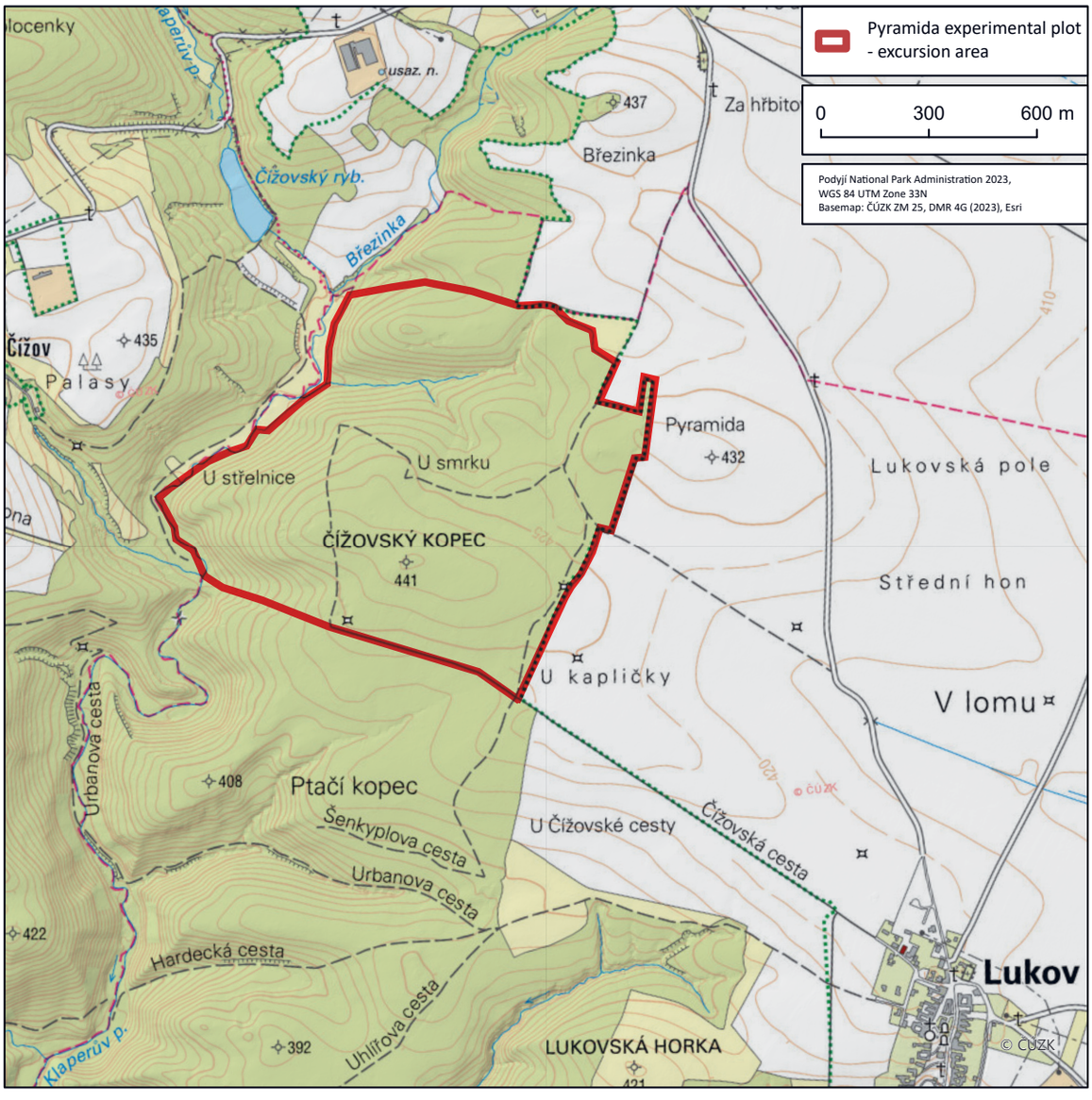
Challenges for future management

- continue with undersowing
- reduce game
- prevent the whole-area onset of spruce rejuvenation

Day 3 / Saturday, September 23rd

Podyjí National Park





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Research Article
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Twenty years of conversion: from Scots pine plantations to oak dominated multifunctional forests

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A conversion of previously even-aged pine-dominated forests to uneven-aged and multi-functional oak-dominated forests has been ongoing since 1993 in the Pyramida experimental forest (95 ha) situated in the buffer zone of Podyjí National Park, Czech Republic. Based on repeated surveys in 1992, 2003 and 2013, the conversion was assessed according to changes in: (i) the proportion of species; (ii) the distribution of DBH; (iii) the distribution of patches; and (iv) the distribution of forest types. The proportion of conifers decreased from 61.0% to 42.0%, and the proportion of broadleaved species increased accordingly. A sharp decline in the number of trees in the DBH class 70-109 mm was caused by the intense release of understorey broadleaved trees in young Scots pine small pole stage stands. The number of large habitat trees steadily increased in the DBH classes 430+ mm. The mean size of one patch decreased from 0.8 ha (1992) to 0.4 ha (2013). The spatial proportion of the target forest type (uneven-aged oak-dominated forest) increased from 8.5% in 1992 to 45.0% in 2013, and 35.1% of the area was fully converted during the 20 years. We expect 69.1% of the area to be converted after 30 years (2023).

Keywords: Scots Pine, Conversion, Oak Dominated Forest, Uneven-aged Silviculture, National Park

Introduction

The rapidly changing societal demands on forest functions, combined with changes in climatic conditions, generally referred to as global climate change, have led to the need for reassessments of old forestry paradigms, as well as the definition of new ones (Brang et al. 2014). By the end of the 19th century, Engler (1905) and Biolley (1920) had already studied the methods of changing forest management from even-aged to uneven-aged forests. However, at that time forestry was primarily focused on the optimization of increment, permanence and the balance of forest revenues. Fundamental changes in conditions during the 20th century brought about by increased and more diverse societal interest in forests. Global climate change have introduced further questions to forestry, many of which are directed at the non-production functions of forests. The originally easily understood and clearly targeted concept of uneven-aged forestry has served as a basis for expanding and defining purpose-modified concepts of forestry and silviculture, including "nature-based" (Johann 2006, Diaci et al. 2011), "close-to-nature" (Schütz 1999), "ecological" (Seymour & Hunter 1999), and "multiaged" (O'Hara 2014).

These broader concepts were in reaction to a diversified demand that had two distinct directions: (i) production management, which had, however, more support for fulfilling non-production functions (Diaci et al. 2011, O'Hara 2014) and (ii) the restoration management of forests located mainly in protected areas, primarily focused on the restoration or maintenance of specific functions and forest structure. These latter forests are more suitable for the protection of threatened species and as niches of biodiversity in the scale of landscape mosaics (Carey 2003, Decocq et al. 2004, Göttmark 2007), where timber production is a possible but secondary product, and not considered necessary. While the first direction is defined more generally and has broader use, the second is almost always variously applied according to purposes defined by nature conservation requirements (Göttmark 2013). Both directions have a common ground, however, *i.e.*, to abandon a uniformity embodied especially by age-evenness and to create a forest environment with heterogenic spatial and species diversity.

An important tool in changing a forest structure from even-aged to uneven-aged is conversion (Schütz 2001, 2002a). The principles of conversion have been broadly used for the even-aged Norway spruce monocultures in Europe (Sterba 2002), with the aim to create mixed forests but where spruce still has an important position in the species mix and spatial vegetation structure. The conversion of pine-dominated even-aged forests is less common, and has mainly been performed in Germany (Zerbe 2002), even though the concept of *Dauerwald* was founded on its basis (Möller 1922). Unlike Norway spruce monocultures, the conversion of pine-dominated even-aged forests is more often associated with complete changes in tree species composition. Silvicultural strategies for the conversion of young and ageing Scots pine stands have been defined according to expected regeneration and the time of con-

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version (Kint et al. 2006), and simulations of conversion have been tested (Kint et al. 2009). However, results verifying these principles in practice have not yet been published, and this is the main goal of our paper.

Between 1992 and 1993, the principles of forest management in both the core and buffer zones of Podyjí National Park (Czech Republic) were defined in terms of goals for each zone (Škorpík 1993). For the buffer zone (where our study is located) the main principles were:

- to protect the core zone from external influences (invasive species, agriculture, etc.);
- to protect the surroundings of the national park from disturbances in the core zone;
- to protect and increase biodiversity using management to promote naturalness, which creates stands with heterogeneous spatial structure, and using older methods of forest management (*e.g.*, coppicing, coppice with standards), higher amounts of deadwood, etc.;
- to provide a steady source of timber for the local communities located in prevailing agricultural land.

According to these main principles, the conversion of pine-dominated even-aged forests in the buffer zone of a national park, such as at Podyjí National Park, must respect the conservation objectives and the variability of management types (*sensu* Göttmark 2013). Such a conversion represents a more fundamental change in the state of the forest than does conversion in an economic forest, with priorities focused rather on: (i) an irregular spatial diversity (*sensu* Schütz 2002a); (ii) autochthonous species diversity; (iii) higher deadwood diversity and amount; and (iv) efforts for an economically profitable system (*e.g.*, firewood for local people).

The original state of forests in Podyjí National Park was evaluated and recorded before conversion, allowing for future assessments of the efficiency and appropriateness of crucial decisions. Here, twenty years after the beginning of conversions, we ask the following fundamental questions:

- what changes have taken place over twenty years in the species composition and diameter at breast height (hereinafter DBH) structure?
- how have the qualitative parameters (spatial structure, forest types distribution) of the forest changed?
- how long will the conversion take?

Material and methods

History

The area of the Podyjí National Park (hereinafter PNP) is among the longest settled areas in Central Europe, being continuously inhabited since 5-6000 BC (Čižmář 2008). The forest history in the PNP has been described by Škorpík (1993), Vrška (1998), and Reiterová & Škorpík (2012). For this study, changes in the proportion of European beech (*Fagus sylvatica*) are particularly important, since this used to be one of the main original forest tree species. However, it was predominantly used for the production of charcoal, and its proportion gradually declined to a level of only several percent, surviving to the present only in the form of large over-matured trees.

During the Cold War period (1948-1989), the territory of today's national park was intersected by the so-called "iron curtain" (built in 1951). The area of actual buffer zone of PNP was managed by the standard procedures of socialist forest management. That primarily meant the gradual removal of ancient oak and hornbeam coppices and their replacement by plantations of Scots pine (*Pinus sylvestris*) monocultures. This process fortunately failed to be completed. This resulted in a mosaic with the remnants of mixed broadleaved forests and Scots pine monocultures where hardwoods regenerated in the understorey thanks to the dispersal of seeds from old trees, as well as shoots growing from stumps and old stools. After the fall of the iron curtain during the "Velvet Revolution" (1989), many border restrictions were lifted and the PNP was established in 1991.

Conversion principles

Based on the definition of the functions of the buffer zone (see Introduction), conversion guidelines were developed for the conversion of Scots pine dominated forests. These stands covered approximately 900 ha of forest in the buffer zone of the national park. Our study is focused on the forest Pyramida (Fig. 1), which has been used as an experimental area since 1992 and represents a complex range of all forest types under the conversion process. Basic indicators (tree species composition, DBH distribution, patch dynamics, forest types changes) were surveyed in 1992, 2003, and 2013 (DBH distribution in 2003 and 2013 only), and analyzed. These indicators were used to verify the accuracy of silvicultural practices, assess forest management planning in the PNP, and to derive the rate of conversion.

The basic principles of conversion were as follows:

- terminate clear-cut logging and stop the artificial regeneration of Scots pine (1992);
- maximize the potential for broadleaves trees in Scots pine stands, avoiding the creation of new homogenous stands by planting on clear-cut areas;
- spatially divide large areas of former even-aged stands;
- artificially introduce beech, which, with some exceptions (rare over-matured trees) were not capable of natural restoration and spreading, in the form of understorey or small scale gaps (0.01-0.06 ha);
- gradually move to the group selection silvicultural system modified for light-demanding tree species with the help of DBH differentiation and spatial differentiation;
- during thinning, primarily prefer oak (*Quercus* sp.) with a mixture of hornbeam (*Carpinus betulus*), small-leaved linden (*Tilia cordata*), European beech (*F. sylvatica*) and other broadleaved species.

Study site

Average yearly temperature in the PNP is between 8 and 9 °C, average precipitation is 550-600 mm, with 65.0% occurring during the vegetation period (Tolasz 2007). In a biogeographical sense, the PNP lies in the

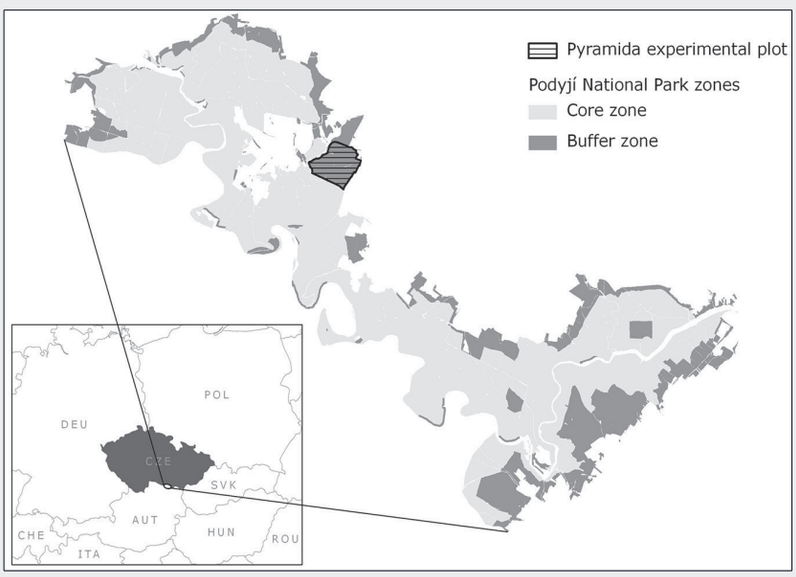
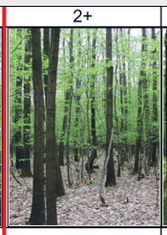


Fig. 1 - Location of the Pyramida study site.

Fig. 2 - Forest types classification.

		3-	3+	2-	2+	1
Forest type						
Tree species composition (%) according the basal area (m^2/ha)	coniferous	95+	60-90	less than 60	up to 5	individually
	broadleaves	up to 5	5-40	40-95	95+	up to 100%
Spatial structure		one layer	formation of second layer (mainly broadleaves in understorey)	two (sometimes three) layers; coniferous dominates in upper layer	more layers; broadleaves in all layers; thickness structure creation	more layers; thickness structure created
Key measures		soft and more frequented increment thinnings; increase of mechanical stability; support of interspersed broadleaves	support of broadleaves in understorey; openning canopy of coniferous layer (mainly Scots pine)	support of promising broadleaves - future target trees; coniferous harvesting - opening new gaps for broadleaves natural regeneration; deadwood and habitat trees management starts	positive group selection in broadleaves; selection of target broadleaves trees in mixed parts; start of increment control	group selection system; target diameters harvesting; habitat trees and deadwood management for biodiversity conservation;
Forest regeneration		underplanting and planting in open gaps of European beech and rare tree species		underplanting and planting in open gaps of European beech and rare tree species + natural regeneration	natural regeneration only	
Silvicultural system		even-aged forestry			uneven-aged forestry	
Forest planning method		age classes			control (statistical inventory)	

transition zone between the Hercynian and Pannonian provinces (mesophytic and thermophytic), which together with the varied morphology of the river valley and plateau creates high species diversity (Chytry & Vicherek 1995).

The Pyramida study site covers 95.1 ha (Fig. 1) on the plateau and north-, west- and south-oriented moderate slopes, with an elevation ranging between 380 and 435 m a.s.l. The geological bedrock consists mainly of gneiss, mica schist and similar rocks of Proteozoic to Paleozoic age (Škorpík 1993). Soils are classified into the cambisol and luvisol units (IUSS Working Group 2014).

Tree species composition and DBH distribution changes

A forest management plan (hereinafter FMP) for the PNP created for the period 1992-2001 (Anonymous 1992) served as a primary source of data for the first stage of assessment. This FMP was prepared by the method of age classes, because at that time even-aged forest stands dominated. Because of how the FMP was created, it was not possible to assess the DBH distribution at the study site, and therefore only the proportion of tree species in the entire Pyramida forest has been assessed since 1992.

In 1993 and 2013, statistical inventories that were part of inventories for the whole national park were conducted in Pyramida. Due to the smaller area of the monitored site (95.1 ha) and the wood storey structure, the inventory of the Pyramida forest used a plot spacing network of 170×175 m, as opposed to the 250×250 m network used for the whole territory of the PNP. Each inventory plot consisted of a circle with a radius of 12.62 m (500 m^2) that was further divided into 4 concentric circles. All measured parameters are given in the Supplementary material (Tab. S1, Tab. S2, Tab. S3). Assessments of the inventory survey, including the calculation of confidence intervals (95%, $\alpha = 0.05$), were performed in Field-Map Inventory Analyst® software (http://www.fieldmap.cz). To compare the changes in tree species composition in 1992/2003/2013 the mean values of confidence intervals (from inventories in 2003 and 2013) were used. Species names follow Kubát (2002).

Patch dynamics (texture changes)

Patch dynamics includes the formation of a multi-aged and heterogeneous spatial forest structure (in combination with forest type changes), represented by the gradual fragmentation of formerly large, homogenous and usually even-aged forests. This should result in an optimization of patchiness for the group selection of light-demanding tree species, where the size of one patch is up to about 0.2 ha. In 1992, 2003 and 2013, texture patches were analyzed primarily in ortho-rectified aerial photographs and located onto maps in the scale 1:5000. These maps were used for the validation and specification of boundaries of all patches in the field. Each patch represents a clearly defined and field-detected area occurring in a certain growth stage of the forest, differing from surrounding stands and exposed to the same type of silvicultural measure. Spatiotemporal data and analyses were carried out in the software ArcGIS® (ESRI, Redland, CA, USA), R (R Development Core Team 2011) and MS Excel®.

Forest types changes and duration of conversion

To assess the conversion process, a five-degree scale of forest types (FT) was developed, characterizing the entire qualitative range of existing stands in 1992 from younger, even-aged Scots pine monocultures to multi-aged heterogeneous oak dominated mixed forests (Fig. 2). The parametrization of individual FTs was performed such that applicability for practical forestry was retained, as well as to maximize clarity for foresters who carried out the measures. The fundamental division in the qualitative assessment of a FT is the conversion between FT2- and FT2+. At this stage, there is a conversion to the management of light-demanding tree species by group selection. The methods of even-aged silviculture techniques are minimized, and the selection of target trees (or groups of target trees) and control methods of forest management planning play the main role. From a broader, silvicultural point of view, this conversion could be considered to be complete in the FT 2+ forest type. However, according to the definitions of the special function of forests in the buffer zone of the national park, all parameters are fulfilled only in the FT1 type.

Assessments of forest types were based on the mapping of patches (see above). Every patch was assessed and classified during field work in 1992, 2003 and 2013 according to forest type parameters - basal area measurement as the basis for evaluating the tree species composition, spatial structure, key measures used during transformation, and regeneration (Fig. 2). Spatio-temporal data and analyses were performed in the software ArcGIS and MS Excel.

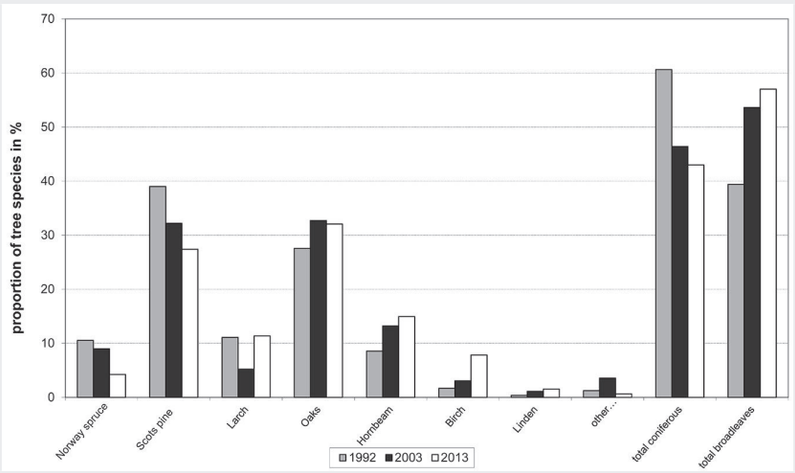


Fig. 3 - Proportion of tree species (in %) according to basal area (m^2) in 1992-2013.

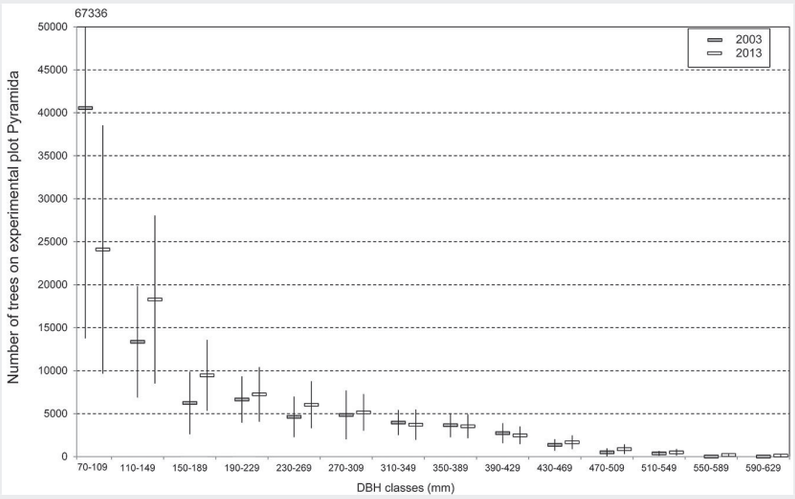


Fig. 4 - Number of trees according to DBH classes. Thin lines show confidence intervals.

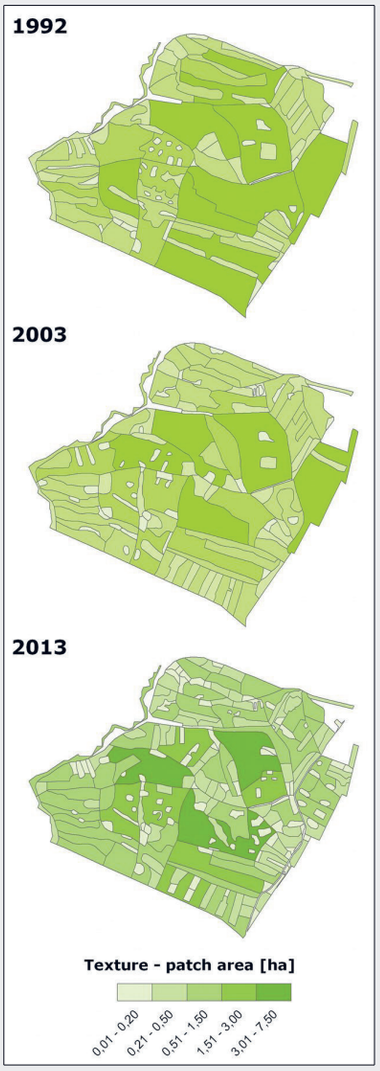


Fig. 5 - Patch dynamics in 1992-2013 according to patch area classification.

A transitional matrix was created for assessing the duration of conversion. Due to the limited range of data (one primary and two repeated surveys) it was not possible to perform a significant model calculation of the expected duration of conversion; therefore, this was derived empirically.

Results

Changes in tree species composition and DBH distribution

In the period 1992-2013 there was a marked change from the previous predominance of coniferous species to a predominance of broadleaved species. The proportion of conifers decreased from 61.0% to 42.0%, and the proportion of broadleaved trees increased reciprocally (Fig. 3). A significant decrease was found for Scots pine, the former main tree species, whose proportion decreased from 39.0% to 28.0%. Similarly, the proportion of spruce declined from 11.0% to 4.0%. In both cases, this was the result of the targeted support of admixed broadleaved trees. The decline of Scots pine would be even more pronounced if assessed according to the number of trees. Larger Scots pines in FT2- and FT2+ reacted to the release caused by the felling of adjacent Scots pines by increased light increment, so the decline in the proportion of Scots pine according to DBH was not so pronounced. An increasing proportion of hornbeam from 8.5% to 15.0% reflected its dynamics as a former strictly understorey species that was not considered a target species in previous production systems. The situation for birch (which increased from 1.7% to 7.8%) is similar, with the presence of pioneer trees becoming a significant source of forest biodiversity. The increase of trees in the DBH classes 110-149 mm and 150-189 mm reflected a clear growing response of broadleaved trees (mainly mixed in young Scots pine small pole stage stands) to the release and their rapid conversion to these DBH classes. This caused a sharp decline in the number of trees in the DBH class 70-109 mm (Fig. 4). Despite the planting and underplanting of beech in 51 groups on a total area of 7.1 ha from 1992-2013, there has not yet been a recorded increase of beech, since these have not yet grown over the DBH ≥ 7 cm threshold. There was also a slow but steady increase in the number of large trees that were left as future habitat trees (in DBH classes 430+ mm).

Patch dynamics (texture changes)

The gradual fragmentation and creation of heterogeneous spatial structure is demonstrated in Fig. 5, which shows the introduction of regeneration felling into former large uniform stands. These patches are used (i) for introducing missing beech, and (ii) for the release of natural regeneration of introduced broadleaved trees in

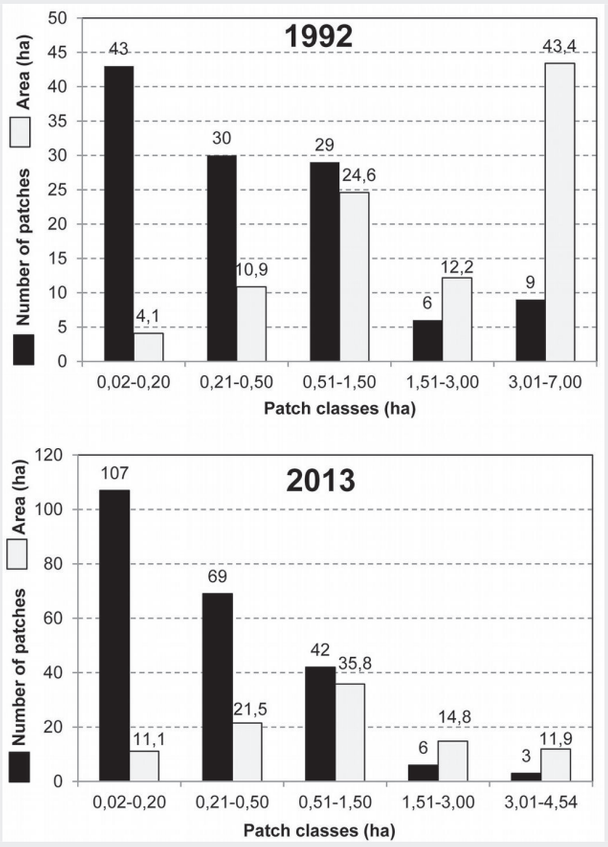


Fig. 6 - Patch structure changes in 1992-2013 according to the number of patches and patch area.

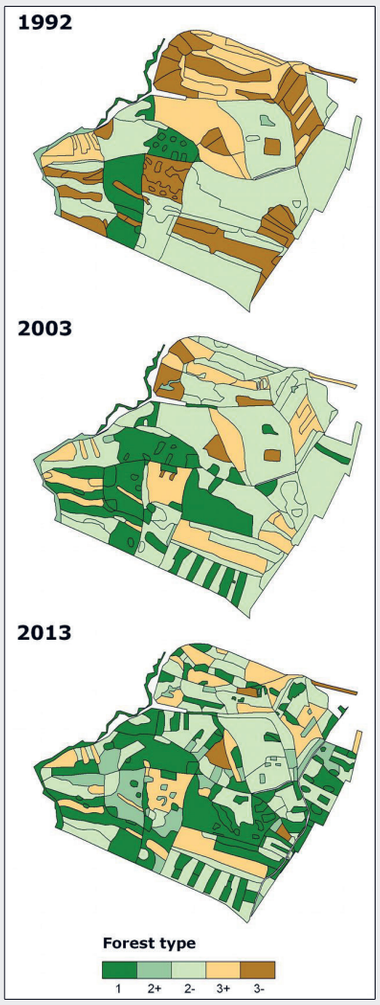


Fig. 8 - Changes in the forest types distribution in 1992-2013.

older stands with a prevalence of Scots pine or Norway spruce. This is shown by an analysis of the number and size of patches (Fig. 6). Originally (1992), spatially dominant patches in the class 3.01-7.00 ha covered 43.4 ha (46% of the area). They are currently being replaced by the predominant 0.51-1.50 ha class, which was "created" by the fragmentation of the largest stands and covered 35.8 ha (38.0% of the area) in 2013. There was also more than a doubling in the number of patches in the 0.02-0.20 ha class, from the original 43 (1992) to 107 (2013). A box-plot analysis (Fig. 7) shows a decline of distant values between 1992 and 2013 and their transfer near the boundary interval of non-distant values in the spatial range of about 1.01-1.50 ha (*i.e.*, between patches from the 0.51-1.50 ha class) in 2013. The median value and the interval of values in the range 25-75% slightly decreased. The average size of one patch decreased from 0.8 ha (1992) to 0.4 ha (2013). The number of patches increased from 117 in 1992 to 227 in 2013 (Fig. 6).

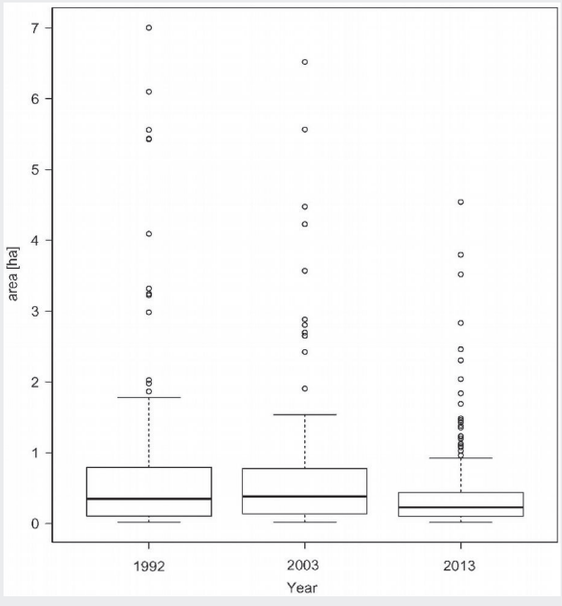


Fig. 7 - Box plot analysis of patch areas in 1992-2013.

Forest types changes and the duration of conversion

The development of the spatial distribution of forest types in the Pyramida experimental forest is shown in Fig. 8. In the southern part of the experimental forest a faster conversion to the target forest types (FT1, FT2+) can be observed, which was caused by the better condition of the stands in 1992. Selectively performed silvicultural practices not only created a finer spatial structure (see Fig. 6), but the selection of target trees and support for the natural regeneration of autochthonous tree species also shifted individual stands toward the target forest type.

A quantification of changes in the areas

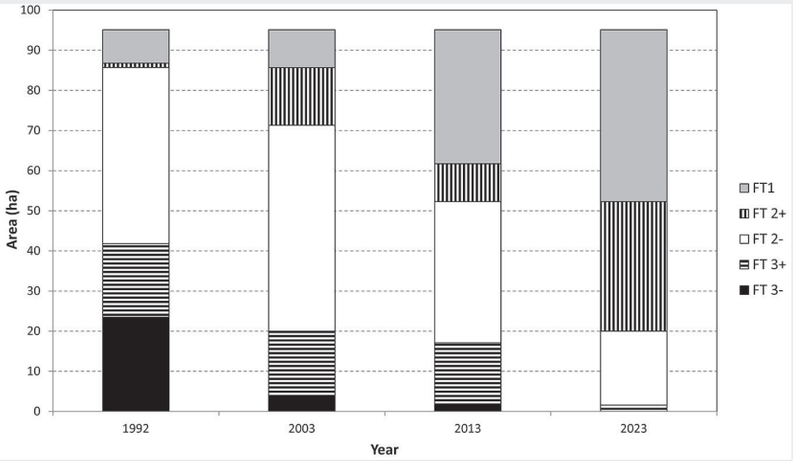


Fig. 9 - Proportion of forest types according to area in 1992-2013 and estimated proportion in 2023.

of forest types (Fig. 9) shows a continuous increase of FT1, with spatial proportion increasing from 8.7% to 45.0% in 2013. The opposite trend is apparent for pine-dominated forest types (FT3-, FT3+), which represented only a minor part of the experimental forest in 2013 (1.7%). The present balance of the spatial proportion of FT 2- and FT2+, which serve as transitional forest types during the conversion, is also evident.

From a broader silvicultural point of view, 33.4 ha (35.1% of the area) of the Pyramida experimental forest were converted during the last 20 years into FT1 and FT2+. In 30 years since the start of conversion (by 2023) we expect a conversion of 65.7 ha (69.1% of the area). If we include the 8.3+1.1 ha area (FT1 and FT2+ in 1992) that did not need to be converted, we can expect a total converted area of 75.1 ha (79.0% of the area - Fig. 10).

When considering only the conversion to FT1, 25.1 ha (26.4%) of the experimental forest were converted during the last 20 years. In 30 years since the start of conversion (2023), we expect a conversion of 34.5 ha (36.3% of the area). If we include the 8.3 ha (8.7% of the area) that did not need to be converted, the total area FT1 forest after 30 years of conversion will be 42.8 ha (45.0% of the area - Fig. 10). Regarding the conversion of former young (20-30 years) pine-dominated plantations with a minimal composition of broadleaved tree species, the conversion duration will last at least 50-60 years (if we do not use massive underplanting of target tree species).

Discussion

The duration of conversion

The duration of conversion always depends on (i) the difference between the initial and target state of the stands and (ii) the selection of silvicultural practices used for achieving the target goal. Among other reasons, such selection depends on the (un)willingness to invest more financial funds into the conversion in the form of introducing missing target species. Considering the conversion of spruce stands (where, *e.g.*, beech and fir are introduced to achieve spatial differentiation), the target goal can be reached in about 50-60 years (Tesař et al. 2004) and the conversion process can be modeled plausibly (Sterba 2002). During this process the even-aged distribution is changed to an uneven-aged distribution by structural thinnings (*sensu* Schütz 2002b), which are (primarily) focused on the structural diversification of DBH. In the case of changes to the total tree species composition (from ageing Scots pine stand to oak-beech-birch mixture) using selective thinning and successive gap creation, the expected modeled time has been estimated as more than 30 years (Kint et al. 2006). The results from Pyramida confirm this time frame. We expect the conversion of former ageing Scots pine dominated stands by 2023, because of disseminated old oaks (conversion from FT3+ and in particular FT2- to FT1). However, there are no known models for such young Scots pine dominated stands (from FT3- to FT2+).

The key role of disseminated oaks

A primary issue is the success of oak natural regeneration from disseminated old oaks. The matrix of old oaks might be very irregular, and not only direct seed rain (and creating new gaps with oak regeneration) but bird dispersal may also need to be used. Mosandl & Kleinert (1998) found that dispersion by jays resulted in oak being more homogeneously distributed in comparison with Scots pine, while Scots pine was obviously more aggregated than oak, except in young timber stands. Such a distribution may be used for the protection of oak at our site: after oaks become established, it is important to leave the shelter of the old Scots pine stand relatively dense. This promotes oak and limits the Scots pine regeneration (Mosandl & Kleinert 1998). According to spatial pattern analyses of seedling distribution from disseminated oaks in an ageing Scots pine forest, there is a high potential for seed dispersion – more than 100 m from an individual or group of trees for both oak and beech (Dobrovolny 2014). Such patterns are confirmed by the number and distances of old disseminated oaks in Pyramida (*sensu* Mosandl & Kleinert 1998, Dobrovolny 2014).

Concerning the creation of gaps, one important question is the size of gaps to be achieved. The number of oak seedlings and

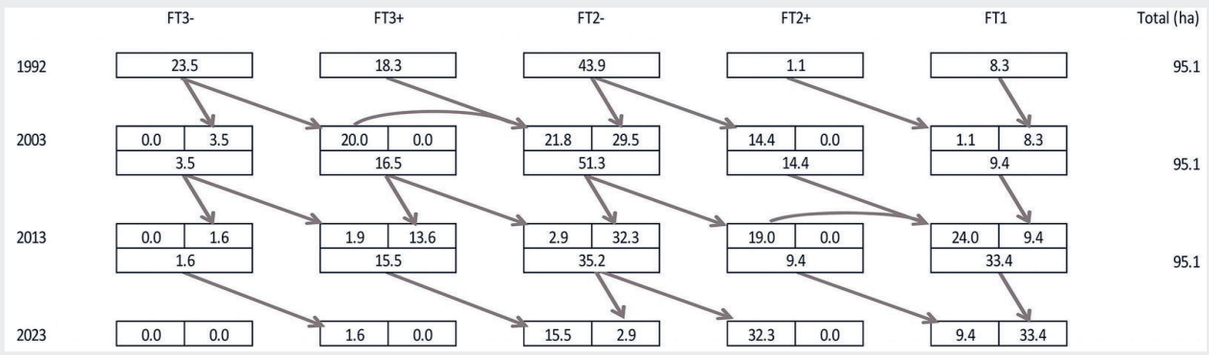


Fig. 10 - Transitional matrix of forest types shifts in 1992-2013 and estimated shift to 2023.

saplings significantly depended on the gap size (Dobrowolska 2006). The highest frequency of oak seedlings less than 0.1 m in height was found in gaps of 100-150 m^2 and 151-300 m^2 ($P < 0.01$). But the number of oak saplings was greatest in the largest gaps (area > 300 m^2). The amount of oak regeneration within a particular gap depended on the number of oak trees surrounding the gap (Dobrowolska 2006). In the mosaic of newly created gaps in Pyramida, the prevailing gap size is 0.05-0.09 ha, and oak is more successful than the predominant Scots pine in such gaps.

Conversion strategies and promoting old-growth attributes

Though experience from the conversion of Scots pine-dominated plantations is rather limited, essential changes in species composition and forest management have been documented (Zerbe 2002). Unfortunately, knowledge from mixed stands with spruce, fir and beech are transferable only to some extent. Light-demanding tree species prefer a group distribution of equally high groups due to their requirements for light. Kint et al. (2009) published a 75-year simulation of the conversion Scots pine stands to oak (birch) stands, using three possible strategies: (i) intensified thinning; (ii) random gap creation in combination with thinning; and (iii) directed gap creation in combination with 12 conversion regimes. Only strategy (iii) was able to maintain and increase the modeled birch admixture within the stand. A conversion regime in which conversion is realized by a combination of thinning from above, retention of Scots pine trees at final felling, and cutting cycles of 6 years was recommended as a good compromise between stand productivity and biodiversity (Kint et al. 2009). In practice, a combination of all the three strategies is necessary. Strategy (i) is most commonly used, but intensified thinning in young Scots pine stands could result in lower stand stability. We recommend light thinning with a short cutting cycle. Random gap creation (strategy ii) is very often supplemented by direct gap creation (strategy iii) for the optimization of stand structure, and is normally combined with the protection of habitat trees (*e.g.*, old oaks that are released for seeds and later left to natural death and decomposition). This combination of strategies diversifies the former uniform stand structure. Differently large patches with various jagged edges create the conditions for various groups of organisms, and therefore create a heterogeneous mosaic of micro-habitats suitable for restoring old-growth attributes in regrowth and secondary forests (*sensu* Bauhus et al. 2009, Göttmark 2007, 2013).

Twenty years of experience with the conversion of forests in the buffer zone of the Podyjí National Park represents 20 years of "thinking in time". The whole process can be considered as forest management designed to maintain old-growth attributes (*sensu* Bauhus et al. 2009), developing from traditional management practices to non-traditional management combined with species management (*sensu* Göttmark 2013).

Conclusions

Conversion of former Scots pine plantations was evaluated after 20 years of conversion. The proportion of conifers decreased from 61.0% to 42.0%, and the proportion of broadleaved species increased accordingly. The mean size of one patch decreased from 0.8 ha (1992) to 0.4 ha (2013). The spatial proportion of the target forest type (uneven-aged oak-dominated forest) increased from 8.5% in 1992 to 45.0% in 2013. 35.1% of the area was fully converted during the 20 years. We expect 69.1% of the area to be converted after 30 years (2023) and the increasing proportion of European beech in the same time.

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References

Anonymous (1992). Lesní hospodárský plán pro lesní hospodárský celek Podyjí. [Forest management plan for Podyjí National Park]. Ústav pro hospodárskou úpravu lesu, Brno, Czech Republic, pp. 333. [in Czech]

Bauhus J, Puettmann K, Messier C (2009). Silviculture for old-growth attributes. Forest Ecology and Management 258: 525-537. - doi: 10.1016/j.foreco.2009.01.053

Biolley HE (1920). L'aménagement des forêts par la méthode expérimentale et spécialement la méthode du contrôle. [Forest management based on experimental methods and on the control method especially]. Attinger, Paris, France, pp. 90. [in French]

Brang P, Spathelf P, Bo Larsen J, Bauhus J, Bončina A, Chauvin C, Drössler L, García-Güemes C, Heiri C, Kerr G, Lexer MJ, Mason B, Mohren F, Mühlethaler U, Nocentini S, Svoboda M (2014). Suitability of close-to-nature silviculture for adapting temperate European forests to climate change. Forestry 87: 492-503. - doi: 10.1093/forestry/cpu018

Carey AB (2003). Biocomplexity and restoration of biodiversity in temperate coniferous forest: inducing spatial heterogeneity with variable-density thinning. Forestry 76: 127-136. - doi: 10.1093/forestry/76.2.127

Chytry M, Vicherek J (1995). Lesní vegetace Národního parku Podyjí. [Forest vegetation of Podyjí National Park]. Academia, Praha, Czech Republic, pp. 159. [in Czech]

Čižmář Z (2008). Zivot a smrt v mladší dobe kamenné. [Life and death in the early Stone Age]. Ústav archeologické památkové péče, Brno, Czech Republic, pp. 293. [in Czech]

Decocq G, Aubert M, Dupont F, Alard D, Saguez R, Wattez-Fanger A, Foucault B, Delelis-Dusollier A, Bardat J (2004). Plant diversity in a managed temperate deciduous forest: understorey response to two silvicultural systems. Journal of Applied Ecology 41: 1065-1079. - doi: 10.1111/j.0021-8901.2004.00960.x

Diaci J, Kerr G, OHara K (2011). Twenty-first century forestry: integrating ecologically based, uneven-aged silviculture with increased demands on forests. Forestry 5: 463-465. - doi: 10.1093/forestry/cpr053

Dobrovolny L (2014). Succession of climax tree species within the allochtonous coniferous stands. In: Book of abstracts of the "9th IUFRO International Conference on Uneven-Aged Silviculture". WSL, Birmensdorf-Zürich, Switzerland, pp. 40.

Dobrowolska D (2006). Oak natural regeneration and conversion processes in mixed Scots pine stands. Forestry 79: 503-513. - doi: 10.1093/forestry/cpl034

Engler A (1905). Aus der theorie und praxis des femelschlagbetriebes. [Theory and practice of shelterwood silvicuture]. Schweizerische Zeitschirft for Forstwesen 56: 123-131. [in German]

Göttmark F (2007). Careful partial harvesting in conservation stands and retention of large oaks favour oak regeneration. Biological Conservation 140: 349-358. - doi: 10.1016/j.biocon.2007.08.018

Göttmark F (2013). Habitat management alternatives for conservation forests in the temperate zone: review, synthesis, and implications. Forest Ecology and Management 306: 292-307. - doi: 10.1016/j.foreco.2013.06.014

IUSS Working Group WRB (2014). World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps. FAO, Rome, Italy, pp. 181.

Johann E (2006). Historical development of nature-based forestry in Central Europe. In: "Nature-based forestry in Central Europe: Iternatives to industrial forestry and strict preservation" (Diaci J ed). University of Ljubljana, Slovenia, pp. 1-17. [online] URL: http://www.anw-niedersachsen.de/Diaci_Nature_based_forestry.pdf#page=11

Kint V, Geudens G, Mohren GMJ, Lust N (2006). Silvicultural interpretation of natural vegetation dynamics in ageing Scots pine stands for their conversion into mixed broadleaved stands. Forest Ecology and Management 223: 363-370. - doi: 10.1016/j.foreco.2005.11.018

Kint V, Lasch P, Lindner M, Muys B (2009). Multi-purpose conversion of Scots pine towards mixed oak-birch stands - A long-term simulation approach. Forest Ecology and Management 257: 199-214. - doi: 10.1016/j.foreco.2008.08.031

Kubát J (2002). Klíč ke kvetene Ceské republiky. [Field guide for the flora of the Czech Republic]. Academia, Praha, Czech Republic, pp. 927. [in Czech]

Möller A (1922). Dauerwaldgedanke. [The idea of Dauerwald]. Springer, Berlin, Germany, pp. 84. [in German]

Mosandl R, Kleinert A (1998). Development of oaks (*Quercus petraea* (Matt.) Liebl.) emerged from bird-dispersed seeds under old-growth pine (*Pinus silvestris* L.) stands. Forest Ecology and Management 106: 35-44. - doi: 10.1016/S0378-1127(97)00237-5

O'Hara K (2014). Multiaged silviculture. Oxford University Press, Oxford, United Kingdom, pp. 213. [online] URL: http://books.google.com/books?id=CcxLBAAAQBAJ

R Development Core Team (2011). A language and environment for statistical computing. Vienna, Austria. [online] URL: http://www.R-project.org/

Reiterová L, Škorpík M (2012). Plán péče o Národní park Podyjí a jeho ochranné pásmo. [Management plan for Podyjí National Park and its protective zone]. Správa Národního parku Podyjí, Znojmo, Czech republic, pp. 316. [in Czech]

Schütz JP (1999). Close-to-nature silviculture: is this concept compatible with species diversity? Forestry 72: 359-366. - doi: 10.1093/forestry/72.4.359

Schütz JP (2001). Der Plenterwald und weitere Formen strukturierten und gemischter Wälder. [The selection forest and other forms of structured and mixed forests]. Parey, Singhofen, Germany, pp. 207. [in German]

Schütz JP (2002a). Silvicultural tools to develop irregular and diverse forest structures. Forestry 75: 329-337. - doi: 10.1093/forestry/75.4.329

Schütz JP (2002b). Die Plenterung und ihre unterschiedlichen Formen. [The selection principle and its diverse forms]. ETH Zentrum, Zürich, Switzerland, pp. 127. [in German]

Seymour RS, Hunter ML (1999). Principles of ecological forestry. In: "Maintaining Biodiversity in Forest Ecosystems" (Hunter ML eds). Cambridge University Press, Cambridge, UK, pp. 22-61. [online] URL: http://nnrg.org/wp-content/uploads/2015/03/seymourchapter.pdf

Škorpík M (1993). Plán péče o Národní park Podyjí a jeho ochranné pásmo. [Management plan for Podyjí National Park and its protective zone]. Správa Národního parku Podyjí, Znojmo, Czech Republic, pp. 167. [in Czech]

Sterba H (2002). Forest inventories and growth models to examine management strategies for forest in transition. Forestry 75: 411-418. - doi: 10.1093/forestry/75.4.411

Tesař V, Klimo E, Kraus M, Souček J (2004). Dlouhodobá prestavba jehličnatého lesa na Hetlíne - Kutnohorské hospodárství. [Long-term conversion of coniferous stands in Hetlín, Kutná hora municipality]. Mendel University Press, Brno, Czech Republic, pp. 60. [in Czech]

Tolasz R (2007). Atlas podnebí Ceska. [Climate Atlas of the Czech Republic]. Czech Hydrometeorological Institute, Praha, Czech Republic, pp. 255. [in Czech]

Vrška T (1998). Historický vývoj lesu na území NP Podyjí a v bližším okolí do roku 1948. [The history of forests in Podyji National Park and its surrounding]. Thayensia 1: 101-124. [in Czech]

Zerbe S (2002). Restoration of natural broad-leaved woodland in Central Europe on sites with coniferous forest plantations. Forest Ecology and Management 167: 27-42. - doi: 10.1016/S0378-1127(01)00686-7

Supplementary Material

Tab. S1 - Measured parameters from statistical inventories at the Pyramida study site.

Tab. S2 - Parameters of concentric circles on the inventory plots.

Tab. S3 - Measured objects and attributes on the inventory plots.

Link: Vrska_1967@suppl001.pdf