




Effects of Ungulate Browsing on Forest Regeneration and Silviculture

Special Implications for Palatable Tree Species such as *Abies alba*

IUFRO International Conference
14 to 16 October 2015

Birmensdorf, Switzerland

Program and Abstracts

Swiss Federal Institute for Forest, Snow
and Landscape Research WSL

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Publisher:
Swiss Federal Institute for Forest, Snow and Landscape Research WSL,
Birmensdorf, 2015

Citation:
Swiss Federal Institute for Forest, Snow and Landscape Research WSL, 2015:
Effects of Ungulate Browsing on Forest Regeneration and Silviculture: Special Implications for Palatable Tree Species such as *Abies alba*. IUFRO International Conference 14 to 16 October 2015. Birmensdorf, Swiss Federal Research Institute WSL. 51 pp.

Layout: Jacqueline Annen, WSL

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Contents

Effects of Ungulate Browsing on Forest Regeneration and Silviculture

Special implications for palatable tree species such as *Abies alba*

Ungulate browsing is one of the many factors that affect tree establishment, growth and mortality and thus both structure and species composition of forests. Tree saplings are part of the usual food of ungulate species, and palatable tree species, like *Abies alba* (European silver fir), are often browsed by ungulates. At the same time, natural regeneration of a mixture of species is valued in mountain protection forests to mitigate damages of snow avalanches, rockfall, mass flow and wind storms. Thereby, species with deep rooting systems (like *Abies alba* and *Acer pseudoplatanus*) are particularly important.

Measuring and monitoring the effects of ungulates on forest regeneration pose, however, major challenges because leader shoot browsing rate linearly correlates neither with tree density nor with species composition. The conference intends to present the current state of knowledge on ungulate impacts on tree regeneration and their implications for forest stand dynamics. We specifically focus on sustainable natural tree regeneration under current and predicted future climate.

Conference Goals

The main goal of the conference is to summarize the state of knowledge on tree – ungulate interactions, with a particular emphasis on

1. measuring the impact of ungulates at the scale of the individuals to the scale of the landscape, in terms of timber quality, stand composition, stand structure and forest dynamics, and

2. silvicultural management techniques to mitigate ungulate effects on natural regeneration, particularly on preferred tree species such as *Abies alba*.

A further goal is to discuss the difficulties of managing forests that simultaneously face climate change, increasing impacts of ungulates and cascading effects of carnivores and human hunting on forest regeneration.

Key topics and questions

1. Monitoring the effects of ungulates on forest regeneration

How can the effects of ungulates on forest dynamics be assessed at both stand and landscape scales? We will discuss methodological considerations of measuring the impact of ungulates in relation to other influencing factors, as well as the opportunity to exploit the results from forest regeneration inventories and browsing impact assessments to help define new monitoring tools. Thereby, the role of indicator species such as very palatable tree species (like *Abies alba*) or non-forest objective goal species when recording browsing impacts will come up for discussion.

2. Reference values for tree regeneration: How much of which phenotype and genotype and special implications with climate change

How much tree regeneration of different species is needed to achieve specific management goals (such as protection against hazards, timber production, biodiversity) in a forest stand? Target values for tree regeneration are needed to properly evaluate ungulate impact, as the success of forest management depends on the density of these saplings that survive and grow up. Are there special phenotypes or genotypes that are less palatable and vulnerable to ungulate browsing? How do such special trees behave under climate change?

3. Trophic interactions: Ungulates, predation (human and carnivores) and tree regeneration

Are there cascading effects of large predators and human hunting on the interactions between ungulates and forest regeneration via ungulate population levels and the spatial distribution of herbivory? What is the impact of human hunting on ungulate impacts? Are the impacts of ungulates on tree regeneration different in large nature reserves than in human – modified landscapes?

4. Ungulate impacts and timber quality

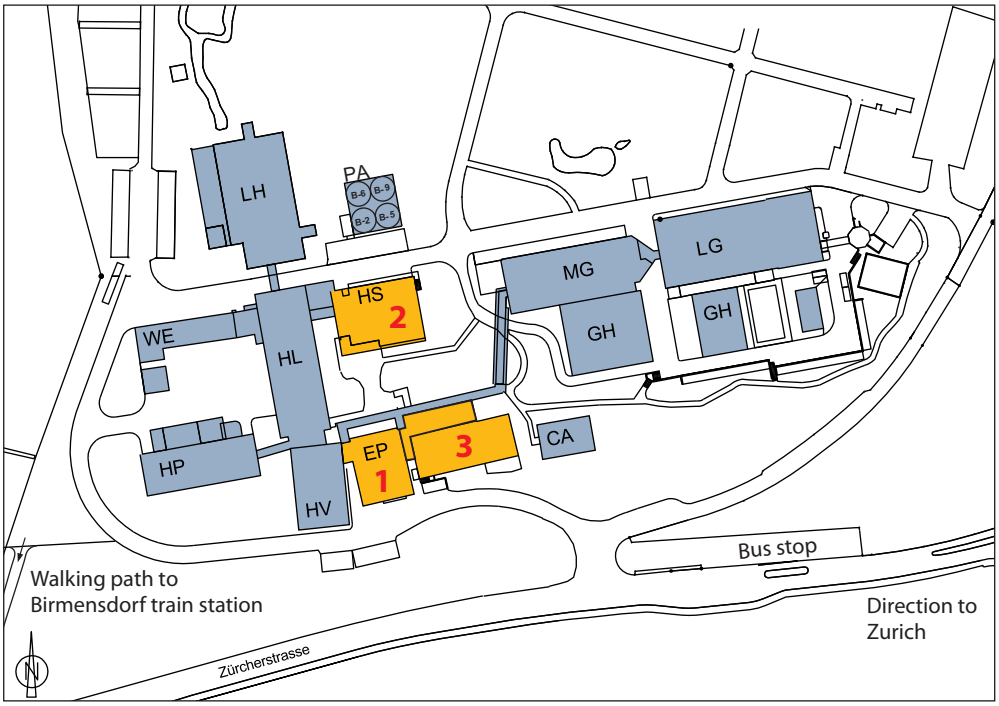
What is the impact of ungulates on timber quality? Do individual saplings recover from being browsed, and thus, does browsing mainly affect regeneration time, sapling densities and species composition? Are other long-term consequences expected? What are the economic consequences of ungulate impacts?

5. Interactions between silviculture and ungulate impacts

Can forest management help controlling ungulate impacts? Are there silvicultural techniques resulting in less vulnerable stand structures to browsing damage? What is the impact of canopy gaps on ungulate browsing? Does silviculture promoting shade tolerant tree species such as *Abies alba* result in stands more prone to browsing due to few alternative forage for ungulates? Are productive habitats generally less vulnerable to ungulate impacts (dilution effect and faster growth)? Which factors and mechanisms can be modified/modulated by silviculture to mitigate ungulate impacts and inversely, how do ungulates influence silviculture?

Andrea D. Kupferschmid
Chair of the Scientific Committee, WSL

Map



Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf

1 Main entrance: Registration desk
2 Foyer / Conference hall
3 Kantine: Lunch

Conference Program

Tuesday 13 October

14.00–18.00	Registration
18.00–20.00	Welcome Party

Wednesday 14 October

08.30–08.35	Opening: Andrea D. Kupferschmid
08.35–08.45	Welcome address, Christoph Hegg, Vice director WSL
08.45–08.55	Welcome of IUFRO Units. 1.01.12 (Silviculture and ungulates) Nobuhiro Akashi 1.01.09 (Ecology and silviculture of fir), Andrej Bončina or Dorota Dobrowolska

Session 1: Monitoring the Effects of Ungulates on Forest Regeneration

	Chair: Göran Ericsson
09.00–09.45	**KEYNOTE by Heurich, M.** Monitoring the Effects of Ungulates on Forest Regeneration
09.45–10.05	**Hasenauer, H.; Hainzl, E.** Concepts and Methods for Assessing Browsing Effects Within Austrian Forests
10.05–10.35	Refreshment break
10.35–10.55	**Hagen, R.; Suchant, R.** Effects of Ungulate Browsing and Forest Management Objectives
10.55–11.15	**Hothorn, T.; Müller, J.** Using Deer-vehicle Collisions for Deer Monitoring and Management
11.15–11.35	**Kalén, C.** Monitoring Impact of Deer on Tree Species Richness in Developing Forest Stands
11.35–11.40	Leg-stretch
11.40–12.00	**Huber, M.; Schwyzer, A.; Kupferschmid, A.D.** A Comparison of Stem-Number-Proportion and Occupied-Area-Proportion as Measures of Browsing Intensity
12.00–12.20	**Kupferschmid, A.D.; Heiri, C.; Huber, M.; Odermatt, O.** Influence of Wild Ungulates on the Swiss Forest. A Multimethodological Overview
12.20–12.30	Plenary
12.30–13.30	Lunch

13.30–13.50	**Kupferschmid, A.D.; Hothorn, T.; Brang, P.** Quantifying the Impact of Terminal Shoot Browsing by Ungulates on Tree Regeneration
13.50–14.10	**Schaubhut, S.; Kupferschmid, A.D.** Monitoring Method and Browsing Severity are Crucial to Describe Browsing Impacts
14.10–14.30	Plenary
14.30–15.00	Refreshment break

Session 2: Reference Values for Tree Regeneration: How much of which Phenotype and Genotype and Special Implications with Climate Change

	Chair: Palle Madsen
15.00–15.45	**KEYNOTE by Brang, P.** Target Values to Evaluate the Success of Natural Regeneration in Forest Management
15.45–16.05	**Trujillo-Moya, C.; Schueler, S.; Konrad, H.** Breeding for Browsing "Resistance" in Norway Spruce?
16.05–16.10	Leg-stretch
16.10–16.30	**Heiri, C.; Frank, A.; Sperisen, C.; Brang, P.; Kupferschmid, A.D.** Does Browsing Resilience of Spruce, Fir and Beech Differ Between Provenances? A Genecological Study for Switzerland.
16.30–16.50	**Cailleret, M.; Heurich, M.; Bugmann, H.** Combined Impacts of Climate Change and Ungulates Browsing on Forest Dynamics in the Bavarian Forest National Park
16.50–17.10	Plenary
17.10–18.10	Poster session possibly including speed presentations of some posters and possibility to visit the genecological clipping experiment at the WSL garden

Thursday 15 October

Session 3: Trophic Interactions: Ungulates, Predation (Human and Carnivores) and Tree Regeneration

	Chair: Marco Heurich
08.30–09.15	**KEYNOTE by Kuijper, D.; Churski, M.; Bubnicki, J.** Landscape of Fear in Europe. Wolves and Humans Shaping Ungulate Top-Down Effects
09.15–09.35	**Baltzinger, C.; Chollet, S.; Martin, J.-L.** Insular Western Red Cedar Response to Introduced Sitka Black-Tailed Deer (Queen Charlotte Islands, Canada)
09.35–09.55	**Cromsigt, J.; Singh, N.; Widemo, F.** Beyond Moose – Diverse Ungulate Communities and their Impact in Human-Modified Landscapes
09.55–10.15	Plenary
10.15–10.45	Refreshment break

Session 4: Ungulate Impacts and Timber Quality

	Chair: Caroline Heiri
10.45–11.30	**KEYNOTE by Wallgren, M.; Bergquist, J.; Bergström, R.; Eriksson, S.** Moose Browsing Effects on Scots Pine Growth and Stem Quality with Implications for Forestry
11.30–11.55	**Boulanger, V.; Rakotoarison, H.** Assessing Economic Impacts of Deer Browsing on Forestry. Fir-Spruce Stands in the Vosges (France) as a Case Study
11.55–12.20	Plenary
12.20–13.20	Lunch
13.25–	Conference field trip: *Abies alba* – browsing experiments
18.00–	Conference dinner

Friday 16 October

Session 5: Interactions Between Silviculture and Ungulate Impacts

	Chair: Peter Brang
08.30–09.15	**KEYNOTE by Tremblay, J.-P.** Integrating Forest and Wildlife Management to Reach Ecosystem-Based Management Objectives
09.15–10.00	**KEYNOTE by Madsen, P.; Buttenschøn, R.M.; Kanstrup, N.; Madsen, T.L.** How Can We Make Forest Regeneration More Robust Against the Overabundant Deer Populations?
10.00–10.30	Refreshment break
10.30–10.50	**Akashi, N.** Sika Deer Damage to *Abies Sachalinensis* Plantations in Hokkaido, Japan
10.50–11.10	**Ericsson, G.; Edenius, L.** Ungulate Browsing, Damages, and Forestry Mitigation Efforts in Sweden – an Overview
11.10–11.30	**Widemo, F.; Ånöstam, F.; Åberg, M.; Månsson, J.** Factors Limiting Recruitment of Rowan and Sallow in Production Forests
11.30–11.35	Leg-stretch
11.35–11.55	**Vor, T.** Impact of Roe Deer Browsing on Rare Tree Species' Regeneration
11.55–12.15	**Mårell, A.; Hamard, J.-P.; Laurent, L.; Rocquencourt, A.; Baltzinger, C.; Balandier, P.** Effects of Deer on Oak Regeneration. Interactions Among Silviculture, Ungulates and Neighboring Plants
12.15–12.30	Plenary
12.30–13.30	Lunch

	Chair: Andrea D. Kupferschmid
13.35–13.55	**Dobrowolska, D.; Borkowski, J.** To Fence or not to Fence? That is a Question
13.55–14.15	**Cutini, A.; Chianucci, F.; Apollonio, M.** Early and Long-Term Impacts of Browsing by Roe Deer in Coppiced Woods in Central Italy
14.15–14.35	**Bottero, A.; Meloni, F.; Motta, R.** Ungulate Browsing Exclusion. Effects and Medium-Term Trends in Coppice Woods in North-Western Italy
14.35–15.05	Refreshment break
15.05–15.25	**Motta, R.; Berretti, R.; Meloni, F.; Partel, P.; Vacchiano, G.** 20 Years of Ungulate Impact on Tree Regeneration in the Paneveggio-Pale di S. Martino Provincial Park (Italy)
15.25–15.45	**Diaci, J.; Roženbergar, D.; Nagel, T.A.; Jerina, K.** Ungulate Browsing in Mixed Beech-Silver Fir Forest Under Different Silvicultural Systems
15.45–16.05	**Bončina, A.; Ficko, A.; Klopčič, M.; Simončič, T.** The Impact of Ungulates on the Regeneration, Recruitment and Abundance of Silver Fir in the Dinaric Mountain Forests in Slovenia
16.05–16.25	Plenary
16.25–16.40	Final discussion – Conclusion remarks

Keynotes

Monitoring the Effects of Ungulates on Forest Regeneration

Heurich, Marco

Since the beginning of the 20th century in Central Europe, the extermination of large predators, landscape transformations, changes in hunting practices, and climate warming have led to a large increase in ungulate herds. Ungulates drive important processes that greatly influence the structure, composition, and development of forest ecosystems by consuming leaves, stems, flowers, and fruits, which lead to reduced plant height growth and reduced biomass accumulation. Because browsing is selective, it also leads to a reduction or even annihilation of preferred plant species. Therefore, ungulate management in a landscape not only is decisive in ensuring the completeness of the respective biocenosis, but also might have considerable economic consequences for forest owners and ecosystem services. As a precondition to ensure suitable ungulate management, the effects of ungulates on forest regeneration must be measured and monitored. Sound evaluations of ungulate browsing pressure began in the 1930s, yet the correct measurement of the impact of ungulates on forest regeneration is still a matter of debate. The development of precise measures that reflect the true condition of the forest regeneration is thus crucial and non-trivial. A monitoring system is needed that can deliver statistically sound information about the development of the browsing pressure under different types of management. The browsing impact on both woody vegetation and herbaceous plants can be monitored; especially monitoring of indicator species susceptible to browsing can be a useful tool. Measuring both the browsing intensity (proportion of browsed trees to total number of trees) and the absolute number and height distribution of unbrowsed trees per area as an indicator of browsing pressure offer advantages and disadvantages. The proportion of leader shoot browsing delivers a snapshot of the current browsing pressure, whereas the demography of saplings provides a long-term view of past impacts but lacks current information. Exclosures are of particular value for assessing ungulate impacts because they offer an experimental setting that provides direct evidence of ungulate browsing and effects on forest regeneration, and the impacts of ungulates over time can be assessed. However, exclosures are artificial because comparisons are made to zero-browsing conditions, which are not natural. Even if browsing pressure can be accurately determined, it is scientifically very challenging to predict its consequences, because of the complexity of the wildlife–forest system. Many factors other than browsing influence the germination, growth, and survival of regeneration; processes have to be observed at different scales, from the leaf to the landscape; the processes occur on a long temporal scale up to 500 years; and there is an exponential reduction in numbers from hundreds of thousands of seeds to a small number of trees in the old growth stand. To understand and manage this complex system, we need to design synthetic research and monitoring approaches. Experiments are crucial for gaining underlying knowledge, for example, by controlling ungulate densities in enclosures, and by setting up replicate exclosures across gradients of deer density and landscape conditions over a long time period. The knowledge gained would be used to design indices and indicators to distinguish between effects on different temporal and spatial scales.

Target Values to Evaluate the Success of Natural Regeneration in Forest Management

Brang, Peter

Target (reference) values of regeneration density and composition have frequently been proposed and are being used in forest management to assess regeneration status, and to derive the need for action. Such values are based on the idea that a minimum status of regeneration is needed to achieve management goals. Target values are thus not focused on damage but on what is left undamaged and is therefore suitable to achieve management goals. Establishing target values for natural regeneration is a challenge because of long regeneration periods, high spatial variability and species mixtures. Regeneration indicators are used in forest inventories in several European countries, providing information on species composition, density, size distribution, and condition of seedlings and saplings. Other indicators such as the density of tree clusters or the proportion of areas devoid of regeneration have been proposed, and target values established. Conceptually sound target values of regeneration indicators should also be based on reliable forecasts of future stand development, and of a strong relationship between these indicators and the products and services envisaged. Much remains to be done to select meaningful indicators, and to determine reliable target values. A combination of longitudinal studies and simulation models could contribute to achieve this.

Landscape of Fear in Europe: Wolves and Humans Shaping Ungulate Top-Down Effects

Kuijper, Dries; Churski, Marcin; Bubnicki, Jakub

Large mammalian carnivores create areas perceived as having high and low risk by their ungulate prey. Despite the large body of literature from North American study systems, we know very little on how predator-prey interactions operate in more human-dominated landscapes. We studied how red deer perceive the landscape of fear in one of the least-disturbed areas in Europe, the Białowieża Primeval Forest, Poland. In several studies we addressed fine-scale and large-scale risk factors for red deer in this old-growth forest. By means of camera traps we showed that deer become more vigilant and reduce foraging in the vicinity of cues indicating predator presence (wolf scats). Deer also perceive tree logs, that block view and escape routes, as a fine-scale risk factor. The strength of these effects depends on the distance to the core of a wolf territory (large-scale risk factor); deer perceive tree logs as more risky and become more vigilant when wolves are more often present. At these locations deer browsing intensity on trees is reduced and more successful tree regeneration occurs with potential effects on tree species composition. Hence, in the Białowieża forest, wolves and tree logs create "patches of fear" with reduced deer browsing intensity. Humans are indirectly important, as wolf core areas are located far from human settlements. This 'human shadow' on predator-prey interactions is therefore an important component that should be taken into account in more human-dominated landscapes in Europe. Human presence, forestry and hunting potentially modify predator-prey interactions largely in other areas in Europe.

Moose Browsing Effects on Scots Pine Growth and Stem Quality with Implications for Forestry

Wallgren, Märtha; Bergquist, Jonas; Bergström, Roger; Eriksson, Stefan

The Swedish moose (*Alces alces*) population is among the densest in the world and a significant functional component of the boreal forest ecosystem. It is highly valued from social and cultural aspects, primarily hunting and to a lesser extent also tourism. The most important winter forage for moose is Scots pine (*Pinus sylvestris*), which is also one of the two most important tree species for Swedish forestry. Moose browsing on young Scots pine may affect the trees in terms of retarded growth, increased risk of mortality and altered stem structure. We have studied a large number of structural and growth-related responses of young Scots pine in relation to simulated browsing from large herbivores. We combined different modes of intensity, timing and duration of clipping for nine consecutive years from 2000 to 2008. Data on tree responses were collected yearly during this period, as well as in 2011, and were analyzed using ordination techniques and generalized linear models. A key result demonstrated is the serious effects of clipping on the youngest pines. Mortality was high when clipping started the first year, indicating that the trees are vulnerable at that stage, but after that increasing intensity and duration of clipping were the main causes of mortality. Among the different treatment factors, intensity of clipping had the largest influence on altering the final growth responses, some of the quality responses, and mortality. Timing of clipping was the most important factor for explaining the occurrence of the majority of responses related to stem structure. Duration of clipping had the largest effect on the responses that included repeated-measures data, such as height development and number of stems. We conclude that Scots pine seems resistant to occasional browsing events taking place after the first year after planting, but that structural damages may occur as a result of a single bite from a browsing herbivore. We further discuss the long-term consequences of browsing for the trees and the implications for forest management.

Integrating Forest and Wildlife Management to Reach Ecosystem-Based Management Objectives

Tremblay, Jean-Pierre

One of the dominant tenets of North American forestry at the beginning of the 21st century is ecosystem-based management. It assumes that keeping forests within their natural range of composition, structure, and function, should improve their resilience. At the same time, populations of many ungulate species of boreal and temperate forests have likely reached abundance levels never encounter since the last Holocene glaciation. Silvicultural treatments aiming at the restoration of natural forest attributes could fail to meet their goal if they do not account for the effects of ungulates on forest regeneration, especially for tree species with advance regeneration such as fir. I will review our knowledge of the impacts of ungulates (namely white-tailed deer *Odocoileus virginianus* and moose *Alces alces*) on the regeneration dynamics of balsam fir (*Abies balsamea*) dominated forests and suggest pathways for their sylviculture. Controlled browsing experiments have helped us identify white-tailed deer densities compatible with the natural regeneration of forests. Local reduction in abundance through selective hunting of antlerless deer can hardly attain and maintain these target densities without concomitant management of the forest structure, and vice-versa. Fencing of cutblocks and reduction of deer abundance have been used to regenerate fir dominated forests. The timing and duration of the reduction relative to forest opening are key to the outcome; legacy effects of browsing can trigger alternative successional trajectories difficult to reverse without further interventions. At the scale of the forest plot (or deer feeding station), silvicultural treatments that manipulates plant communities, such as precommercial thinning or plantation, could reduce the risk of browsing on fir if they favor associations of fir with neighbor species (associational defence) or maintain a high stocking of fir. At the landscape scale, or at a scale larger than a typical home range, dilution in a pool of high quality forage is more likely to bring together wildlife and forest management objectives. In this context, browsing can accelerate the succession from shade-intolerant deciduous species to later successional species such as fir. Managing forest ungulates to achieve forest management objectives is challenging because they are both a resource and a disturbance. Meeting the challenge involves integrating forest and wildlife management from the elicitation of management issues, identification of targets, planning of actions, and monitoring of results.

How Can We Make Forest Regeneration More Robust Against the Overabundant Deer Populations?

Madsen, Palle; Buttenschøn, Rita Merete; Kanstrup, Niels; Madsen, Torben Lynge

Dense deer populations pose one of the greatest challenges for successfully including all desired tree species in forest restoration and forest regeneration activities. This is a key challenge since a restricted tree species diversity of our forests caused by selective deer browsing or fraying may critically limit the forest adaptive capacity now when climate change, new disease and pest scenarios as well as loss of biodiversity call for exactly the opposite. Overabundant ungulate populations have emerged in most of the industrialized countries since the 1950's. Numerous scientific studies and practical experiences have documented undesired impact of forest regeneration and cascading effects on biodiversity including e.g. ground flora, insects and song birds. Overabundant deer populations do also challenge people in more direct ways by e.g. carrying diseases, browsing gardens and parks as well as causing traffic collisions. We need, however, to move beyond documenting the problems and challenges and instead suggest, develop, test and document approaches, methods and techniques that may contribute to solutions. Research and development of deer browse tolerant regeneration methods is an example of such efforts. The deer browse tolerant regeneration is defined as densely stocked regeneration resting on natural regeneration and/or direct seeding that is tolerant enough to support regeneration of even tree species that are attractive to deer without or with very restricted use of deer fences or repellents. Natural regeneration and direct seeding are low cost regeneration methods that has the potential to support densely or very densely stocked regeneration (> 10000 trees ha^{-1}) which is considered important to support implementation in practice. Deer browse tolerant regeneration is, however, only one component in the integrated forest, nature and game management. One such component is usually not enough to secure successful outcome and as such it is very much about involving all the important stakeholders to establish an integrated approach. By limiting or avoiding the use of deer fences at the regeneration areas silviculturists maintain deer access to some of the highest quality deer habitats in the landscape – the forest or forest restoration regeneration areas. Additionally, densely stocked regenerations both offer food and cover for the deer – and as such this approach to forest regeneration may serve as a valuable contribution for hunters and game manager interests. However, even very densely stocked forest regenerations may not be tolerant enough to the deer impact if the deer populations by far exceeds the carrying capacity of the landscape. Therefore, the integrated approach is also very much about engaging the various stakeholders and make them realize their potential role and importance as well as their responsibility for the sustainable management of the forests, landscapes and deer as a whole. Increased and more balanced culling of both male and female as well as young deer are important components to bring the deer in balance with the carrying capacity of the forests and landscapes. This is not comparable to the often requested intensive culling to reduce the deer populations as much as possible, which is a statement requested by silviculturists and farmers. The integrated approach seek balanced population densities with respect to all stakeholder interests, yet the deer browse tolerant regeneration approach is expected to elevate forest carrying capacity to a level high enough to support relative high deer population densities to avoid unacceptable levels of damage and support good health and quality of the individual deer. The question is then if such a silvicultural contribution to the integrated management can stimulate the hunters and game managers to contribute by keeping the deer population and its distribution between males, females and fawn at a balanced level with respect to forest and landscape carrying capacity? Results from field experiments with deer browse tolerant regeneration based primarily on direct seeding as well as experiences with projects on integrated management will be presented.

Sessions

Session 1:
Monitoring the Effects of Ungulates on Forest Regeneration

Concepts and Methods for Assessing Browsing Effects Within Austrian Forests

Hasenauer, Hubert; Hainzl, Erwin

Density of wild (hoofed deer) and its influence on forests and forest regeneration is an old topic where hunters and foresters have had severe discussions for decades. Hence, to build up a basis for management of wildlife, different monitoring systems were established in Austria. These monitoring systems were designed to answer different questions on different spatial- and timescales. An overview of these methods used in Austria (Austrian national forest inventory, Austrian national game influence monitoring system, federal province wide used systems [Upper Austria, Vorarlberg], and systems used by forest enterprises) will be shown. These monitoring systems were designed to answer different questions, so one cannot replace the other. A combination of the systems can help to provide an information basis for forest development comprising an acceptable density of game under many different habitat conditions.

Effects of Ungulate Browsing and Forest Management Objectives

Hagen, Robert; Suchant, Rudi

Climate change and forest management are important drivers for the relationship between ungulate browsing and its effect on forest regeneration. However, population dynamics of ungulates, time lags between population size and forest growth, forest management regimes and climate variations led to a high uncertainty for the quantification how ungulate browsing effect forest regeneration. Beside the objective to quantify the effect of ungulates on natural tree regeneration we rather should implement measures to take uncertainty into account. Here we present the results of the "Forstliches Gutachten" (2009, 2012, 2015) which monitors not only the browsing level on the level of hunting grounds for a time span of three years in the federal state of Baden-Württemberg (Germany) but also considers the forest management objectives classified as "objective can be reached", "objective cannot be reached locally", "objective cannot be reached". We investigated if the browsing level in the categories low, medium and high is related to the management objective. Results are presented for oak (*Quercus*), fir (*Abies*) and beech (*Fagus*). Our investigation highlights that browsing is an important factor affecting natural forest regeneration but also that the browsing intensity itself can not explain the success or failure of forest management objectives.

Using Deer-vehicle Collisions for Deer Monitoring and Management

Hothorn, Torsten; Müller, Jörg

Roe deer *Capreolus capreolus* as a risk factor for deer-vehicle collisions and as browser of palatable trees has implications for forest regeneration. However, no large-scale management systems for roe deer have been implemented, mainly because of the high efforts and costs associated with attempts to estimate population sizes of free-living animals. Based on browsing inventories performed in 2006 and 2009 and more than 340 000 deer-vehicle collisions observed between 2002 and 2011 in Bavaria, Germany, we show (i) that the temporal pattern of deer-vehicle collisions is strongly linked to activity patterns of roe deer, (ii) that the spatial risk of deer-vehicle collisions is increased in areas with large browsing intensities, and (iii) that there is a positive relationship between deer-vehicle collisions and harvest numbers. These findings suggest a close relationship between numbers of deer-vehicle collision on the one hand and browsing intensity and deer density on the other hand. We therefore propose the number of deer-vehicle collisions as indirect measure of deer densities as the basis of deer management plans. In the densely populated and intensively used landscapes of Central Europe, a model-based risk assessment for deer-vehicle collisions provides a cost-efficient instrument for deer management at the landscape scale.

Publications:
http://dx.doi.org/10.1016/j.aap.2015.04.037
http://dx.doi.org/10.1371/journal.pone.0029510
http://dx.doi.org/10.1016/j.foreco.2010.07.019

Monitoring Impact of Deer on Tree Species Richness in Developing Forest Stands

Kalén, Christer

The impact of ungulate browsing on long term forest transition towards unpalatable tree species is in Sweden a cumbersome process to disentangle by monitoring. As Norway spruce (*Picea abies*) mostly is avoided by deer it not only gains competitiveness in relation to other tree species, but also gain in popularity amongst forester's choice during stand regeneration of a stand. The National Forest Agency monitors browsing in forest stands to estimate damages on commercial trees as well as impact on stand development and tree species composition. By collecting field data of site characteristics and tree species regenerated, information about whether foresters avoid regenerating with palatable tree species is gained. The competitive status of trees important for biodiversity but with low or no commercial value is also monitored. The aim is to monitor to what level these are out-competed by unpalatable tree species with a secondary influence on tree species composition on the mature forest. The method can to some extent distinguish between the effects caused by deer browsing from forestry on the tree species composition during stand development. The method, used all over Sweden, renders valuable information but also hard to interpret.

A Comparison of Stem-Number-Proportion and Occupied-Area-Proportion as Measures of Browsing Intensity

Huber, Markus; Schwyzer, Andreas; Kupferschmid, Andrea D.

The most common measure of browsing intensity (BI) is the proportion of browsed stems (SP), but there is still debate on whether to use the Ratio-of-Means (RoM) or the Mean-of-Ratios (MoR) estimator. An alternative yet uncommon measure for BI is the occupied-area-proportion (AP), which can be estimated using k-tree sampling with k = 1 (KTS). We used data of the Swiss National Forest Inventory (NFI) and simulated examples of a one hectare forest to demonstrate and compare the measures. Analysis of the NFI data showed significant differences: BI, calculated over all species, was 13.1 ± 0.975 %, 16.9 ± 0.687 % and 16.9 ± 0.90 % according to RoM, MoR and KTS, respectively. RoM is an asymptotically unbiased estimator of SP, while KTS of AP. SP and AP were equal only in the case of an equal distribution of BI over the stand area. If BI was larger at low stem density sites, SP was lower than AP, and vice versa. AP has high potential from a practical point of view, since it requires much less fieldwork and is much less error prone than to count each tree by browsing class, as it has to be done to derive SP.

Influence of Wild Ungulates on the Swiss Forest: A Multimethodological Overview

Kupferschmid, Andrea D.; Heiri, Caroline; Huber, Markus; Odermatt, Oswald

Terminal shoots of tree regeneration are part of the diet of chamois, roe and red deer, which in turn can affect forest regeneration. We investigated the current extent of browsing influence on the Swiss forest and if there are regional differences. Our overview includes all available, regionally assessed data on the influence of roe deer, chamois and red deer in Switzerland, i.e. data of the fourth Swiss National Forest Inventory (NFI2009/2013) and data from the cantons derived by i) representative sample plot inventories, ii) surveys in selected forest areas and iii) assessments by expert opinion. In the time period between approx. 2009 to 2014 no larger region of Switzerland stood out with respect to browsing influence. Locally, browsing on tree regeneration varied on the level of the ungulates home range/forest districts and altitudinal vegetation belts, respectively. However, on at least $^{2}/_{3}^{rd}$ of the assessed forest area of Switzerland browsing had no major influence on single tree species nor on forest regeneration in general (browsing level 1). Frequent browsing has the most adverse influence in the colline vegetation belt on oak, in the montane belt on fir and in the lower subalpine belt on maple and rowan.

Quantifying the Impact of Terminal Shoot Browsing by Ungulates on Tree Regeneration

Kupferschmid, Andrea D.; Hothorn, Torsten; Brang, Peter

We investigated the impact of site, climate and ungulate specific variables i) on the occurrence of leader shoot browsing by ungulates and ii) on the relative influence of browsing on tree regeneration compared to other factors. On 1704 permanent plots in 49 study areas, seedlings were repeatedly assessed for browsing. A two-step modelling procedure was applied: Browsing probability was first estimated for each stratum based on GLMM. Random forest models were then used to explain browsing probability as well as seedling density and tree species composition. Browsing probability was positively associated with ungulate density. Red deer and chamois browsed seedlings more frequently than roe deer. Browsing was among the most important variables explaining size-dependent species composition; more tall than small seedlings of *Fagus* and *Fraxinus* were present, but an inverse pattern was found for *Abies, Acer, Sorbus* and *Picea* due to browsing. In relation to other variables, such as basal area, light and slope, browsing was less crucial for explaining tree density, but all species declined in density if annual browsing exceeded a threshold value of about 5–10 %, but did almost not change further above this threshold. Results and probable consequences for monitoring the effects of ungulates will be presented.

Monitoring Method and Browsing Severity are Crucial to Describe Browsing Impacts

Schaubhut, Swantje; Kupferschmid, Andrea D.

Ungulate density and the percentage of browsed tree regeneration (browsing intensity [BI]) were positively correlated in 49 browsing inventories across Switzerland. However, BI indicates a non-linear relation to tree density and development (see Abstract Kupferschmid *et al.,* p. 25). Hence, there are areas with little or no tree regeneration partly due to ungulates despite low BI. Contrary are areas with high regeneration density and trees developing through all height classes despite high BI (>50 %). Browsing severity, tree reaction after browsing and tree growth could cause such site-specific differences. Data were collected on 15 sampling points on 12 areas with different regeneration densities and BI. Information were obtained on litter layer, humus type, soil pH, light, basal area, stand development etc. With regards to regeneration browsing severity of the terminal shoot and entire tree, browsing frequency, reaction after browsing and height increment where examined on trees in four height classes with i) the nearest 5 trees up to 10 m distance, ii) the 6 dominant trees and iii) all trees in a 2–5 m circular plot per sampling point. First results indicate that – apart from the monitoring method – browsing severity, soil attributes and height increment are important components to describe browsing impacts.

Session 2:
Reference Values for Tree Regeneration: How much of which Phenotype and Genotype and Special Implications with Climate Change

Breeding for Browsing "Resistance" in Norway Spruce?

Trujillo-Moya, Carlos; Schueler, Silvio; Konrad, Heino

Red Deer browsing on Norway spruce seedlings in Austria can result in delayed establishment of regeneration, plantation failure and subsequent economic losses for the forest owner. Observations in natural and artificial regenerations show high variation in browsing damage among individual trees and suggest that Red Deer may have preferences for certain phenotypes.

4 forest observation sites were established in the province Carinthia (Austria) on elevations among 1280–1629 m asl. At each site, 200 Norway spruce seedlings with heights among 40–231 cm are exposed to high deer pressure. Within two vegetation seasons all individuals were phenotyped for physical characters, browsing, flushing, overall assessment and other damages caused by biotic or abiotic factors. We use AutocorrQ to characterize and test the spatial autocorrelation of quantitative traits. Moran's I statistics, indicate the absence of spatial autocorrelation among individuals. Then, most extreme phenotypes were selected as putatively browsing "resistant" and susceptible genotypes, respectively.

To test for genetic causes of the phenotypic variation in browsing damage, phenotypic differences will be related to candidate genes putatively associated with browsing "resistance". Customized targeted sequencing has been envisaged to re-sequence selected candidate genes involved in plant secondary metabolites pathways (terpenoids, phenypropanoids), anti-nutritional enzymes and proteins (proteases inhibitors, polyphenol oxydases, arginases) and defense signaling routes (jasmonates, ethylene, salicilic acid …).

Does Browsing Resilience of Spruce, Fir and Beech Differ Between Provenances? A Genecological Study for Switzerland.

Heiri, Caroline; Frank, Aline; Sperisen, Christoph; Brang, Peter; Kupferschmid, Andrea D.

Due to long-term selection processes, forest trees are well adapted to their local environments. Consequently, they often show large genetic variation among provenances that might also induce provenance-specific reactions of trees to ungulate browsing. In an extensive experiment we investigated quantitative genetic variation within and among populations of spruce *(Picea abies),* fir *(Abies alba)* and beech *(Fagus sylvatica)*. For each species present in the experiment, phenology and growth traits of approx. 4000 seedlings from 77–92 autochthonous provenances sampled throughout their ecological range in Switzerland were recorded at one resp. for *Fagus* at two study sites. Provenance differences were related to environmental variables of seed sources. This spring, $^1/_3$ of the seedlings was slightly and $^1/_3$ heavily clipped to evaluate resilience to browsing by ungulates. Largest genetic variation among provenances was found in second flushing of spruce and beech, in height growth of spruce and bud break of beech, whereas lower variation was detected in seedling traits of fir. Genecological models relating provenance variation to climate differed among seedling traits and species. Our results showed considerable genetic variation among Swiss provenances driven by local climates. The clipping experiment will show if these variation patterns apply also to the resilience of seedlings to browsing.

Combined Impacts of Climate Change and Ungulates Browsing on Forest Dynamics in the Bavarian Forest National Park

Cailleret, Maxime; Heurich, Marco; Bugmann, Harald

Climate change may change stand-level dynamics by altering the regeneration, growth and mortality of tree species, and by modifying interspecific competition. Some studies have shown that these effects can be compensated by lower browsing pressure, but it is not clear how species composition and stand basal area may respond in the short and long term, and to which extent. We investigated potential combined effects of changes in climatic conditions and ungulate browsing intensity on the short- and long-term development of different forest types in the Bavarian Forest National Park using the forest gap model ForClim. The model predicted a large dieback of the dominant *Picea abies* and *Abies alba* due to the increase in summer drought and winter temperatures, which were replaced by *Fagus sylvatica*. While species composition was strongly dependent on browsing intensity under current climate through the changes in seedling selectivity by ungulates and in light regimes, the trajectory of vegetation development under climate change was not significantly altered by browsing. We conclude that reducing ungulates population may not be sufficient to compensate for the reduction in basal area of drought-intolerant species that is induced by climate change, even for highly palatable species such as *Abies alba*.

Session 3:
Trophic Interactions: Ungulates, Predation (Human and Carnivores) and Tree Regeneration

Insular Western Red Cedar Response to Introduced Sitka Black-Tailed Deer (Queen Charlotte Islands, Canada)

Baltzinger, Christophe; Chollet, Simon; Martin, Jean-Louis

Western red cedar, *Thuya plicata*, is an economically, ecologically and culturally dominant tree species of the temperate coniferous rainforests of the Canadian pacific coast. On the Queen Charlotte Islands (British Columbia), free of native large herbivores, western red cedar regeneration underwent a dramatic decline since the introduction of Sitka black-tailed deer, *Odocoileus hemionus sitchensis*. We review here the selective browsing effects from Sitka black-tailed deer populations on the regeneration of the long-lived western red cedar within a simplified tree community reduced to three species (*Thuya plicata, Picea sitchensis* and *Tsuga heterophylla*) in both old- and second-growth forests. We present synthetic results from complementary approaches conducted since the beginning of the research program 20 years ago (http://rgis.cefe.cnrs.fr/): herbivory pressure gradient linked with hunting accessibility in 15-years old stands (Martin and Baltzinger 2002); deer exclosure network in old-growth forests (Stroh et al. 2008); a natural laboratory based on delayed deer colonization events (Martin *et al*. 2010); rocky outcrops as natural deer-free refuges (Chollet *et al*. 2013) and eventually deer eradication on a remote island to assess forest recovery *(in prep.)* We discuss how relevant these different protocols are to assess deer effects on highly palatable tree species and tree composition.

Beyond Moose – Diverse Ungulate Communities and their Impact in Human-Modified Landscapes

Cromsigt, Joris; Singh, Navinder; Widemo, Fredrik

Several ungulate species have increased rapidly in numbers and distribution across southern, central and parts of northern Sweden. Communities of 5–6 species are now increasingly common where a few decades ago only 1–2 species occurred. This represents challenges for sustainable management of these multi-species communities and their habitat and calls for actions that aim at moving from single- to multispecies management. In the Swedish context, we have to move "Beyond Moose". In the "Beyond Moose" program we will develop understanding of the functioning of these multi-species communities in relation to game management and other land use practices (agriculture and forestry). We aim to understand trophic interactions in multi-species ungulate communities in relation to these land use practices and ultimately how these interactions influence their impact on the landscape. This understanding is crucial both for managing the ungulate community, but also for finding trade-offs between competing ecosystem services such as game meat and recreation from hunting *vs.* fiber from forests and food from crops. In an international perspective, the project provides a platform for a global discussion on how to manage diverse and increasing ungulate communities throughout Europe and North America.

Session 4:
Ungulate Impacts and Timber Quality

Assessing Economic Impacts of Deer Browsing on Forestry: Fir-Spruce Stands in the Vosges (France) as a Case Study

Boulanger, Vincent; Rakotoarison, Hanitra

Although the recent increase in deer populations is becoming a major concern for forest managers, economic assessments of big game damages are rare and often based on expert estimates. Selective deer browsing can severely affect forest ecosystem by promoting the establishment of unpalatable tree species, replacing the palatable ones through the increase in young stage mortality. However, palatability does not necessary match with forestry objectives defined according to site potential, adaptation to climate constraints and economic considerations. Browsing on shoots is also likely to delay regeneration growth or depreciate the future trees. These impacts are less obvious and detectable, but may imply significant production loss as well. First, we performed a literature review to quantify physical impacts of deer damages on the mixed fir, spruce and beech stands. Second, we modelled a reference scenario without deer damage for a silver fir stand in the Vosges and calculated its land expected value (LEV) using a cost-benefit framework. Finally, we ran several scenarios including different damage types and intensities, their possible consequences and management actions (protective or curative) in order to estimate the induced changes in LEV. These results provide an operational outline for illustrating deer impacts and discussing management strategies.

Session 5:
Interactions Between Silviculture and Ungulate Impacts

Sika Deer Damage to *Abies Sachalinensis* Plantations in Hokkaido, Japan

Akashi, Nobuhiro

Abies sachalinensis is a native species to Hokkaido, Japan. Because natural regeneration is difficult due to vigorous growth of herbs and dwarf bamboo, seedlings are planted after clear-cutting. Sampling survey of young plantations revealed that browsing damage to *A. sachalinensis* is less severe than both *Larix kaempferi* and hardwood species, though antler scrubbing to trunks causes serious economic damage by wood decay. Recently some planted forests of conifer species are advocated to convert to hardwood or mixed forests because too much forest area is covered with plantations of a few conifer species. I and colleagues studied browsing damage and browse preferences of hardwood seedlings in *A. sachalinensis* plantations. The results suggest that differences in browse preferences among species are continuous between preferred and avoided, and cannot be categorized discretely. Percentages of browsed seedlings can be used as an index of deer impact level regardless of browse preferences, though these may be inaccurate, especially when the site is dominated by significantly preferred or avoided species.

Ungulate Browsing, Damages, and Forestry Mitigation Efforts in Sweden – an Overview

Ericsson, Göran; Edenius, Lars

A key challenge for forestry is to handle the impact from large ungulate. Currently, ungulate browsing in Sweden follows a latitudinal gradient from the north (moose-pine interactions) to the south (multi-deer-pine-spruce-deciduous trees interactions). Sweden has experienced – first along the increase of the moose population, and then later along the increase of other deer species populations – a stronger and stronger focus on forestry practices to mitigate browsing effects. Particularly in southern Sweden, the discussion about ungulate-adapted forest management has been vivid involving forestry, hunting and conservation interests. In a joint research effort involving the multitude of national actors in forestry and browsing, we launched the national thematic program Wildlife and Forestry. During 2007–2012 we studied various silvicultural techniques previously proposed to mitigate impact of browsing e.g. effects of harvest timing and slash treatment on forage availability, adapted final felling and commercial thinning, and food Plots. In our paper we summarize, review and synthesize our finding about ungulate-adapted forestry during the last decade in Sweden from Wildlife and Forestry, Environmental monitoring programs (FOMA) and Beyond Moose.

Factors Limiting Recruitment of Rowan and Sallow in Production Forests

Widemo, Fredrik; Ånöstam, Filip; Åberg, Malin; Månsson, Johan

Tree forming rowan and sallow are important carriers of biodiversity in coniferous production forests. Both species are weak competitors and constitute preferred browse for moose. Thus, both browsing and silvicultural practices may limit recruitment and tree formation. Here, we show that density of rowan and sallow decreases throughout the rotation time in Swedish coniferous production forests. There was no difference in height or age of rowan or sallow between young and old stands, suggesting that both species recruit into stands but perish before forming trees. Alternatively, previous PCT may have limited rowan and sallow. PCT instructions have changed, but 9 % of the rowan and 36 % of the sallow had been cut. Indivuals that had been cut during PCT were shorter (rowan) or thinner (sallow) than individuals that had not been cut, suggesting that PCT may still limit recruitment and tree formation. Browsing pressure decreased with increasing density of rowan and sallow and was lowest in stands of intermediate age. Our results suggest that silvicultural practices are more important limiting factors than browsing. Furthermore, discussions about recruitment and tree formation in rowan and sallow must take the whole rotation time into consideration.

Impact of Roe Deer Browsing on Rare Tree Species' Regeneration

Vor, Torsten

Within the project "Concepts to promote rare tree species", funded by the German DBU, mortality, height and diameter growth and browsing damages of the tree species wych elm *(Ulmus glabra),* yew *(Taxus baccata),* service tree (*Sorbus torminalis*), field maple *(Acer campestre),* Norway maple *(Acer platanoides),* pedunculate oak *(Quercus robur),* rowan (*Sorbus aucuparia*), wild apple *(Malus sylvestris),* wild pear (*Pyrus pyraster)* and wild cherry *(Prunus avium),* were investigated. Main objective was to identify the most important factors for the successful establishment of these species. 9600 saplings of the 10 above mentioned species were planted on 96 experimental plots in central Germany under different site, ownership, hunting and tree canopy conditions. 10 % of these planted trees were individually protected by mini fences. Mortality, browsing damages, height and root collar diameter as well as natural regeneration were assessed. Mortality and growth performance of the planted trees varied considerably among tree species and study plots. It was obvious that the main growth factor during the first two growing seasons was the differing browsing pressure by roe deer. Protected trees grew significantly faster and natural regeneration was quite scarce. Overall, a combination of browsing pressure and light conditions seemed to be most important for the establishment of rare tree species.

Effects of Deer on Oak Regeneration: Interactions Among Silviculture, Ungulates and Neighboring Plants

Mårell, Anders; Hamard, Jean-Pierre; Laurent, Lisa; Rocquencourt, Agnès; Baltzinger, Christophe; Balandier, Philippe

Owing to their high value as timber, sessile oak *(Quercus petraea)* and pedunculate oak *(Q. robur)* are among the most important tree species in temperate lowland forests. Forest managers are faced with numerous constraints when regenerating these forests. Among them, deer impacts associated with competing vegetation are highly significant. These factors affect both the growth and survival of oak seedlings and saplings. Here, we present some of our current and recent works on deer impacts on oak regeneration. First, we show how deer browsing and fraying affect the growth and survival of oak seedlings and saplings. Then, we describe and discuss preliminary results of an ongoing controlled cross-factorial experiment where we test how shade and drought (abiotic stresses) modify plant-plant and plant-herbivore interactions. Our studies highlight the high degree of tolerance of oak trees to deer damages. Finally, we illustrate how our work on deer impacts on oak regeneration have led to the development of a tool for assessing regeneration success at the stand and landscape level and give some examples of how this tool can help in solving forestry-hunting conflicts. We end by discussing the implications of our research for forest management and future challenges.

To Fence or not to Fence? That is a Question

Dobrowolska, Dorota; Borkowski, Jakub

In Polish forest most plantations are fenced. Is it possible to reduce the costs of seedling protection and grow stand forests without fencing? The aim of the study was to find out the effect of forest management on the damages caused by ungulates after catastrophic blowdown. The level of damages depends on the base of food, the higher quantity of tree species in plantation the lower the level of tree damages (browsing and stripping). In the case of Scots pine the hypothesis was tested by comparing the damages in planted and sown young plantations. The impact of ungulates on pedunculate oak was compared according to the type of oak planting in pine stands (individualy or on large spots [1.2 m] in different spacing [8×8 m and 6×6 m]). Study plots established in 2006 were situated in forests with the free access of ungulates. They were not fenced. All oaks were browsed in all variants of experiment (3 variants). Since 2013 decrease in oak browsing has been observed. Height of oaks depended of the variant of experiment. The level of pine stripping was subjected to the variant of experiment and type of pine regeneration (sowing/planting).

Early and Long-Term Impacts of Browsing by Roe Deer in Coppiced Woods in Central Italy

Cutini, Andrea; Chianucci, Francesco; Apollonio, Marco

Starting from the 2002 we investigate roe deer (*Capreolus capreolus* L.) pressure on coppice stands vegetative regeneration. In a first research programme (Alpe di Catenaia, Central Italy, roe deer density 32.8 ± 1.7 km^{-2}), six fenced and non-fenced plots were established after coppicing in *Quercus cerris* and *Castanea sativa* stands. Each plot was periodically measured. After 4 years, *C. sativa* did not show any browsing-related damage, while in *Q. cerris* differences were significant. Last surveyes showed the impact on *Q. cerris* coppice was not ephemeral but produced prolonged impacts (–41 % in volume eleven years after coppicing). The results agreed with an experimental browsing index, which was proved to be quick and reliable. More recently, we investigated the effect of roe deer browsing on *Q. cerris* sprouts along a gradient of density (from 14 to 38 deer km^{-2}) in the Province of Arezzo (Central Italy). Results revealed that browsing impact was high at any given roe deer density but increased at higher density, with the browsing rate ranging from 65 % to 79 %. Our results confirmed the situation is critical not only for conifers natural regeneration but for coppice stands too; new and more integrated management schemes between forestry and wildlife, urged.

Ungulate Browsing Exclusion: Effects and Medium-Term Trends in Coppice Woods in North-Western Italy

Bottero, Alessandra; Meloni, Fabio; Motta, Renzo

Wild ungulates can significantly impact forest regeneration, with potential negative consequences on the growth and productivity of whole stands. Although several studies have been conducted on browsing, our understanding of medium- to long-term effects of browsing in coppice stands, especially at population-level, is still lacking. We investigated the effects of browsing by European roe deer in *Quercus pubescens, Fagus sylvatica* and *Castanea sativa* coppice stands in north-western Italy. We analysed three coppice stands in the eleven years following coppicing, in comparison to deer exclosures, excluded from browsing after the initial coppicing, to gain insights on the influence of browsing on regeneration growth in the short- and medium-term. Browsing was very intense (> 75 % of shoots browsed) in the first few years after coppicing and on the most appetible species. Significant differences in basal area and regeneration height were found among stands, with exclosures showing higher values. Differences in height were not significant in the medium-term. Despite the initial severe impact of browsing on regeneration, the coppice stands analysed recovered within a few years, exhibiting resilience. However, the ability of coppice stands to re-grow after several rotations, following repeated browsing and the natural weakening of stools, still needs to be examined.

20 Years of Ungulate Impact on Tree Regeneration in the Paneveggio-Pale di S. Martino Provincial Park (Italy)

Motta, Renzo; Berretti, Roberta; Meloni, Fabio; Partel, Piergiovanni; Vacchiano, Giorgio

Ungulate densities in the Italian Alps have rapidly increased in the last decades due to both natural recolonization and active reintroduction. The ungulate impact on forest regeneration is relevant in the Trento Autonomous Province where a close-to-nature forestry has been applied since 1950s. Paneveggio-Pale di S. Martino Park has been one of the site of the red deer reintroduction and it is still one of the sites with the highest ungulate density. The impact of the ungulates on the forest regeneration was assessed in the Park in more than 200 plots since 1995 through four regeneration inventories. During this 20-year experimental study the impact of the ungulates has shown an increment (from 15 % to 23% of the regeneration) and a territorial extension from some sites to almost the entire Park forest range. The study revealed a strong impact of the ungulates on the species composition and recruitment of tree regeneration, especially on rowan and silver fir, even if data regarding the most affected species are underestimated. The last inventory has shown a strong browsing impact on the ground vegetation with special reference to the bilberry. Methodological and management issues are presented and discussed with special reference to the mountain forests.

Ungulate Browsing in Mixed Beech-Silver Fir Forest Under Different Silvicultural Systems

Diaci, Jurij; Roženbergar, Dušan; Nagel, Tom A.; Jerina, Klemen

There are important interactions between silviculture and ungulate populations. Here we examine how ungulate densities affect the browsing on regeneration in various silvicultural systems (selection, group selection, irregular shelterwood) in mixed forest. Browsing damage was highest in areas with a low-density of red and high density of roe deer. We found relatively high levels of browsing on all major tree species (beech, fir, maple). The density of seedlings was > 20 000 ha^{-1}, but the proportion of fir was low. We expected more browsing damage in small gaps (< 500 m^2) due to a favourable combination of protective cover and food availability, yet this was not confirmed. There was more damage in large gaps, which could be explained by a greater variety and amount of food and availability of coverage. The influence of gap size on browsing damage was not clear, which could be due to species composition of regeneration and variation in developmental phases. Results suggest there are minor differences in browsing damage among the silvicultural systems. Therefore, it is important to maintain an appropriate level of open canopy to increase light, heat and precipitation in the understory, which increases food availability and speeds up the regeneration process.

The Impact of Ungulates on the Regeneration, Recruitment and Abundance of Silver Fir in the Dinaric Mountain Forests in Slovenia

Bončina, Andrej; Ficko, Andrej; Klopčič, Matija; Simončič, Tina

The impact of ungulates on fir was assessed on several scales. By pairwise comparison of tree species regeneration and plant species composition in six fenced and unfenced sites (132 plots, 16 m^2 each) we estimated the regeneration potential of fir at the stand scale. At the landscape scale (5000 ha, 165 plots, 500 m^2 each), we analyzed tree species regeneration and browsing in contrasting ungulate densities. At the regional scale (> 100 thousand ha, 1710 permanent sampling plots [PSP], 200 m^2 each), we assessed the recruitment of fir into forest stands. Based on the observed vital rates (898 PSP) we projected 100 years of stand dynamics under four alternative management scenarios. We found significant difference in the number of palatable tree species (e.g. *Abies alba, Acer pseudoplatanus*) in the regeneration and contrasting abundance of several plant species (e.g. *Rubus hirtus, Atropa belladonna*) between fenced and unfenced sites. The surveys at the landscape and regional scale showed that fir regenerated abundantly ($n = 3462$ ha^{-1}), but less than one fir per hectare recruited annually ($dbh \geq 10$ cm). Alternative management can improve the demography of fir population but cannot prevent fir from decline in chronically browsed forests suffering from limited recruitment.

Posters

Analyzing and Modelling Crossed Effects of Climate Change and Deer Browsing on the Regeneration of Mixed-Forests

Bernard, Marianne

The recent increase of the population of *Cervidae* in France causes a misbalance with forest. Deers selective browsing on mixed forest regeneration might modify relative species composition and have consequences on forest adaptation to climate change. The purpose of this thesis is, first, to quantify the effects of deer and roe deer on the regeneration of the fir-beech-spruce mix, and then to assess the consequences for climate change adaptation. We also aim at simulating long-term evolution of this mix according to various browsing pressures, climatic scenarios and sylvicultural strategies. This work will mobilize long-term enclose/exclose monitoring from disposals settled in the North-East of France. We will also use a climatic gradient in the Alps to look at the effect of the variations on the regeneration of this mix. These data will enable us to estimate the elementary parameters of regeneration, in order to implement dynamic growth models. Samsara2 and ForCEEPS will be used to simulate the long-term effects of game on regeneration, integrating various sylvicole variables. We will assess at various time scales the adaptation of trees to future climates. The interest of this approach is the crossed analysis and simulation of long-term effects of two major issues affecting forest.

The Effect of Fencing around Forest Plantation upon the Population Density of Wild Ungulates, and on Damage Caused by Deer in the Forests of Northeastern Poland

Bobek, Boguslaw; Wojciuch-Ploskonka, Marta; Bobek, Jan; Furtek, Jakub; Ulejczyk, Sylwester

In fragmented deciduous forests of combined area of 38,700 hectares, the population densities of red deer, roe deer, and wild boars were estimated using driving method, whereas in 32 subunits of 2 forest districts the level of damage exerted by deer in young forest plantations (aged up to ten years) was assessed. The red deer and roe deer contributions to the damage was determined on the basis of the diameter point at browsing. In the study area forest districts, the population densities were positively correlated to the proportion of non-fenced young forest plantations in the area of forest districts (r = 0.604, p = 0.012), and negatively correlated with the proportion between fenced and non-fenced plantations (r = 0.694, p = 0.012). No such correlations were found with regard to red deer and wild boars. The proportion of young seedlings damaged by roe deer reached 84.8%, and by red deer –15.2%. A statistically significant correlation (r = 0.721, p = 0.016) was found between the area of fenced young forest plantation in the total area of this age class, and the density of heavily damaged seedlings within young forest plantation. Impact of fencing upon biodiversity of forest habitats is discussed.

Long-Term Effects of Ungulate Browsing on Forest Composition and Structure

Didion, Markus; Kupferschmid, Andrea D.; Bugmann, Harald

Forest attributes such as species and age class diversity have been incorporated into forest management as indicators for forest health. Browsing by ungulates is known to alter forest species composition and to hamper forest regeneration. In this presentation, we employ the stand succession model FORCLIM to examine the potential effects of herbivory on the composition and function of mountain forests. By means of a sensitivity analysis, we are investigating a) browsing thresholds at which forest health and function are compromised, b) effects of fluctuating browsing intensities as a proxy for the dynamics of ungulate population density, and c) interactions of browsing with other drivers of forest regeneration such as seed production. The sensitivity analysis revealed that browsing thresholds are site-specific and differ by the examined indicator. For example, the species and diameter class composition as a proxy for the protective function of a forest against avalanches and rockfalls may be disrupted at relatively low browsing levels. Our results indicate that the effect of fluctuating browsing intensities is not linear and that feedbacks between drivers of forest regeneration are cumulative rather than additive. We discuss the implications for forest management and identify further research needs.

Publication:
Didion, M.; Kupferschmid, A.D.; Bugmann, H., 2009: Long-Term Effects of Ungulate Browsing on Forest Composition and Structure. Forest Ecology and Management 258, Supplement. 44–55.

Ungulate Herbivory Modifies the Effects of Climate Change on Mountain Forests

Didion, Markus; Kupferschmid, Andrea D.; Wolf, Annett; Bugmann, Harald

The general warming trend causes the range of tree species to shift to higher latitudes or altitudes. Since disturbances such as herbivory can change species composition, it is important to understand the combined effect of such factors and climate change. We used the forest gap model FORCLIM v2.9.6 to simulate forest development along altitudinal transects in three climatically different valleys in the Swiss Alps covering a wide range of forest types from the cold to the dry treeline. This allowed us to investigate altitudinal range shifts in response to climate change, consequences for tree species composition, and combined effects of climate change and ungulate herbivory. We found that tree species responded differently to the change in climate and did not migrate concurrently, which caused a succession to new stand types. While climate change partially compensated for reductions in basal area caused by ungulate herbivory, the combined effect of these two agents on the mix of the dominant species and forest type was non-compensatory as browsing selectively excludes species from establishing or reaching dominance and alters competition patterns, particularly for light. We conclude that there is an need for research that address the joint effects of climate change and ungulate herbivory.

Publication:
Didion, M.; Kupferschmid, A.; Wolf, A.; Bugmann, H., 2011: Ungulate Herbivory Modifies the Effects of Climate Change on Mountain Forests. Climatic Change 109: 647–669.

Response of *Vaccinium Myrtillus* Height to Ungulate Populations

Saïd, Sonia; Malengreaux, Celine; Lievens, Julien; Licoppe, Alain

Increasing populations of large herbivores during the last decades have had a major impact on vegetation. While several studies have sought to quantify this impact in terms of plant biomass, plant survival, or financial costs, the potential benefit of using the vegetation response to changes in browsing pressure by large herbivores for monitoring their populations has been poorly investigated. Since getting accurate estimates of density in populations of large herbivores is problematic, the use of indicators measuring browsing intensity might provide a reliable alternative for managers. From the intensive monitoring of a deer population subject to an experimental manipulation of density, we aimed to assess the response of bilberry to changes in abundance of roe and red deer populations. Using a vaccinium index calculated as the difference in height between the bilberry inside cages (deer exclosures) and in open controls with data over 8 years, we found that this vaccinium index linearly increased with increasing population size of deer. This suggests that such an index might be a reliable indicator for monitoring deer populations in forests.

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