Mixed species forests
risks, resilience and management

Program and book of abstracts

Report 54, Southern Swedish Forest Research Centre

Mixed Species Forests: Risks, Resilience and Management

25-27 March 2020, Lund, Sweden

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Prof Magnus Löf, Swedish University of Agricultural Sciences (SLU), Sweden
Prof Hans Pretzsch, Technical University of Munich, Germany
Senior researcher Miren del Rio, Spanish Institute for Agriculture and Food Research and Technology (INIA)-CIFOR, Spain

Involved IUFRO units and other networks
SUMFOREST ERA-Net research project Mixed species forest management: Lowering risk, increasing resilience
IUFRO research groups 1.09.00 Ecology and silviculture of mixed forests and 7.03.00 Entomology
IUFRO working parties 1.01.06 Ecology and silviculture of oak, 1.01.10 Ecology and silviculture of pine and 8.02.01 Key factors and ecological functions for forest biodiversity

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PROGRAM: Mixed Species Forests: Risks, Resilience and Management

Wednesday 25 March 2020

7:00-08:45. Registration
08:45-09:00. Welcome speeches by Lund city council, scientific committee and REFORM

Session 1: Resistance and resilience of mixed forests following disturbances (Moderator: Miren del Rio, INIA, Spain)

09:00-09:25. **Key-note talk**: ***Having the right neighbors: how tree species diversity modulates drought impacts on forests.*** **Charlotte Grossiord**, EPFL/WSL, Switzerland.

09:25-09:45. Oral communications (10 min each)
• *Interactive effects of drought and species mixture on European beech (Fagus sylvatica) in Southeastern France*. **Soline Martin-Blangy**, INRAE, France.

• *Growth reactions of single trees to time-lagged climate effects under pure- and mixed-stand scenarios*. **Arne Nothdurft**, BOKU University, Austria.

09:45-09:55. Discussion

09:55-10:20. Oral communications (5 min each)
• *Are tree species likely to benefit from the mixture in the same way? A study of drought stress response across forest types in Europe*. **Marta Pardos**, INIA, Spain.

• *Influence of tree neighbourhood on soil characteristics, tree growth and tree growth resistance to drought*. **Xavier Serra-Maluquer**, Pirenaico de Ecología (CSIC), Spain.

• *The effect of species mixing on the drought response of Scots pine and oak (pedunculate oak, sessile oak) across Europe.* **Mathias Steckel**, TUM, Germany.

• *Facilitation of beech in mixture with silver fir turns into competition upon drought.* **Ruth Magh**, SLU, Sweden.

• *Understanding the effects of species mixing on water use and drought stress in Mediterranean forests: a modelling approach.* **Miguel De Cáceres**, FSCC, Spain.

• *Are Mediterranean pine-oak mixed stands more resistant and resilient to drought than their monospecific counterparts?* **Enrique Andivia**, University of Madrid, Spain.

10:20-10:30 Discussion

10:30-11:00. Coffee break and poster session

Session 1: (Continued) Resistance and resilience of mixed forests following disturbances (Moderator: Magnus Löf, SLU, Sweden)

11:00-11.20. **Key-note talk. *Mixing tree species to improve forest resistance to insect pests, in the context of global change.* Hervé Jactel, INRAE, France.**

11:20-11:35. Oral communications (5 min each)
• *Resistance and resilience of Engelmann spruce-Aspen forests to a spruce bark beetle epidemic*. **Mike Battaglia**, USDA-FS, USA.

• *Effects of wild ungulates on forest regeneration in mixed forest of Scots pine (Pinus sylvestris) and sessile oak (Quercus petraea).* **Nathalie Korboulewsky**, INRAE, France.

• *Study of dieback of mixed stands (Pinus halepensis and Pinus pinea) in Northern Spain by field evaluation and remote sensing*. **Carmen Romeralo**, SLU, Sweden.

11:35-11:45. Discussion

11:45-11:55. Oral communication (10 min each)
• *Temporal stability of productivity in mixed vs monospecific forest stands across Europe*. **Miren del Río**, INIA, Spain.

11:55-12:05. Oral communications (5 min each)
• *A trait based approach to elucidate the mechanisms behind diversity effects on productivity and stability in mixed-species forests*. **Florian Schnabel**, Leipzig University, Germany.

• *Managing for mixed forests: sustainable road to increased resilience?* **Floortje Vodde**, EMU, Estonia.

12:05-12:15. Discussion

12:15-13.30. Lunch

Session 2: Ecosystem services from mixed forests (Moderator: Anna Barbati, University of Tuscia)

13:30-13:55. **Key-note talk**: ***Biodiversity and ecosystem multifunctionality: which measure of multifunctionality, which species, which scale?*** **Lars Gamfeldt,** GU, Sweden.

13:55-14:25. Oral communications (10 min each)
• *Is multifunctionality greater in mixed than in pure forests? A meta-analysis of a latitudinal network of European forest triplets*. **Charlotte Poeydebat**, INRAE, France.

• *Tree species diversity and identity as drivers of soil carbon stocks in European mixed forests*. **Lars Vesterdal, KU, Denmark.**

• *Tree species identity and site conditions have stronger impact on soil organic carbon storage than species diversity in European forests*. **Richard Osei,** UCLouvain, Belgium.

14:25-14:35. Discussion

14:35-14:55. Oral communications (5 min each)
• *Identifying the tree species compositions that excel in the provision of multiple benefits.* **Jill Mayberry**, University of Aberdeen, UK.

• *Effects of spruce budworm outbreaks and suppression on carbon dynamics in forest soils.* **Michael Stastny,** Canadian Forest Service, Canada.

• *Effects of tree species mixing on ecosystem carbon and nitrogen stocks in a Swedish boreal forest*. **Róbert Blaško**, SLU, Sweden.

• *Species-specific deadwood density and its driven factors in a virgin European beech-silver fir mixed forest in the Southern Carpathians*. **Any Mary Petritan**, Brasov University, Romania.

14:55--15:05. Discussion

15:05-15:35. Coffee break and poster session

Session 2: Continued) Ecosystem services from mixed forests (Moderator: Hervé Jactel, INRAE, France)

15:35-15:55. **Key-note talk**: ***Can mixed forests play the jack-of-all-trades in ecosystem services provision?*** **Anna Barbati,** University of Tuscia, Italy.

15:55-16:15. Oral communications (10 min each)
• *Tree Species Composition and Diversity Influence Provision of Multiple Ecosystem Services in Pacific Northwest US Plantation Forests.* **Austin Himes,** Mississippi state university, USA.

• *How do sessile oak and Scots pine admixtures affect carabid beetles in the eastern part of the German lowlands?* **Alexandra Wehnert**, TU Dresden, Germany.

164:15--16:25. Discussion

16:25-16:50. Oral communications (5 min each)
• *Retaining border zones for the benefit of conservation: a case study from southern Sweden*. **Isak Lodin**, SLU, Sweden.

• *Disentangling the relationship between tree biomass yield and biodiversity in Mediterranean Mixed Forests*. **Felipe Bravo**, Universidad de Valladolid, Spain.

• *Mixture-effects on tree biomass production and soil organic C quality in a temperate plantation forest*. **Iftekhar Ahmed**, BOKU University, Austria.

• *A simulation-based study to explore the impact of climate change on pure and mixed forests across Europe.* **Xavier Morin,** CNRS, France.

• *Mixed longleaf, slash, and loblolly pine plantations in southern Georgia, USA*. **Thomas Harris,** University of Georgia, USA.

16:50-17:00 Discussion

Thursday 26 March 2020

Session 3: ***Dynamics and management of mixed forests*** *(Moderator: Hans Pretzsch, TUM, Germany)*

08:30-08:55. **Key-note talk**: ***Evidence from controlled experiments for interactions of spacing and species mix on productivity, stand dynamics and vertical structure.*** **Douglas A. Maguire, Oregon State University, USA.**

08:55-09:15. Oral communications (10 min each)
• *Gisburn mixtures experiment: a new analysis of stand dynamics for the first 25 years of the second rotation*. **Gary Kerr**, Forest Research, UK.

• *Restoring American Chestnut in Mixed-Species Forests: What Can We Learn From New Stocking Approaches?* **Mark Ducey,** University of New Hampshire, USA.

9:15-9:25. Discussion

09:25-09:45. Oral communications (5 min each)
• *Spacing effects in spruce-pine plantations: trade-offs between yield, size and damage*. **Ignacio Barbeito**, SLU, Sweden.

• *Effects of mixture forms on the early growth performance and survival of sessile oak and Scots pine in central Poland*. **Kamil Bielak**, Warsaw University of Life Sciences, Poland.

• *Mixedwoods enhance northeast British Columbia's boreal forest resilience and carbon storage in a changing climate*, **Christoffer Hawkins**, Association of Peace River Woodlots, Canada.

• *The potential of mixed plantations with local species to reforest the Sudanese area in West Africa.* **Brahima Coulibaly**, CNRA, Ivory Coast.

9:45-9:55. Discussion

09:55-10:25. Coffee break and poster session

Session 3: (Continued) ***Dynamics and management of mixed forests*** *(Moderator: Andres Bravo-Oviedo, CSIC)*

10.25-10:45. Oral communications (10 min each)
• *Mixedwood silviculture: the science and art of managing for complex, multi-species forests of eastern North America*. **Patricia Raymond**, Quebec Min Forest Wildlife & Parks, Canada.

• *Model projections of mixed-species stands for two climate scenarios in the Netherlands*. **Maike Bouwman**, Wageningen University, The Netherlands.

10:45-11:00. Oral communications (5 min each)
• *Long-term changes in tree species composition of mixed forests in Swiss natural forest reserves*, **Amanda Mathys,** WSL, Switzerland.

• *Natural diversification processes in Mediterranean forests: an analysis using forest typologies and forest inventory data*, **Lluis Coll**, University of Lleida, Spain.

• *Forecasting the future of forests and the importance of mixed stand management in the Alps under climate change*. **Marion Jourdan**, Université Paris-Saclay, France.

11:00-11:10. Discussion

11:10-11:40. Oral communications (5 min each)
• *Thinning responses of individual trees in mixed stands of Norway spruce and Scots pine*. **Silke Houtmeyers,** NMBU, Norway.

• *Simulating the effects of thinning and species mixing on stands of oak (Quercus petraea (Matt.) Liebl. / Quercus robur L.) and pine (Pinus sylvestris L.) across Europe*. **Marcus Engel**, BOKU, Austria.

• *Growth and development of young mixed Scots pine and Norway spruce stands*. **Simone Bianchi**, LUKE, Finland.

• *Approaches to restoring and regenerating shortleaf pine-oak mixedwoods in the Ozark Highlands*, USA. **Daniel C Dey**, USDA-FS, USA.

• *Management alternatives of spontaneously regenerated mixed stands of Birch and Norway spruce in Sweden*. **Felicia Lidman**, SLU, Sweden.

• *The birch-spruce mixed forest of southern Sweden in contemporary forestry*. **Emma Holmström**, SLU, Sweden.

11:40-11:50. Discussion

11:50-13.00. Lunch

13:00-18:00 FIELD TRIP TO SNOGEHOLMS LANDSCAPE LABORATORY (Busses leaves from conference venue and return by 18:00).

20:00. Social dinner

Friday 27 March 2020

Session 3: (Continued) ***Dynamics and management of mixed forests*** *(Moderator: Felipe Bravo, Universidad de Valladolid, Spain).*

08:30-08:50. **Keynote speaker**: ***Mixed-species forest stands. From understanding to design*. Hans Pretzsch, TUM, Germany.**

08:50-09:10. Oral communications (10 min each)
• *Proportion of mixture influences overyielding in a long-term nursing mixtures experiment in northern Scotland*. **Bill Mason**, Forest Research, UK.

• *Productivity-diversity relationships in mixed-hardwood plantations*. **Madeline Montague**, Purdue University, USA.

19:10-09:20 Discussion

09:20-09:40. Oral communications (5 min each)
• Tree species mixture effects on growth vary with stand density – an analysis based on *individual tree responses*. **Andreas Brunner**, NMBU, Norway.

• *Inter- and intra-specific mode of competition of Scots pine in pure and mixed stands along an environmental gradient in Europe*. **Andres Bravo-Oviedo**, CSIC, Spain.

• *Individual tree growth for coexisting Norway spruce and Scots pine as function of competition of neighboring tree species*. **Jorge Aldea**, SLU, Sweden.

• *Stand density and growth in mixed compared with monospecific stands*. **Eric A. Thurm**, LandesforstMV, Germany.

09:40--09:50 Discussion

09:50-10:20. Coffee break and poster session

Session 3: (Continued) ***Dynamics and management of mixed forests*** *(Moderator: Emma Holmström, SLU, Sweden).*

10.20-10:40. Oral communications (10 min each)
• *Mixture effects on Scots pine and Norway spruce productivity along a climatic gradient in Europe.* **Ricardo Ruiz-Peinado**, INIA, Spain.

• *Effects of tree diversity, fine-root traits and (micro-) climate on the decomposition of absorptive fine roots of 13 European tree species*. **Janna Wambsganss**, University of Freiburg, Germany.

10:40-11:10. Oral communications (5 min each)
• Tree mixture modify the nutrient cycling: evidence from foliar diagnosis and litterfall in oak-*pine stands?* **Nathalie Korboulewsky**, INRAE, France.

• *Facilitation and competition in regeneration in mixed-conifer forests of the southern and central Rocky Mountains*. **Keith W. Moser**, USDA-FS, USA.

• *Effect of spatial distribution on forest growth as function of species composition in Fagus sylvatica (L.) mountain forests across Europe*. **Giustino Tonon**, Free University of Bolzano, Italy.

10:40-11:10. Oral communications (5 min each, Continued)
• *Admixing other tree species to European beech forests: Effects on soil organic carbon and total nitrogen stocks. A review*. **Stephanie Rehschuh**, Karlsruhe Institute of Technology, Germany.

• *Spatial nitrogen and water uptake strategies of mature Norway spruce and Scots pine in monocultures and in the two species mixed stands*. **Reimo Lutter**, SLU, Sweden.

• *Mixing has limited impacts on the foliar nutrition of European beech and Scots pine trees across Europe*. **Géraud deStreel**, UCLouvain, Belgium.

11:10-11:20. Discussion

*Session 4**: Mixed forests and policy aspects** (Moderator: Miren del Rio, INIA, Spain).*

11:20-11:45. **Keynote speaker. *Mixed forests in the EU Forest Strategy and under the Common Agricultural Policy.* Tamas Szedlak**, European Commission, Belgium.

11:45-11:55. Oral communications (10 min each)
• *Landscape restoration for mixed forests: key strategies for navigating the constraints and opportunities of multi-scale forest governance and management*. **Lucas Dawson**, SLU, Sweden.

11:55-12:05. Discussion

12:05-13.20. Lunch

*Session 4**: (Continued) Mixed forests and policy aspects** (Moderator: Miren del Rio, INIA, Spain)*

13:20-13:30. Oral communications (10 min each, Continued)
• Foresight studies as a tool to estimate future impacts of forest pests and diseases. **Johanna Witzell**, SLU, Sweden.

13:30-13:45. Oral communications (5 min each)
• *Are mixtures a good option to reduce drought-induced risk of forest decline? Carbon accounting and economic approach*. **Sandrine Brèteau-Amores**, INRAE, France.

• *Forest Development Types: defining a useful concept for the design and management of site adapted mixed species stands in Britain*. **Jens Haufe**, Forest Research, UK.

• *Long-term development of spruce-birch mixed stand on drained peat soil and its carbon pools*. **Janis Vuguls**, LSFRI SILAVA, Latvia.

13:45:13:55. Discussion

13:55-14:40. Concluding remarks and discussion

Departure

Session 1: Resistance and resilience of mixed forests following disturbances

Key-note talk: Charlotte GROSSIORD, Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf, Switzerland.

Having the right neighbors: how tree species diversity modulates drought impacts on forests

Droughts are expected to set in more rapidly, last longer and be more intense with global warming. Because of rising concerns associated with the recent drought-induced reductions in forest growth and survival, mitigation processes that buffer forest drought vulnerability have become a major research frontier in ecology, ecophysiology and forest management. Yet, while knowledge on fine-grained physiological responses to drought is continuously progressing and contributing to improved predictions, the vast majority of empirical studies and climate-vegetation models do not account for community-level processes that could mediate drought impacts on individual trees and on a forest as a whole. Biodiversity has long been acknowledged as an important component modulating ecosystem functions, including mitigating their vulnerability to climate-related stresses. Yet the impact of tree diversity on forest vulnerability to drought is unclear. In this presentation, I identify consistent mechanisms by which tree diversity could reduce vulnerability to drought and reveal evidence that tree diversity is not systematically positively related to drought resistance in forests. I then suggest a path to further increase our knowledge on this subject in the face of climate change, proposing a standardization of methods to quantitatively establish diversity impacts on the drought-resistance of forests.

How does global warming affect plants - and thus the important functions and services provided for humans by ecosystems? Charlotte Grossiord, an ecophysiologist at EPFL/WSL, has been investigating this question throughout her entire scientific career. Her research spans from biodiversity impacts on ecosystem functioning to understanding climate impacts on survival and mortality of trees. Charlotte's research has made great steps forward in our understanding of plant survival under extreme conditions and on the significance of species interactions in forests. In her doctorate at Lorraine University and INRA-Nancy in France, she explored how tree species diversity affects the water and carbon balance of trees. She focused in particular on the resistance of plants to extreme events. In her PostDoc at the Los Alamos National Laboratory in the USA, Grossiord investigated how forests adapt to the exacerbation of droughts with higher temperature. To continue and expand her research on these topics, EPFL and WSL have jointly appointed her tenure-track assistant professor in September 2019.

Interactive effects of drought and species mixture on European beech (*Fagus sylvatica*) in Southeastern France.

Soline Martin-Blangy[1], Marie Charru[2], Sylvain Gérard[1], Nicolas Angeli[1], Christian Hossann[1], Loïc Louis[1], Hervé Jactel[3], Marion Jourdan[4], Xavier Morin[4], Damien Bonal[1]

[1] INRA, Université de Lorraine, AgroParisTech, Silva UMR 1434, Nancy, France
[2] Bordeaux Sciences Agro, INRA, ISPA UMR 1391, Gradignan, France
[3] INRA, Université de Bordeaux, BIOGECO UMR 1202, Cestas, France
[4] CNRS, Université de Montpellier, Université Paul-Valéry, EPHE, CEFE UMR 5175, Montpellier, France

Tree species mixtures may improve productivity of temperate forests (Ammer 2019). However, in the context of climate change, it remains unclear whether mixed-species forests will help mitigate impacts of droughts and, if so, through which belowground and aboveground mechanisms (Grossiord 2019). This study aims to characterize (i) the interactive effects of drought and tree species interactions on European beech (*Fagus sylvatica*) in Southeastern France and (ii) whether belowground complementarity underlies these effects.
We focused on beech-silver fir (*Abies alba*) and beech-pubescent oak (*Quercus pubescens*) natural forests in the French Alps (Jourdan et al. 2019). We used a triplet approach across five sites to compare traits in pure and two-species stands. We estimated drought exposition levels of individual trees using differences in tree-ring carbon isotope composition ($\delta^{13}C$) between dry and wet years (Grossiord et al. 2014) and water extraction depth using stable isotopes in xylem and soil water. There was an effect of drought on beech $\delta^{13}C$ at most sites. Beech tended to be more exposed to drought when mixed with fir, and less exposed to drought when mixed with oak, as compared to pure stands. We evidenced differences in water extraction depth between beech and fir, but not between beech and oak.
Our results suggest positive effects of tree species mixture on drought exposition of beech in drier sites – with oak, and negative effects in wetter sites – with fir. Belowground interactions between the species could explain these patterns.

Selected references

Ammer, C. (2019). Diversity and forest productivity in a changing climate.N ew Phytol., 221, 50–66.

Grossiord, C. (2019). Having the right neighbors: how tree species diversity modulates drought impacts on forestsN. ew Phytol.

Grossiord, C., Granier, A., Ratcliffe, S., Bouriaud, O., Bruelheide, H., Checko, E.,e t al. (2014). Tree diversity does not always improve resistance of forest ecosystems to drought. Proc. Natl. Acad. Sci., 111, 14812–14815.

Jourdan, M., Lebourgeois, F. & Morin, X. (2019). The effect of tree diversity on the resistance and recovery of forest stands in the French Alps may depend on species differences in hydraulic features. For. Ecol. Manage., 450, 117486.

Growth reactions of single trees to time-lagged climate effects under pure- and mixed-stand scenarios

Arne Nothdurft[1], Markus Engel[1]

[1] University of Natural Resources and Life Sciences Vienna (BOKU), Department of Forestand Soil Science, Institute of Forest Growth

Major goals of the study are to quantify the growth reactions of single trees to climate conditions in the past and to reveal possible differences in these effects between pure- and mixed-stand scenarios. The study uses tree-ring width measurements from Austrian longterm monitoring plots, which were installed within the SUMFOREST ERA-Net project “REFORM-Mixed species forest management: Lowering risk, increasing resilience”. A novel inferential technique of distributed lag-models demonstrated in Nothdurft & Engel (2019) and Nothdurft & Vospernik (2018) enables simultaneous trend elimination and regression modeling of radial stem growth. Past climate conditions are expressed by time-lagged sequences of monthly precipitation sums and monthly average temperatures. Inference on the relationship between single-tree productivity rates and the time-lagged climate effects is approached through a frequentist as well as a Bayesian setting. Model predictions and credible intervals are finally used to quantify the sensitivity of single trees to possible climate fluctuations as well as to assess trees’ resistance capacity against unfavourable climate conditions, especially in terms of drought periods. Measures of both climate sensitivity and resistance are compared between pure- and mixed-stand scenarios and among the mixture types oak-pine, beech-spruce, beech-larch, spruce-larch, and spruce-pine.

Selected references

Nothdurft A. & Engel M. (2019) Climate sensitivity and resistance under pure-and mixed-stand scenarios in Lower Austria evaluated with distributed lag models and penalized regression splines for tree-ring time series. European Journal of Forest Research. https://doi.org/10.1007/s10342-019-01234-x

Nothdurft A. & Vospernik S. (2018) Climate-sensitive radial increment model of Norway spruce in Tyrol based on a distributed lag model with penalized splines for year-ring time series. Canadian Journal of Forest Research, 48(8): 930–941. https://doi.org/10.1139/cjfr-2018-0027

Are tree species likely to benefit from the mixture in the same way? A study of drought stress response across forest types in Europe

Marta PARDOS[1], Rafael Calama[1], Ricardo Ruiz-Peinado[1], Jorge Aldea[2], Hans Pretzsch[3], Enno Uhl[3], Antonio Tomao[4], Loredana Oreti[4], Felipe Bravo[5], Arne Nothdurft[6], Markus Engel[6], Xavier Morin[7], Aris Jansons[8], Gediminas Brazaitis[9], Kšištof Godvod[9], Quentin Ponette[10], Kristoffel Jacobs[10], Herve Jactel[11], Miren del Río[1]

[1] INIA-CIFOR. Spain
[2] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Sweden.
[3]Technical University of Munich, Germany
[4] Department for Innovation in Biological, Agro-food and Forest systems DIBAF – University of Tuscia, Italy
[5] ETS Ingenierías Agrarias Universidad de Valladolid, Spain
[6] University of Natural Resources and Life Sciences, Vienna Department of Forest- and Soil Sciences Institute of Forest Growth, Austria
[7] CNRS Team FORECAST & Responsable Plateforme SIE Centre d'Ecologie Fonctionnelle et Evolutive (CEFE),France
[8] Latvian State Forest Research Institute "Silava", Department of Forest Tree Breeding, Latvia
[9] Institute of forest Biology and Silviculture, Faculty of Forest Science and Ecology Vytautas Magnus University Agricultural Academy, Lithuania
[10] Université Catholique de Louvain - UCLouvain , Belgium
[11] Biodiversité, Gènes et Communautés (BioGeCo), INRA Paris, France

Due to possible species complementarity, mixed stands are reported to be more productive and less vulnerable than pure stands for many forest biomes. Under the increased intensity and frequency of drought events predicted by IPCC scenarios, mixing would be a sound management strategy to increase the resistance and resilience of forests. However, only a limited number of species combinations have been studied in detail, revealing variable mixing effects. In this study, we analysed how tree resistance, recovery and resilience to specific drought events are modulated by species mixture. We test whether the relationship between drought stress and tree diversity would be consistent across a range of climatic and ecological conditions. We hypothesize that the reduced risks in mixed stands arising from drought events will be determined by species mixture. We focused on tree species of four different forest types found across Europe: (1)hemiboreal forests and broadleaved-coniferous forests, (2)alpine coniferous forests, (3)mountainous beech forests, and (4)broadleaved evergreen forest and coniferous forests of the Mediterranean. We analysed increment cores of the common tree species in each forest type and sampled both mixed and pure stands. We used dendrochronological techniques to estimate resistance, recovery and resilience indices during the drought events identified between 1980 and 2017. We found that higher diversity enhanced higher ability to cope drought depending on the forest type and biogeographical region. The explanatory power of the drought indices differed across the drought events, with a cumulative drought effect after successive drought episodes that suggest an increased vulnerability to drought.

Selected references

Grossiord et al. 2014. Tree diversity does not always improve resistance of forest ecosystems to drought. PNAs 111 (41)

Jucker et al. 2016. Climate modulates the effects of tree diversity on forest productivity. J. Ecol 104, 388-398

Serra-Maluquer et al. 2018 Changes in tree resistance, recovery and resilience across three succesive extreme droughts in the northeast Iberian Peninsula. Oecologia 187

Thurm et al. 2016. Mixture reduces climate sensitivity of Douglas for stem growth. For Ecol Manag 376

Influence of tree neighbourhood on soil characteristics, tree growth and tree growth resistance to drought.

Xavier Serra-Maluquer[1], Antonio Gazol[1], José M. Igual[2], J.Julio Camarero[1]

[1] Instituto Pirenaico de Ecología (IPE-CSIC), Avda. Montañana 1005, Zaragoza 5009, 8 Spain
[2] Instituto de Recursos Naturales y Agrobiología de Salamanca (IRNASA-CSIC), C. Cordel 13 de Merinas 40-52, Salamanca 37008, Spain.

Effects of tree diversity on productivity and resilience to extreme events of temperate mixed forests are complex and not always fully understood. Furthermore, tree to tree interactions can vary depending on several factors (climate, soil conditions, species composition, etc). In this study we evaluate how soil characteristics (biotic and abiotic), tree growth performance and resilience to drought are affected by tree neighbourhood. Three mixed forests dominated by silver fir and with presence of Scots pine and European beech were sampled. In each forest cores were obtained for 30 focal silver fir trees. Furthermore, soil physico-chemical properties and PhosphoLipids Fatty Acid (PLFA) profiles were done to characterize soil abiotic and biotic conditions under each focal tree. Finally, the neighbourhood of each focal tree was described. Variation of growth (BAI, 30-year basal area increment), soil chemical properties and PLFA structure were evaluated as a function of dominant neighbour (silver fir, Scots pine or broadleaved species). Furthermore, soil chemical properties, soil PLFA, neighbourhood diversity (Shannon diversity index; H), tree size and tree competitive status were used to evaluate long term BAI and drought resistance, recovery and resilience to drought. Differences on BAI and PLFA structure depending on neighbourhood identity were found. However, such differences varied between sites and across time in the case of BAI. Furthermore, we found a positive relationship between neighbourhood H index and tree resistance to drought. Our results indicate that while neighbourhood identity influences soil biotic characteristics and tree growth, neighbourhood diversity may buffer growth reductions during drought.

The effect of species mixing on the drought response of Scots pine and oak (pedunculate oak, sessile oak) across Europe

Mathias Steckel[1], Hans Pretzsch[1]

[1] Chair of Forest Growth and Yield Science, TUM School of Life Sciences Weihenstephan, Technical University of Munich

Extreme climate events, such as severe droughts, have increased in frequency and intensity in many regions, often with detrimental effects on tree and forest growth and health. In this context, the mixing of tree species has been widely promoted as a promising silvicultural option to mitigate adverse effects associated with climate change. However, only a limited number of species mixtures have so far been studied in detail, revealing a great variety of results, far away from consistent reaction patterns. In this study we focused on one of the most important naturally occuring forest mixtures in Europe, Scots pine and oak (pedunculate oak, seessile oak), with the objective to improve the knowledge regarding tree growth responses under drought in mixed versus monospecific stands and to identify general response patterns that facilitate forecasting and management of mixed forests. Based on increment cores of both species, sampled in mixed and monospecific stands, covering different site conditions across Europe, we investigated tree-level growth responses to drought (resistance, recovery and resilience) involving selected periodic drought events. Our findings constitute a stable knowledge base on how Scots pine and oak react to periodic drought stress under different competitive environments (intraspecific versus interspecific competition) along varying ecological growing conditions across Europe. The results provide support for species mixing as a valid management option to reduce the drought vulnerability of European forest ecosystems and highlight the opportunities and limitations associated with the ecological concept of complementarity.

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Facilitation of beech in mixture with silver fir turns into competition upon drought

Ruth-Kristina Magh[1,2], Stephanie Rehschuh[3], Michael Dannenmann[3], Maren Dubbert[4], Heinz Rennenberg[2]

[1] Department of Forest Ecology. Swedish University of Agricultural Sciences, Umeå, Sweden
[2] Department of Tree Physiology, University of Freiburg, Freiburg, Germany
[3] Karlsruher Institute of Technology, Garmisch-Partenkirchen, Germany
[4] Department of Ecosystemphysiology, University of Freiburg, Germany

In the context of climate change, it was suggested to replace monocultures with mixed forest, to increase resistance and resilience by increasing species diversity. In Central Europe, beech constitutes an important deciduous tree species, but is characterized as drought sensitive. Since the future performance of beech is under debate, the cultivation of beech mixed with silver fir has recently received attention since both species are native to Europe. Fir is described as less drought sensitive because of a more isohydric water use strategy, and its taproot system. Thus, the admixture effect of fir on beech in mixed stands has been investigated considering water relations at stand level. The results revealed a facilitative effect of fir on water relations of beech at times of sufficient water supply.
During drought beech trees at the pure and mixed stands still revealed a more anisohydric behavior, until soil water availability became limiting, causing transpiration to decrease severely. Firs did not reduce transpiration, likely due to their access to moister soil layers, thereby outcompeting beech for water in the mixed stands. While beeches in monoculture recovered from reduced transpiration rates within a few days after rewetting of the soil, transpiration rates of beech at the mixed stand remained decreased, probably due to cavitation and reduced hydraulic conductivity of its root system. It was shown that drought can turn facilitation into competition for water, and forest management should promote this species mixture solely at sites that are able to support the high transpiration demand of beech.

Understanding the effects of species mixing on water use and drought stress in Mediterranean forests: a modelling approach

Miquel De Cáceres[1, 2], Jordi Martínez-Vilalta[2, 3], Maurizio Mencuccini[2, 4], Rafael Poyatos[2], Antoine Cabon[1], Víctor Granda[2], Lluís Coll[1, 5], Jean-Marc Limousin[6], Nicolas Martin-StPaul[7], Alicia Forner[8], Fernando Valladares[8, 9]

[1] Joint Research Unit CTFC – AGROTECNIO, Crta. de St. Llorenç de Morunys, km 2, E- 25280, Solsona, Spain
[2] Centre for Ecological Research and Forestry Applications (CREAF), Cerdanyola del Valles, Spain
[3] Universitat Autònoma de Barcelona, Cerdanyola del Vallès, 08193, Spain
[4] ICREA, Pg. Lluís Companys 23, 08010 Barcelona, Spain
[5] Department of Agriculture and Forest Engineering (EAGROF), University of Lleida, Lleida, Spain
[6] CEFE UMR 5175, CNRS, Univ Montpellier, Univ Paul Valéry Montpellier 3, EPHE, IRD, F- 34293 Montpellier, France
[7] URFM, INRA, 84000, Avignon,France
[8] LINC-Global, Museo Nacional de Ciencias Naturales (MNCN, CSIC), E-28006 Madrid, Spain
[9] Departamento de Biología y Geología, Universidad Rey Juan Carlos, E-28933 Móstoles, Spain

Predicting how forest water use and drought stress change in relation to tree species composition is critical to anticipate forest responses to climate change. Species mixing effects on forest water balance can be tested in experimental plantations, by comparing pure and mixed stands in similar conditions or mixed stands under different conditions. Empirical studies have shown that the effects of mixing on water use and drought stress are dependent on species combinations, stand structures and environmental conditions. A complementary approach is to use model simulations to: (1) systematically examine the effect of differences in specific plant traits; and (2) interpret the net effect of species mixing as a result of differences in multiple traits. Here we use a process-based forest ecosystem model designed to study water relations in forest stands to evaluate how species mixing affects water use and drought stress in Mediterranean forests co-dominated by holm oak (*Quercus ilex* L.). Sensitivity analyses focusing on individual traits show that water use and summer drought stress respond critically to differences in plant height, root distribution, hydraulic efficiency and vulnerability. The comparison of simulations results on pure stands with those on species mixtures indicate that complex mixing effects can arise as a result of the combination of trait differences between the co-occurring species, and that differences in one trait may decrease (or override) the effect of differences in another. Despite their limitations, mechanistic forest ecosystem models are valuable tools to evaluate the consequences of alternative mixtures on drought responses in water-limited ecosystems.

Are Mediterranean pine-oak mixed stands more resistant and resilient to drought than their monospecific counterparts?

Francisco Muñoz-Gálvez[1], Asier Herrero[2], Esther Pérez-Corona[1], **Enrique Andivia**[1]

[1] Department of Biodiversity, Ecology and Evolution, Complutense University of Madrid, Madrid, Spain.
[2] Forest Ecology and Restoration Group, Department of Life Sciences, University of Alcala, Alcalá de Henares, Spain.

Climate change projections point to an increase in the intensity and frequency of extreme drought events with important negative impacts on forest functioning especially in drought prone areas. Anticipating these impacts constitutes a crucial challenge for forest managers and for the maintenance of ecosystem services supply. In this context, promoting mixed stands seems a promising strategy for decreasing risk and enhancing long-term resilience. However, some uncertainty exists regarding whether mixed stands can improve forest stability to drought events. Here, we aim to assess tree growth response to drought in mixed and monospecific stands of *Pinus sylvestris* L. and *Quercus pyrenaica* Willd. In central Spain. For this, we built tree-ring chronologies and evaluated tree growth sensitivity to water availability, and resistance and resilience to extreme drought events using linear mixed models. We found contrasting species responses to admixture. Oak growth was significantly higher in mixed than in monospecific stands, especially in years without water limitations. Pines showed higher growth in mixed stands but only under dry conditions. Regarding growth stability, pines showed higher resistance to drought in mixed than monospecific stands whereas oaks were more resistant in monospecific stands. We did not find significant differences in resilience between forest types. Our results suggest that tree growth is enhanced in mixed stands compared to monospecific counterparts, yet growth resistance to drought is species-specific. Thus, whereas pine is favoured in mixed stands because of higher growth and drought resistance, oak performance could be determined by the trade-off between growth rate and resistance to drought.

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Session 1: Resistance and resilience of mixed forests following disturbances

Key-note talk: Hervé JACTEL, Biodiversité, Gènes et Communautés (BIOGECO) – INRA, France

Mixing tree species to improve forest resistance to insect pests, in the context of global change

The health of the world's forests is increasingly threatened by damages caused by insect pests, which are increasing due to climate change and biological invasions. At the same time, the use of insecticides is being phased out in many European forests under public pressure. There is therefore an urgent need to develop nature-based solutions for the protection of forest ecosystems. Empirical and experimental evidence has accumulated over the past 20 years on the effect of tree species diversity on forest resistance to insect herbivores. We retrieved these published data to conduct a new meta-analysis, based on the examination of more than 600 cases worldwide, to test the concept of associational resistance. The results of this updated quantitative review will be used to discuss the main ecological mechanisms that might explain why mixed forests are less vulnerable to damage by insect pests than tree monocultures. Possible interactions between the effect of forest diversity and climate change on pest population dynamics will also be addressed. Based on these findings, we will propose ways of adapting forest management to prevent emerging biotic risks and thus improve the resilience of managed forests.

Hervé Jactel is a Senior Scientist at the French National Institute for Agricultural Research. He graduated as an agronomist from AgroParisTech, obtained a PhD in Forest Entomology and a habilitation thesis to supervise research in Forest Ecology.

His main topic of research is on biodiversity and forest ecosystem functioning, with a special focus on pest insect regulation. He also works on biodiversity conservation in planted forests and develops methods in forest risk analysis, investigating effects of global change.

He is currently coordinating the HOMED project (Horizon 2020, http://homed-project.eu/) which aims to develop a full panel of scientific knowledge and practical solutions for the management of emerging native and non-native pests and pathogens threatening European forests.

In addition, Hervé has the role of expert at the French Agency for Food, Environmental and Occupational Health and Safety (ANSES). He is deputy coordinator of the IUFRO Research Group on Forest Entomology (7.03.00). He is member of the scientific committee of the French Foundation for Biodiversity Research. He is member of the French Academy of Agriculture.

Resistance and resilience of Engelmann spruce-Aspen forests to a spruce bark beetle epidemic

Mike Battaglia[1], Jason Sibold[2], Kevin Barrett[3], Antony Cheng[3]

[1] USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA
[2] Colorado State University, Department of Anthropology, Fort Collins, CO, USA
[3] Colorado State University, Colorado Forest Restoration Institute, Fort Collins, CO, USA

Over the last decade, Engelmann spruce (*Picea engelmanni*) forests in Colorado, USA have been impacted by the spruce bark beetle resulting in high levels of tree mortality. In response to this mortality, salvage logging to recover some of merchantable material has been proposed. We quantified how the spruce bark beetle epidemic initially impacted spruce-dominated forest structure and regeneration in unmanaged areas and areas previously harvested in the late 1980's. In spruce-dominated forests, mortality in unmanaged and previously harvested stands exceeded 95% of tree basal area but only 60% to 70% of the trees per hectare. Much of the living trees were small diameter spruce or aspen (*Populus tremuloides*) that were not susceptible to spruce beetle. Areas that were previously harvested had higher density of advanced spruce regeneration. However, both unmanaged and previously harvested areas had abundant post-beetle spruce regeneration. In spruce-aspen mixed stands, tree mortality for both unmanaged and previously harvested stands was about 50% based on basal area and trees per hectare. However, basal area remained higher with more trees per hectare in the previously managed stands. Furthermore, advanced regeneration of spruce in previously harvested was greater than that found in unmanaged stands. Results from this research continues to provide data and input to an adaptive management framework intended to inform management actions in both forest types across National Forests in Colorado.

Effects of wild ungulates on forest regeneration in mixed forest of Scots pine (*Pinus sylvestris*) and sessile oak (*Quercus petraea*).

Laura Chevaux[1], Nathalie Korboulewsky[1], Jean-Pierre Hamard[1], Philippe Balandier[1], Anders Mårell[1]

[1] Irstea, UR EFNO, Nogent-sur-Vernisson, Domaine des Barres, 45290 Nogent-sur- Vernisson, France

Wild ungulates, sometimes referred as ecosystem engineers, are key components of the forest ecosystem. They can modify plant communities and plant-plant interactions down to the lowest strata, including forest regeneration. Several types of behaviour can affect forest regeneration: herbivory, rubbing or trampling. The effects of ungulates on forest regeneration, mainly herbivory, have frequently been studied in overabundance conditions and in monospecific stands. However, studies on the effects of ungulates in mixed deciduous-coniferous forest in temperate zones are rather rare. We are trying to evaluate the effects of ungulates on growth and seedling survival of the two species of interest. With this in mind, we monitored regeneration at the OPTMix experimental site in mixed Scots pine (*Pinus sylvestris*) and sessile oak (*Quercus petraea*) forest. The ungulates present in the forest where the experimental site is located are red deer (*Cervus elaphus*), deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*). We worked on an exclosure system in three different conditions: pure oak, pure pine, mixed stand. In total, we have been monitoring regeneration since 2014 on 18 different plots, representing 360 plots. On all plots, corresponding to a circle with a radius of two metres, we counted all seedlings, and we marked and measured all individuals over 20cm to monitor their growth. We also described the health status of seedlings over 20cm.

Study of dieback of mixed stands (*Pinus halepensis* and *Pinus pinea*) in Northern Spain by field evaluation and remote sensing

Carmen Romeralo[1,2], Chantal Côté[3], Gaston Laflamme[3], Vanessa Paredes[4], Oscar Santamaría[5], Julio Javier Diez[2]

[1] Southern Sweden Forest Research Center, SLU, PO Box 49, SE-230 53 Alnarp, Sweden.
[2] Sustainable Forest Management Research Institute, University of Valladolid-INIA, Avda. Madrid 44, Building E, 34004, Palencia, Spain.
[3] Laurentian Forestry Centre, Natural Resources Canada, 1055 Rue du P.E.P.S., G1V 4C7, Quebec, QC, Canada
[4] Instituto Tecnológico Agrario de Castilla y León (ITACyL), Finca Zamadueñas, Ctra. De Burgos Km 119, Valladolid, España.
[5] Instituto Universitario de Investigación de la Dehesa (INDEHESA), Universidad de Extremadura. Avda. Adolfo Suárez, s/n. 06007 Badajoz, España.

Gremmeniella abietina is a pathogenic fungus that causes severe damage to coniferous forests in the northern hemisphere. In Spain, it was isolated in 2001 from symptomatic trees of Aleppo pine (*P.halepensis*). In that year, 36 mixed stands of *P.halepensis* and *P.pinea* were evaluated around the detection zone to determine the distribution of the pathogen. Fruiting bodies of the pathogen were found in 5 plots although 25 additional plots presented typical infection symptoms. In 2012, the same stands were reviewed again but in addition to visual and field inspection, samples were brought to the laboratory to detect by molecular procedures the presence of *G.abietina* in symptomatic plant samples. Finally, to test if the use of vegetation indices could be a good estimate of the phytosanitary status in our stands, the standardized vegetation index (NDVI) of Landsat images was calculated and compared with the field data. We found fruiting bodies in 3 of the 36 plots sampled, while the laboratory results showed the presence of DNA of the pathogen in 10 plots. In addition, satellite images were generated for the NDVI for the stands of study and it was observed that vegetation indices showed a good correlation with the defoliation but not with the presence of the pathogen. Defoliation and presence of the pathogen were not dependent on whether the stands were pure or mixed. Most of the stands showed symptoms of decay, suggesting other possible factors or the combination of several, as responsible for these symptoms.

Temporal stability of productivity in mixed vs monospecific forest stands across Europe

Miren Del Rio[1, 2], Hans Pretzsch[3], Magnus Löf[4], Michael Heym[3], Ricardo Ruiz-Peinad[1, 2], Arne Nothdurft[5], Quentine Ponette[6], Jakub Cerný[7], Miroslav Svoboba[8], Thomas Lardson[9], Nathalie Korboulewsky[10], Catherine Collet[11], Marek Metslaid[12], Lars Droessler[13], Christian Ammer[14], Barbara Wolff[15], Mathias Steckel[3], Aris Janson[16], Gediminas Brazaitis[17], Aksel Granhus[18], Maciej Pach[19], Kamil Bielak[20], Roman Sitko[21], Rafael Calama[1, 2], Felipe Bravo[2, 22], Lluís Coll[23], Stig-Olof Holm[24], Ignacio Barbeito[4], Hervé Jactel[25]

[1] Spanish Institute for Agriculture and Food Research and Technology (INIA)-CIFOR, Spain
[2] Sustainable Forestry Management Research Institute (iuFOR) UVa-INIA, Spain
[3] Technical University of Munich (TUM), Germany
[4] Swedish University of Agricultural Sciences (SLU), Sweden
[5] University of Natural Resources and Life Sciences (BOKU), Austria
[6] Université catholique de Louvain (UCL), Belgium
[7] Forestry and Game Management Research Institute (FGMRI), Czech Republic
[8] Czech Univeristy of Life Sciences (CZU), Czech Republic
[9] University of Copenhagen (KU), Denmark
[10] Institut national de Recherche en Sciences et technologies pour l'Environnement et l'Agriculture (IRSTEA), France
[11] Université de Lorraine, AgroParisTech, (INRA), France
[12] Estonian university of Life Sciences (EMU), Estonia
[13] Ilia State University (USI), Georgia
[14] Georg-August-Universität Göttingen (GAU), Germany
[15] Eberswalde University for Sustainable Development (HNEE), Germany
[16] Latvian State Forest Research Institute (SILAVA), Latvia
[17] Vytautas Magnus University Agriculture Academy (VDU), Lithuania
[18] Norwegian Institute of Bioeconomy Reseach (NIBIO), Norway
[19] University of Agriculture in Krakow (UAK), Poland
[20] University of Life Sciences (SGGW), Poland
[21] Technical University Zvolen (TUZVO), Slovakia
[22] University of Valladolid (UVa), Spain
[23] University of Lleida (UdL), Spain
[24] Umeå University (UMU), Sweden
[25] UMR BIOGECO – INRA, France

Species diversity had been found to increase temporal stability of productivity in plant communities, although there are still few studies in forest ecosystems. The main drivers of species diversity stabilising effect are species asynchrony, overyielding, and species interactions, which are inter-related among them. In this study we investigate the temporal stability of productivity in mixed vs monospecific forest stands along Europe and explore the role of the different drivers. The analysis was based on three triplets-transects of mixtures of *Pinus sylvestris* L. with species of different functional traits (*Picea abies* (L.) Karst, *Fagus sylvatica* L and *Quercus petraea* (Matts.) Liebl.), established along Europe. There are a total of 88 triplets and 264 plots (one triplet includes one mixed plot and two monospecific plots of the component species). Stand basal area increment was used a proxy of forest productivity. Annual basal area increments by plot were reconstructed from forest inventory data and tree ring analyses for a 15-year period, and were used to estimate temporal stability, overyielding and species asynchrony. Species composition influenced on temporal stability of productivity, resulting in greater or similar stability in mixed than in monospecific stand depending on the mixture and the reference monospecific stand. Inter-specific asynchrony in growth was related to temporal stability, although there was a great variability along the transects. Our findings corroborate the relevance of mixing species to reduce forest vulnerability to climate change. The implications for adapting forest management to future climate conditions were further discussed.

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A trait based approach to elucidate the mechanisms behind diversity effects on productivity and stability in mixed-species forests

Florian Schnabel[1,2], Kathryn E. Barry[1,2], Helge Bruelheide[1,3], Andreas Fichtner[4], Werner Härdtle[4], Goddert von Oheimb[1,5], Julia A. Schwarz[6], Jürgen Bauhus[6], Christian Wirth[1,2]

[1] German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig, Germany
[2] Systematic Botany and Functional Biodiversity, Leipzig University, Leipzig, Germany
[3] Institute of Biology/Geobotany and Botanical Garden, Martin Luther University Halle- Wittenberg, Halle (Saale), Germany
[4] Leuphana University of Lüneburg, Institute of Ecology, Lüneburg, Germany
[5] Technical University Dresden, Institute of General Ecology and Environmental Protection, Tharandt, Germany
[6] Chair of Silviculture, Institute of Forest Sciences, Freiburg University, Freiburg, Germany

There is increasing evidence from natural forests and tree diversity experiments that mixing tree species can increase productivity and its temporal stability in forest stands[1-4]. However, underlying mechanisms and species traits that drive these observed diversity-productivity and diversity-stability relationships are still poorly understood. In particular, we lack an understanding of how to design productive and stable forest stands based on species properties under climatic change. Here, we use data from a large-scale tree diversity experiment in subtropical China[5] to understand which traits of species and mixtures drive observed diversity effects on productivity and stability. We based our analysis on two trait gradients related to (1) the leaf economics spectrum (LES) and drought resistance (resistance to cavitation) and (2) water use strategies in terms of stomata control. We hypothesize that mixtures consisting of species with contrasting drought resistance and water use strategies may have increased productivity during drought and a higher temporal stability of productivity. Preliminary results from our experimental site point in this direction as these show positive effects of tree species richness on tree growth during drought. This stability-focused analysis, however, cannot explain mechanisms related to above-ground competition for light as a principle driver of diversity-productivity relationships in species mixtures. Modelling size asymmetric competition between trees in response to neighbourhood diversity in traits of the leaf economics spectrum could be used to elucidate levels of trait dissimilarity that maximize overyielding in mixed stands.

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Managing for mixed forests: sustainable road to increased resilience?

Floortje Vodde[1], Kalev Jõgiste[1], Jeroen Engelhart[1], Raul Rosenvald[1]

[1] Chair of Silviculture and Forest Ecology, University of Life Sciences, Tartu, Estonia

The relatively new concept of resilience in forest ecology is often described as consisting of two components. The first is the resistance of forest – or the immediate response – to disturbance: which trees, stands go down or are otherwise damaged, what share of the stand appears undamaged. The second component is the capacity of the forest to recover to pre-disturbance levels of functioning or composition, also defined as the intermediate to long-term effect. The main perception, in line with the insurance hypothesis, is that forests with a high number of species are better able to spread the risk. Increasing the species numbers also enables to come closer to the indigenous species composition. The species are affected differently and they have different life history strategies, which increases the range of potential responses after a disturbance. In this sense, managing for and restoring mixed-species forests offers benefits both from economic and ecological perspectives.

We support the pros and cons of mixed forests with a literature review and analysis of the Estonian digital forest database. The latter was used for testing the effects of tree species composition, overall species richness, tree diameter, height and age distribution on occurrence, type, severity and size of disturbances (resistance – both in natural and managed stands) and the post-disturbance successional pathways (recovery capacity – in natural stands). In general, stand heterogeneity is positively correlated with resistance to natural disturbances. However, natural recovery capacity should be studied across disciplines by e.g. tree ring analysis, on-ground species composition assessment and modelling.

What are the impacts of mixed species forests on pathogen outbreaks? A systematic review and meta-analysis

Elsa Field[1], Andrew Hector[1], Gilian Petrokofsky[2], Julia Koricheva[3]

[1] Plant Ecology Lab, Department of Plant Sciences, University of Oxford, Oxford, UK
[2] Long Term Ecology Lab, Department of Zoology, University of Oxford, Oxford, UK
[3] Department of Biological Sciences, Royal Holloway University of London, Egham, Surrey

The impacts of forest pathogens on tree health are on the increase as a result of increasing trade globalisation and anthropogenically driven environmental change. Diversifying planted forests to reduce natural disturbances, such as pathogen outbreaks, is a major theme in sustainable forest management. For forest insects, previous meta-analyses have shown that associational resistance (a reduction in pest damage in mixtures) is the dominant trend, as opposed to associational susceptibility (e.g. Jactel and Brockerhoff 2007; Castagneyrol et al, 2014). However, a meta-analysis of the effects of mixed forest stands on forest pathogens has, up until now, not been undertaken. This has represented a major knowledge gap in our understanding of diversity effects on tree damage agents overall.
Here, we report results of a global systematic review and meta-analysis of the previous literature on the impacts of mixed species forests on forest pathogen damage. We surveyed the English language literature available in major global databases, as well as Forestry literature archives and grey literature, and carried out a critical appraisal of the available studies. We present preliminary results from a meta-analysis of relevant studies, and suggest potential underlying mechanistic explanations for these results, considering variables such as pathogen specialisation. Finally, we provide recommendations for forestry practitioners based upon our results.

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Session 1: Resistance and resilience of mixed forests following disturbances. Poster presentations

General growth resilience patterns of Scots pine and Norway spruce mixed forest caused by drought events

Jorge Aldea[1], Ignacio Barbeito[1], Kamil Bielak[2], Gediminas Brazaitis[3], Aksel Granhus[4], Michael Heym[5], Stig-Olof Holm[6], Gro Hylen[4], Aris Jansons[7], Marek Metslaid[8], Thomas Nord-Larsen[9], Arne Nothdurft[10], Hans Pretzsch[5], Miren del Río[11,12], Ricardo Ruiz Peinado[11,12], Roman Sitko[13], Magnus Löf[1]

[1] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Sweden.
[2] Faculty of Forestry. Department of Forest Silviculture. Warsaw University of Life Sciences, Poland
[3] Institute of Forest Biology and Silviculture, Faculty of Forest Sciences and Ecology, Aleksandras Stulginskis University, Lithuania
[4] Norwegian Institute of Bioeconomy Research (NIBIO), P.O. Box 115, N- 1431 Ås, Norway
[5] Chair of Forest Growth and Yield Science, Technical University of Munich, Freising, Germany
[6] Department of Ecology and Environmental Sciences, Umeå University. Sweden.
[7] Latvian State Forest Research Institute Silava, Salaspils, Latvia
[8] Institute of Forestry and Rural EngineeringEstonian University of Life Sciences(EMU),Tartu,Estonia
[9] Department of Geosciences and Natural Resource Management. University of Copenhagen. Denmark
[10] Institute of Forest Growth, University of Natural Resources and Life Sciences, Vienna. Austria
[11] Department of Forest Dynamics and Management, INIA-CIFOR, Madrid, Spain
[12] Sustainable Forest Management Research Institute, University of Valladolid - INIA, Palencia, Spain
[13] Tehnical University in Zvolen, Faculty of Forestry, Zvolen, Slovakia

Climate change is projected to lead to more frequent and intense climate extremes such as heat waves and severe droughts. Boreal tree species are not an exception, and extreme drought events have already been evidenced as one of the main causes of dieback for Norway spruce and Scots pine along Europe. Consequently, the increment of tree species diversity by mixed stands has been widely proposed as an effective measure to counteract the adverse impacts of droughts on tree growth. Here, we aim to identify generalizable growth response patterns from drought events for former species in mixed versus monospecific stands. We used tree ring data from triplets (mixed and monospecific stands) included into REFORM project to show differences in drought resilience indices (resistance, recovery and resilience) involving drought events between 1985 and 2015. Significant differences were found between the species and between stand composition, i.e., mixed compared with monospecific stands. Commonly, Scots pine showed a higher resistance but lower recovery than Norway spruce in pure stands. Scots pine in mixed stands exhibited a higher growth resistance but lower recovery compared with monocultures. Species mixing decreased drought recovery and resilience for Norway spruce. Resilience components were also modified by site characteristic for both species studied. Results obtained here may evidence that mixing effect mainly results from one-sided competition release, where Scots pine improves resources availability with detrimental effects on Norway spruce growth.

The cost of deer to trees: changes in resource allocation from growth to structural defence in fir-spruce-beech mixed forests

Julien Barrere[1,2,3], Sonia Saïd[3], Xavier Morin[2], Vincent Boulanger[4], Nick Rowe[5], Bernard Amiaud[1], Marianne Bernard[6]

[1] UMR Silva, Université de Lorraine, AgroParisTech, INRA, F-54000 Nancy, France
[2] CEFE UMR 5175, CNRS – Université de Montpellier – Université Paul-Valéry Montpellier –EPHE, 1919 Route de Mende, F-34293 Montpellier cedex 5, France
[3] Office National de la Chasse et de la Faune Sauvage, Direction Recherche et Expertises, Unité Ongulés Sauvages, ''Montfort", 01330 Birieux, France
[4] Office National des Forêts, Département Recherche, Développement et Innovation, Boulevard de Constance, 77300 Fontainebleau, France
[5] AMAP, Université de Montpellier, CNRS, CIRAD, INRA, IRD, Montpellier, France
[6] AgroParisTech, 19 avenue du Maine, 75015 Paris, France

Plants may use various defence mechanisms to protect their tissues against deer browsing and the allocation of resources to defence may trade-off with plants' growth. In a context of increasing deer populations in European forests, understanding the resource allocation strategies of trees is critical to better assess their ability to face an increasing browsing pressure. The aim of this study was to determine how deer removal affects the resource allocation to both defensive and growth-related traits in field conditions for three tree species (*Abies alba, Picea abies* and *Fagus sylvatica*) emblematic of European mixed forests. We compared eight pairs of fenced-unfenced plots to contrast plots with and without browsing pressure. We measured leaf and shoot traits related to the defence against herbivores (phenolic content, structural resistance, C:N ratio) and to the investment in plants' growth and productivity (specific leaf area and nutrient content). For the three species, the structural resistance of leaves and shoots was negatively correlated with SLA, nutrient content and phenolic content. For *Abies alba*, exclusion of deer decreased shoot structural resistance in favour of higher nutrient content, SLA and phenolic content. Our results support the assumption of a trade-off between structural defence and growth-related traits at the intraspecific scale for the three studied species. We also confirmed the hypothesis that exposure to deer browsing is involved in the resource allocation of woody species. For *Abies alba*, fencing led to a change in resource allocation from structural defence to growth-related traits and chemical defence.

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Vegetative propagation of reophyte species for use in recovery of riparian forest through soil bioengineering

Dione Dambrós Raddatz[1], Rossana Cortelini da Rosa[2], Mario Lima dos Santos[3], Anderson Marcos de Souza[3], Fabrício Jaques Sutili[2]

[1] University of Brasilia and Embrapa Genetic Resources and Biotechnology, Brasília, Brazil
[2] Federal Universit of Santa Maria, Santa Maria, Brazil
[3] University of Brasilia

Natural resources, especially the forest formations have been destroyed through the disordered occupation and without planning of the Brazilian territory, the removal of these formations causes several problems to the environment, mainly collaborating with the extinction of species of flora and fauna, climatic changes, soil erosion and silting of watercourses. These sites, once degraded, require different forms of recovery, because where periodic flooding occurs the vegetative propagation by means of cuttings is the most indicated. In this context, we aimed to select tree and shrubby ten species through the vegetative propagation by cuttings for use in the recovery of degraded areas in the river. The experiment was carried out in a greenhouse, the cuttings had 15 cm long and were planted in 1.7 L pots using medium sieved sand as the substrate. At 180 days, survival rate was evaluated and the aerial part: the mean number, mean length and dry mass of shoots per cutting. For the root system was evaluated the mean number, mean length and dry mass of roots per cutting, the number of roots, sum of root length per meter of buried cutting, and the absolute distribution of roots. The results, species showed a mean survival rate ranging from 51% to 96%, all ten had an aerial system, however only the three species presented root system effective. Still in this work, is described a new species of *Maytenus* sp., comprises a new species related to *Maytenus ilicifolia* Mart exReiss.

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Mixed forest for reduced insect damage probability: a case study of spruce bud scale

Iveta Desaine[1], Endijs Baders[2], Aris Jansons[2]

[1] Skogssällskapet, Valmiera, Latvia
[2] Latvian State Forest Research Institute silava, Salaspils, Latvia

Single-species forest landscapes facilitate rapid spread of dendrophagous insects; however, there is limited information on the extent of reduction of insect damages in multi-species landscapes. Aim of our study was to assess the effects of landscape heterogeneity on the damage caused by spruce bud scale (*Physokermes piceae* (Schrnk.) in Norway spruce stands. Landscape metrics for forest surrounding middle-aged (40 to 70 years old) Norway spruce-dominated stands (>70% of basal area) stands – the main target for the spruce bud scale – was analysed, using binary logistic generalized linear mixed effects model (GLMMs). Four of the most affected (in the outbreak of 2010) forest massifs and two un-affected were used for the study. Increased local (up to 500m from particular stand) forest diversity significantly reduced the probability of spruce bud scale damages. Landscape parameters significant for lower damages risks were found and further tested on two other forest massifs, not used in first part of the study. IN this assessment damage probability for actually damaged Norway spruce stands was significantly ($p<0.05$), but not greatly larger than the probability for the actually un-affected stands (74.6% *vs*. 61.2%). not completely prevented them. Increased landscape heterogenty not prevented the damages by this dendrophagous insect, but clearly reduced it, indicating, that it can be part of the toolkit to create less damaged forests.

Impact of tree species interactions on intra-specific trait variability in temperate forests

Margaux DIDION-GENCY[1], Nina BUCHMANN[2], Arthur GESSLER[1], Charlotte GROSSIORD[1,3]

[1] Swiss Federal Research Institute WSL, Zürcherstrasse 111, 8903, Birmensdorf, Switzerland
[2] Institute of Agricultural Sciences, ETH Zurich, Universitatsstrasse 2, 8092 Zurich, Switzerland
[3] École Polytechnique Fédérale de Lausanne EPFL, School of Architecture, Civil and Environmental Engineering ENAC, 1015 Lausanne, Switzerland

Warmer and drier climatic conditions associated with recent climate change will affect forest ecosystems, including reducing productivity and increasing tree mortality. Predictions on how extreme events will affect forests rarely account for community-level processes, which could potentially mitigate climate impact. For instance, tree species interactions are particularly recognized processes that modulate tree responses to environmental variability, but to date they remain largely misunderstood.
To improve our understanding of the role of tree species interactions on forest responses to warming and drying conditions, we conducted an observational study in forest stands located across a latitudinal gradient with varying tree species compositions and climatic conditions. Multiple physiological, anatomical and biogeochemical traits were measured on adult beech trees (*Fagus sylvatica* L.) to determine intra-specific variability in carbon- and water-dependent processes. We found high trait variability along the latitudinal gradient and within sites. Moreover, while temperature and soil moisture significantly impacted trait variability, species composition had moderate impact on the measured traits. Overall, our results show that increased temperature and reduced soil moisture promote differential carbon- and water use strategies of individuals within a species, suggesting stronger intra-specific complementarity with increased stress.

What is the natural insurance value of adapting European boreal forestry to storms?

Jeannette Eggers[1], Thomas Hahn[2], Narayanan Subramanian[1], Tord Snäll[1]

[1] Swedish University of Agricultural Sciences
[2] Stockholm Resilience Centre, Stockholm University

Changes in climate and disturbance patterns call for resilient ecosystems, which provide a natural insurance value to the landowner and to society. This study examines the private financial effects of one disturbance type, storm, on one forest ecosystem service, wood production. We used data from the Swedish National Forest Inventory and the forest decision support system Heureka RegWise to simulate effects of storms on Net Present Value (NPV) in spruce-dominated forests in Southern Sweden, comparing a no storm regime with historic storms and a regime with 30% increased storm intensity. For each of these storm regimes, five different management options were simulated, BAU (the present spruce-dominated stands) and four adaptations: More broadleaves, Continuous cover forestry (CCF), Spruce monoculture, and No thinnings. Simulations at landscape level suggest that No thinnings results in the highest, and Spruce monoculture in the lowest NPV when storms are accounted for. BAU has the highest NPV only when no storms are assumed, which is often the case in forest planning. All management options except for Spruce monoculture reduced damage costs compared to BAU when storms are included. Analysis for the most vulnerable forests - 20% of the forest area - showed that NPV for the two storm regimes was higher for No thinning, CCF and More broadleaves compared to BAU. These are good arguments for adapting forest management, at least in vulnerable areas or if forest owners are risk-averse. Our results also stress the importance of accounting for disturbances in forest planning.

Effect of mixed plantations and neighbouring species in the resistance to ash dieback disease

Iwan Evans[1], Rachel Bromley[1], Matthew Ashpole[1], Deemah Ziari[1], Ana Pua[1], Mark Raw[1], **Estrella Luna**[1]

[1] Birmingham Institute of Forest Research, University of Birmingham

The outbreak of pathogenic ash dieback (AD) disease in the European continent from 1992, caused by the fungus *Hymenoscyphus fraxineus*, has resulted in the death of millions of European ash trees, a species with huge economic, ecological and social relevance due to its versatility, fast growth and tolerance to different environments. *H. fraxineus* infects all species of ash and no full genetic resistance to the disease has been identified. However, partial resistance has been documented. Here, we report on how mixed species forest plantations affect the expression of resistance. We assessed disease incidence in over 300 ash trees growing in a mixed plantation consisting of 7,000 trees of 23 different species. The results have unravelled different levels of disease resistance to AD in the plantation. Also, we have identified different areas where the damage by AD disease is greater than in others. Tree species identification in the plantation allowed us to study a potential role of neighbouring tree species in disease resistance. We found that disease expression was at its highest when ash trees were neighbouring with *Alnus glutinosa* (alder) and at its lowest when ash trees were cohabiting with *Pinus sylverstris* (Scots pine). Further research is needed to elucidate the mechanisms by which these tree species result in enhanced resistance to AD disease. Nevertheless, these results provide guidance to policy makers and woodland owners to increase the number of thriving forests in the years to come.

Study of the regeneration and renewal processes in reforestations affected by fire

Roberto Greco[1], Manuela Persia[1], Emanuele Barca[2], Maria Immacolata Marzulli[1], **Patrizia Tartarino**[1]

[1] Department of Agricultural and Environmental Science, University of Bari, Bari, Italy
[2] Water Research Institute, IRSA – CNR, National Research Council, Bari, Italy

Reforestations are an important heritage for biodiversity conservation and carbon storage, very important for climate change mitigation occurring in our planet. In the Mediterranean environment, conifer reforestations are often affected by the spontaneous spread of native species but also by forest fires, which are a significant disturbing factor. The aim of this study was to analyse the regeneration and renewal processes of the planted or spontaneous forest communities in a conifers reforestation located in the Alta Murgia National Park (Puglia, southern Italy), which was affected by a canopy fire that burnt about 600 ha in 2012. It is extended on an area of about 1,100 ha with an elevation between 350 and 650 m a.s.l.
The considered variables were pre-fire and post-fire vegetation and their location related to the morphological aspects of the area. Their existing relationships have been studied using some specific approaches of multivariate statistics. The division into homogeneous areas was performed by processing remote sensing images applying an integrated approach based on Isodata Clustering and Multiresolution segmentation algorithms, using the eCognition software. Some drone surveys (UAV equipped with a 20 mpx RGB camera) were performed in sample areas of variable extension depending on the type of renovation or regeneration in progress. The high resolution orthophotos obtained were segmented and classified with an object-oriented approach. The results have been validated in the field. The described methodology was used for planning of forest restoration projects in the forests owned by the Puglia region.

Mixed forests of allochthonous conifer and native broadleaf species from central Romania (Brasov)

Ana-Maria Hereş[1, 2], Ştefan Petrea[1], Alexandru Lucian Curtu[1], Ion Catalin Petriţan[3], Jorge Curiel Yuste[1, 2, 4]

[1] Department of Forest Sciences, Transilvania University of Braşov, Brașov, Romania
[2] BC3-Basque Centre for Climate Change, Scientific Campus of the University of the Basque Country, Leioa, Spain
[3] Department of Forest Management, Transilvania University of Braşov, Brașov, Romania
[4] IKERBASQUE, Basque Foundation for Science, Bilbao, Bizkaia, Spain

Climate change models forecast an increase in the severity, frequency, and duration of droughts and / or heat waves. Forests, important providers of ecosystem services, have already started to show worrisome decline and mortality rates following such stressful climatic phenomena all over the world. In line with this global trend, temperate-continental regions have also started to witness within the last decades important tree declining and / or mortality events following sequences of consecutive drier and hotter than the average years. Here we used tree-rings to study the historical growth patterns of allochthonous conifers (i.e., Black pine, Scots pine) and native broadleaves (i.e., European beech, sessile oak) tree species, growing together in mixed forests, in order to see which of them might be able to better cope with upcoming climate change challenges. The forests used in this study are located in central Romania (county area of Brasov) and are characterized by the fact that in 2012 they have witnessed important mortality rates among the allochthonous conifers following the 2011 severe drought event. Native broadleaf species, instead, didn't register mortality following this severe drought event. Preliminary results show that planted pines have problems to maintain good growth rates (i.e., significant negative temporal trends), while native broadleaves manage to perform better. These results indicate that native species might be better adapted to cope with stressful conditions than allochthonous planted conifers, and that forest management plans should follow a more natural (i.e., native) composition forest model in the face of climate change.

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The effect of bedrock and species heterogeneity on wood density of submediterranean species

Luka Krajnc[1], Polona Hafner[1], Jožica Gričar[1]

[1] Slovenian Forestry Institute

This study aims to examine the wood density of standing trees of different species in the submediterranean area of SW Slovenia in relation to the underlying bedrock and species heterogeneity. Based on the initial inventory data this study will include trees of *Quercus pubescens* Willd., *Pinus nigra* J.F.Arnold, *Quercus cerris* (Matt.) Liebl. and *Ostrya carpinifolia* Scop. This study will be conducted in two adjacent stands of similar age on two different bedrocks (limestone and flysch) with different water holding capacities (lower in limestone, higher in flysch). Several characteristics will be measured on all trees, including diameter at breast height, tree height and crown length. Wood density of each tree will be estimated using high-resolution resistance drilling and the species heterogeneity will be evaluated on each plot using a species diversity index. Existing data of anatomical and physiological properties of *Q. pubescens* from the nearby experimental plots will be used to explain the source of any potential differences in wood density. A subset of *Q. pubescens* trees was also cored using increment borer and it has been demonstrated that pubescent oaks on limestone had on average 35 % narrower rings than oaks on flysch. This implies a significant difference in wood densities of ring-porous oak trees on different bedrocks, as density is positively related to ring width in oaks. As wood density is directly connected to carbon sequestration potential, the results will provide new insights into the relationship between ecosystem productivity and carbon sequestration.

Effects of forest tent caterpillar outbreaks on soils properties and tree regeneration in boreal mixedwoods

Benoit Lafleur[1], Josh Jarry[1], Emma Despland[2]

[1] Université du Québec en Abitibi-Témiscamingue
[2] Concordia University

The boreal mixedwood forest (BMF) is among the most productive forest ecosystems in eastern Canada. Although fire is the main disturbance agent in the BMF, forest tent caterpillar (FTC) outbreaks periodically and may influence forest dynamics. Indeed, during outbreaks, FTC creates canopy gaps that allow solar radiation to penetrate the canopy, which could increase the growth rate of tree seedlings and saplings. In addition, during outbreaks, FTC corpses and feces litter the forest floor which could increase soil nutrient availability. Depending on the nutrient requirements of the tree species present in infested stands, an increase in light and soil nutrient availability could favor the growth of some species to the detriment of others and influence the future composition of the stands. Our results showed a significantly higher soil total N, exchangeable P, extractible Ca and Mg, and CEC, as well as significantly higher soil moisture and light availability in defoliated sites. Abundance of aspen saplings and seedlings was also significantly higher in defoliated sites, although defoliation did not influence growth rates of aspen seedling. Furthermore, although conifer saplings and seedlings were found in significantly lower numbers in defoliated sites, their growth rate was significantly higher, indicating a positive effect of FTC outbreaks on conifer growth conditions. The results indicate that outbreaks of defoliating insects have the potential to modify soil properties and influence the growth dynamics of tree sapling and seedlings in forest ecosystems.

Successional Dynamics of Boreal Mixedwoods Following the Natural Disturbances in Eastern Canada

Kobra Maleki [1], Mohamadou Alpha Gueye[1], Benoit Lafleur[1], Alain Leduc[2], Yves Bergeron[1, 2]

[1] Univeristy of Quebec in Abitibi-Témiscamingue
[2] Univeristy of Quebec in Montreal

Natural disturbances such as wildfires and insect outbreaks play an important role in natural forest dynamics, that are characterized by changes in stand composition and structure, on the long term. Forest simulators could provide better understanding and prediction of the forest responses to such disturbances. This study, aimed to model the post-disturbance dynamics of the boreal mixedwoods of eastern Canada, using the SORTIEND simulator*. In 1991 and 2009, we sampled all trees in 431 (256 m2) plots located in western Quebec. Plots were distributed in stands originating from seven wildfires that occurred between 1760 and 1944, and represent a chronosequence of post-disturbance stand development. We used the 1991 inventory data to parametrize the model to simulate short to long-term dynamics of post-fire stands, in the absence and the incidence of spruce budworm outbreaks. We compared the short-term simulated stand composition and structure with those observed in 2009 using a chronosequence approach. Results showed that the model successfully generated the composition and structure of empirical observations. Regarding the long-term simulations, due to possible differences in post-fire stand compositions and stand disturbances history, species dominance of old-growth forests was not accurately estimated. Therefore, devising the model with proper information about stand composition and disturbances history may considerably increase the strength and accuracy of the model. The mid to long-term simulations showed that the spruce budworm outbreak causes no important changes in early-successional stages, whereas it sets back the successional dynamics of middle-aged stands and accelerates the dominance of cedar in late-successional stands.

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*Detailed information about SORTIE-ND forest simulator is provided at http://www.sortie-nd.org.

Tree diebacks in the mixed pedunculated oak forests

Marko Marinkovic[1], **Bojan Tubic**[1]

[1] Public Enterprise “Vojvodinašume“, Sector for forestry, ecology and development, Petrovaradin, Serbia

Pedunculate oak (*Qercus robur* L.) is among the most economically important deciduous forest trees in Vojvodina province of the Republic of Serbia. As a dominant species in the mixed forests, managed with rotations of over 160 years, it covers about 25% of the forested area or 25 000 ha, which accounts for about 35% of the total growing stock. Global climate change, in particular warming, leads to the decline of forests or dieback of trees in forest. Mixed forests of pedunculate oak and other lowland tree species are most intensively affected by these occurrences. From the management point of view, the problem entails the increased quantity of dead or severely damaged trees and increased management costs. From the ecological point of view, the problem centers around changed site conditions, which is unfavorable for both present and future growth of oak trees. In managed mixed forests, the volume of trees cut in a sanitation harvests is often used to show the intensity of tree dieback, and may be used as an indicator of the stands condition.

In this paper, growing volume of withered pedunculate oak trees, as well as stand structure elements were collected from the forest management plans. Dieback intensities were calculated on the basis of growing volume of the withered trees per area unit ratio. The paper addresses the pedunculate oak tree dieback dynamics and its ecological impact. Also, it provides feedback on the socioeconomic consequences of tree dieback and how they reflect unfavorably on the entire forestry sector.

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Possible ways to establish mixed stands in hemiboreal forest

Marek Metslaid[1]

[1] Chair of Silviculture and Forest Ecology, Estonian University of Life Sciences, Tartu, Estonia

Estonia belongs to the hemiboreal vegetation zone. The main tree species are Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* [L.] Karst), birches (*Betula pendula* Roth and *Betula pubescens* Ehrh.), European aspen (*Populus tremula* L.), alders (*Alnus incana* [L.] Moench and *Alnus glutinosa* [L.] Gaertn.), and which are grown either in pure stands or in mixtures. When establishing mixed stands it is important to take into account the light demand of different tree species. Light-demanding tree species (Scots pine, birches) prefer conditions resulting from larger disturbances and stronger fellings. Shade-tolerant tree species (Norway spruce) can grow in shade of other trees, respond to favorable conditions, and accelerate growth after release. After major disturbances, advance regeneration and postdisturbance regeneration can form a mixed stand. However, after moderate disturbances, advance regeneration of shade-tolerant tree species (Norway spruce) have advantage. Forest management can promote the development of mixed forests. Combining different regeneration methods and tending measures it is possible to promote the development of mixed stands and to improve stand productivity and stability. For example, when establishing a coniferous stand, there will generally be sufficient amount of natural regeneration of deciduous species, which, if retained during the tending and thinning operations, will allow the development of a productive and viable coniferous-deciduous mixed forest. Similarly, in deciduous dominating areas left for natural regeneration it is possible to promote the natural regeneration of coniferous species, or a combination of natural and artificial regeneration.

Managing forests for resilience: a framework for balancing the structure, function and ecosystem services of a social-ecological system

Laura Nikinmaa[1, 2], Marcus Lindner[1], Elena Cantarello[3], Barry Gardiner[1], Jette Bredhal Jacobsen[4], Alistair Jump[5], Constanza Parra[2], Tobias Plieninger[6, 7], Andreas Schuck[1], Rupert Seidl[8], Thomas Timberlake[9], Kristen Waring[10], Georg Winkel[1], Bart Muys[2]

[1] European Forest Institute
[2] KU Leuven
[3] Bournemouth University
[4] University of Copenhagen
[5] University of Stirling
[6] Georg-August-Universität Göttingen
[7] Universität Kassel
[8] Technical University Münich
[9] Colorado State University
[10] Northern Arizona University

Global environmental and social changes cause unprecedented challenges for forest management. An increasingly popular approach to deal with these changes and associated uncertainties is managing for resilience. While some management recommendations for resilient forest ecosystems may exist, an operational framework for enhancing resilience of wider forest-related social-ecological systems is lacking. The interlinkages of such systems (e.g. social acceptance of disturbance risk prevention on bark beetle spread) may limit the enhancement of system's resilience. We organized an interdisciplinary workshop to develop an operational framework to assess resilience. It resulted in an indicator framework that considers the resilience of the ecological, economic and social parts of the forests and indicates where on a balancing gradient between minimum and maximum value the indicator is and how it affects the resilience of the system. We apply the framework to a monoculture and mixed productive forest via traffic light system, where each indicator is evaluated with "good", "intermediate", and "weak" resilience depending on the management context. We furthermore test the applicability of the framework and discuss how suitable it is for generalization. We found that optimal values for each indicator depend on the context and determining the most resilient system state can be challenging. However, we believe this framework can help practice to better implement resilience thinking into their daily management, identify vulnerable parts of their system and select pro-active measures, e.g. to mitigate disturbance impacts.

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Greenhouse gas fluxes from forest soils of a fire chronosequence in hemiboreal Estonia

Argo Orumaa[1], Kajar Köster[2], Kalev Jõgiste[1], Marek Metslaid[1]

[1] Institute of Forestry and Rural Engineering, Estonian University of Life Sciences, Kreutzwaldi 5, 51006, Tartu, Estonia
[2] Faculty of Agriculture and Forestry, Institute for Atmospheric and Earth System Research/Forest Sciences, University of Helsinki, Latokartanonkaari 7, 00014, Helsinki, Finland

Disturbances are playing a key role in the development of forest ecosystems. Forest fires have a great impact on the forest structure, functioning and the accumulation of carbon stocks in tree biomass and forest soils. The aim of this study was to evaluate changes in greenhouse gas (carbon dioxide, methane and nitrous oxide) fluxes from forest soils after forest fire. There are six different sample areas where fire occurred in 1837, 1940, 1951, 1982, 1997 and 2008 located in northwestern Estonia, in Nõva and Vihterpalu. After fire, the sites in aforementioned areas were regenerated with birch (*Betula* spp.), Scots pine (*Pinus sylvestris* L.), European aspen (*Populus tremula* L.) and Norway spruce (*Picea abies* L.). Later on, pure Scots pine stands develop in time. Measurements of greenhouse gas fluxes from forest soils were carried out from May 2016 till October 2016.
Results showed that highest soil respiration (carbon dioxide emission) value was measured in area where fire occurred in 1940. Lowest value was measured in area where fire occurred in 2008. Highest uptake of methane was measured in 2008 area and lowest uptake was measured in sample area where fire occurred in 1837. All sample areas except 1982 area (where soil emitted nitrous oxide fluxes) were nitrous oxide sinks.

Combining tree physiology, fire science and forest management principles to predict tree survival and damage in burned forests

Marina Peris-Llopis[1], Blas Mola-Yudego[1], Jordi García-Gonzalo[2], José Ramón González-Olabarria[2]

[1] School of Forest Sciences, University of Eastern Finland. Yliopistokatu 7, PO Box 111, FI-80101, Joensuu, Finland
[2] Forest Sciences and Technology Centre of Catalonia (CTFC). Ctra de St. Llorenç de Morunys, km 2, 25280 Solsona, Spain

Severe fires in Spanish forests cause damages at tree and stand level, altering the existent landscapes and causing socioeconomic and ecological losses. The study area is characterized by complex landscapes hosting diverse forests with a wide range of species mixtures. The study aims to highlight the influence of morphological traits in the survival of tree species in burned areas as well as to provide an explicit assessment of the effect of species mixture in stand damage due to fire. Data are retrieved from the Spanish National Forest Inventory (periods 1986-1996 and 1997-2007) and data concerning species traits (BROT database). Based on previous research, the models analyse stand damage and tree mortality due to forest fires, considering the morphological traits of the present species, seeking to identify the effect of present species and their traits on tree level resistance and the influence of species mixture on modifying stand level vulnerability. The developed models will serve as a tool for forest planning at stand and landscape level. The results will help identify resistant landscapes with forests that due to the species mixture and species adaptations among others, will mitigate the impact of fire.

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Climate warming predispose to drought-induced tree mortality regardless of conservation status of sessile oak mixed forests

Ion Catalin Petritan[1], **Any Mary Petritan**[2], Andrea Hevia[3], Helge Walentowski[4], Raul Sánchez-Salguero[5]

[1] Transilvania University of Brasov, Romania
[2] National Institute for Research and Development in Forestry “Marin Drăcea”, Romania;
[3] Dept. de Ciencias Agroforestales, Escuela Técnica Superior de Ingeniería Universidad de Huelva, Palos de la Frontera 21819, Spain
[4] HAWK, University of Applied Sciences and Arts, Goettingen, Germany
[5] Dept. Sistemas Físicos, Químicos y Naturales, Universidad Pablo de Olavide, Crta. Utrera km. 1, 41013 Sevilla, Spain

The role of global-change drivers, such as climate warming-related drought stress and the interaction with past management in temperate forests, where growth of tree species is influence by strong competition, is still not fully understood. In this study we examine the role played by those drivers as factors causing recent dieback in two *Quercus petraea* mixed forests –old-growth vs. managed located in Western Romania. We analyze how environmental factors – climatic (drought, temperature, precipitation anomalies) and site conditions –stand structure (age, tree size, competition) – driving radial growth patterns in recent dead vs. healthy trees. A temperature rise and changes in seasonal patterns of precipitation let to increasing drought stress during the late 20th century affecting similarly both stands. Dead trees from both forests showed less growth than healthy trees in the last three decades. Dead trees from managed stands experienced stronger growth reductions after 1980s although displayed less tree-to-tree competition than those of old-growth forests. The highest resilience to extreme events was found in healthy trees for old-growth forests. A significant association is displayed by both *Q.petraea* mixed forests among droughts, competition and growth releases. These findings highlight the importance of legacies, such as the past use and releases in driving recent forest dieback in temperate forests, making them more vulnerable to climate-warming related drought in central Europe.

Resistance of mixed forests to insect herbivory in drought conditions

Charlotte Poeydebat[1], Bastien Castagneyrol[1], Inge van Halder[1], Hervé Jactel[1]

[1] INRA, BIOGECO, 33610 Cestas, France

Forests are likely to experience more stressful conditions in the future because of climate change. Mixed forests are expected to be more resistant to specific hazards. However little is known about resistance of mixed-species forests to multiple biotic and abiotic disturbances. Here we used a tree diversity experiment combine with an irrigation treatment to investigate the effect of mixing tree species on resistance of maritime pine (*Pinus pinaster*) to pest damage in contrasting drought conditions. We focused on patterns of attacks by two primary and specialist pest insects, i.e. the pine stem borer (*Dioryctria sylvestrella*) and the pine processionary moth (*Thaumetopoea pityocampa*). We further tested whether the attack patterns resulted from direct effects of tree diversity and drought, or from indirect effects mediated by pine vigor or size. We found less attacks of both pests in mixed vs. pure plots, i.e. associational resistance, which was mainly due to the presence of birch in mixed plots. In the case of *D. sylvestrella*, tree diversity and drought effects were mediated by pine vigor. Those patterns may result from chemical host-finding disruption possibly promoted by the presence of non-host trees (here birch) and modulated by drought conditions. Functional characteristics of herbivorous insects and tree species composition must therefore be considered when predicting the interactive effects of climate change and loss of diversity on forest health.

Assessment of the impact of land use change

Iuliia Polevshchikova[1]

[1] Volga State University of Tecnology, Yoshkar-Ola

Ecological security has become an important research topic because of serious ecological degradation and environmental pollution in the Republic of Mari El. Land use change can directly transform wide landscapes, impact on the biodiversity and eco-productivity. The relevance of the problem is due to the importance of implementing the concept of sustainable forest management, monitoring and protection of forests from emergency situations in the framework of the national project of the Ministry of Natural Resources of Russia “Ecology”. The overarching objective of research is to assess the patterns, drivers, and outcomes of the climate change on the ecological security of the Middle Volga region using ground-based observations and GIS technologies. A model for assessing the environmental security of the territory is developed and tested using spatial and temporal data obtained from satellite images. The work used modern methods of simulation and situational modelling of environmental security assessment based on numerous criteria.
Spatio-temporal analysis of the dynamics of climatic features of the studied regions over a long period will allow identifying trends in the changes of forest cover, soil cover of the territory and identify the main factors contributing to the restoration of environmental security in these areas. The study proposes to use patterns of spatial and temporal differentiation of vegetation cover, as well as various simulation scenarios in accordance with the goals of socio-economic development and strategies of the national project “Ecology”.

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Net ecosystem carbon exchange at forest disturbance sites: measured with the eddy covariance method

Sille Rebane[1], Kalev Jõgiste[1], Eneli Põldveer[2], John Stanturf[2], Marek Metslaid[1, 3]

[1] Chair of Silviculture and Forest Ecology, Institute of Forestry and Rural Engineering, Estonian University of Life Sciences, Tartu, Estonia;
[2] Chair of Forest Management Planning and Wood Processing Technologies, Institute of Forestry and Rural Engineering, Estonian University of Life Sciences, Tartu, Estonia
[3] Norwegian Institute of Bioeconomy Research, Ås, Norway

Boreal and temperate forests cover a large part of the Earth´s land. Forest ecosystems are in the key role because it´s importance in climate change. Climate change, increasing atmospheric temperature, different disturbances and forest management have a huge effect on forest ecosystems. Forest ecosystems C status will be considerably changed by disturbances, such as fire, storm, insects and clear-cutting. After these changes forest ecosystems obtain C status, whether it is functioning as a C-sink, C-source or C-neutral. For better understanding of forest ecosystem functioning is used eddy covariance (EC) method.
Using the EC method we can define interactions between canopy and atmosphere. In our review of published studies and examples from our own of studies, which include different disturbances, have focused on net ecosystem exchange (NEE) measured by EC technique. Generally, after disturbances it takes several years to recover. Recovery to Csink status after a fire can take up to 50 years and even more, while recovery following clear-cut areas requires up to 20 years. Although, storm and insect outbreaks have huge damages to ecosystems, is recovery period much shorter, 5 years long. We can not predict an overall recovery period after the storm and insect outbreaks, because of the missing data.

An in situ experiment of shifts between alternative stable states defined by canopy dominance

Juanita C. Rodríguez[1], Evic Mestre[2], Mélanie Jean[1], Nicole J. Fenton[1], Steven W. Kembel[2], Yves Bergeron[1, 2]

[1] Forest Research Institute, Université du Québec en Abitibi-Témiscamingue (UQAT), Rouyn- Noranda, QC, Canada.
[2] Forest Research Institute, Université du Québec à Montréal (UQAM), Montréal, QC, Canada.

Plant community composition in stable states is defined by local environmental conditions and successional processes. Canopy dominance creates these conditions in the understory and affects ecosystem processes[1,2]. Therefore, changes in canopy dominance, due to natural or anthropogenic causes, can induce plant reorganization in alternative configurations, affecting plant dynamics and ecological functions[3]. Species will react depending on their resistance to disturbance and their resilience capacity to return in their initial state[4,5]. As forests experience increasing change, it is important to understand which environmental factors induce shifts in understory plant communities. With a 5-year in situ experiment in the Canadian boreal forest, we determined the factors (light, litter, nutrient status) influencing community composition in a matrix with two alternative stable states as defined by tree canopy dominance (black spruce vs. trembling aspen stands). Our results indicate that the herbaceous community in trembling aspen stands was both resistant to shifts in local conditions and resilient in the alternative state dominated by black spruce. In contrast, mosses and ericaceous plants that typically compose black spruce stands were significantly affected by aspen litter (though a physical rather than a chemical effect) and were not resilient in an alternative state dominated by trembling aspen. A feedback loop between overstory and understory creates microconditions affecting decomposition and nutrient cycling, in turn influencing plant regeneration and growth. Shift in communities depend on plant community resilience that can push back to their stable state, or transform to a transient state that give rise to alternative configurations.

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Mesophication in temperate Europe: a dendrochronological reconstruction of tree succession and fires in a mixed deciduous stand in Białowieża Forest

Andreea Petronela Spinu[1, 2] , Mats Niklasson[1, 3], Ewa Zin[1, 4]

[1] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences (SLU), P.O. Box 49, SE-230 53 Alnarp, Sweden
[2] Chair of Silviculture, University of Freiburg, Tennenbacherstr. 4, 79106 Freiburg, Germany (present address)
[3] Nordens Ark Foundation, Åby Säteri, SE-456 93 Hunnebostrand, Sweden
[4] Department of Natural Forests, Forest Research Institute (IBL), ul. Park Dyrekcyjny 6, 17- 230 Białowieża, Poland

The shift from shade-intolerant to shade-tolerant mesophytic species in deciduous and mixed forests of the temperate zone is well described in studies from North America. This process, termed mesophication has been linked to changes in fire regime. Fire suppression results in the cessation of establishment of heliophytic, fire-dependent tree species such as oak (*Quercus*) and pine (*Pinus*). In Europe, data on long-term compositional changes in mixed forests is limited, as is the number of studies exploring whether fire played a role in shaping their dynamics. This study aimed to reconstruct succession in a 43-ha natural mixed deciduous forest stand in Białowieża Forest (BF), Poland using dendrochronological methods. The presence of fire legacies (charred and fire-scarred deadwood) enabled the fire history reconstruction. Data revealed tree establishment back to the end of the 1500s and fires back to 1659. Under a regime of frequent fires only oak and pine regenerated sporadically until the end of the 18th century. Afterwards, a shift in the fire regime triggered *Quercus* and *Pinus* cohort regeneration, followed by *Picea* encroachment. Under an increasingly dense canopy and less flammable conditions, regeneration of *Carpinus*, *Tilia* and *Acer* began simultaneously with the cessation of oak and pine recruitment. The study reports the first evidence of mesophication in temperate Europe and proves that fire was involved in the long-term dynamics of mixed deciduous forest ecosystems. Our data suggests that fire exclusion promoted a gradual recruitment of fire-sensitive, shadetolerant species that inhibited the regeneration of oak and pine in BF.

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Modelling and reviewing forest stability: a holistic approach

Astor Toraño Caicoya[1], Hilmers Torben[1], Pretzsch Hans[1]

[1] Chair of Forest Growth and Yield Science, TUM School of Life Sciences Weihenstephan, Technical University of Munich

Growing evidence suggests that climate change could substantially alter forest disturbances. However, interactions between individual disturbance agents and their effects on forests with different forest structures are complex and difficult to predict. Within disturbance regimes, individual disturbance agents are rarely independent of each other, but interact in space and time. For example, interactions exist between wind and bark beetle disturbances, bark beetles and wildfire, as well as drought and bark beetle outbreaks. Due to this complexity, forest stand stability needs to be treated as a system that is affected by many interacting disturbing factors. Morevoer, depending on how the structural parameters are linked, a forestry system can potentially either form selfbalancing loops increasing stability against disturbances, or reinforcing ones enhancing damages. The challenge we face therefore requires the use of tools and processes such as system dynamics (SD) to help us understand this complexity.

We summarized and later analyzed the main consequences and casual connections that we consider relevant for the further construction of a forest stability model using SD. For this purpose, we considered wind and snow damages, wildland fires, drought, pests and plagues as disturbance agents. We also identified and analyzed the main stabilizing criteria and their casual relationships with the disturbance agents as well as the importance of forest structures and tree species composition within the system. With a special focus on drought and tree species mixing, we than analyzed the potential of the implementation of different forest structures to increase the future stability of forestry systems.

Influence of climatic variations and competitive interactions on stem radial growth of beech and silver fir in Italian mountain forests.

Soraya Versace[1, 2], Vittorio Garfì[1], Michele Dalponte[2], Damiano Gianelle[2], Lorenzo Frizzera[2], Roberto Tognetti[1]

[1] Università degli Studi del Molise
[2] Dipartimento di Agrosistemi Sostenibili e Biorisorse, Centro Ricerca e Innovazione, Fondazione Edmund Mach

Tree growth is influenced by multiple factors, including climate, site conditions and competition processes. Climate change affects structure, composition and distribution of forests. Increasing temperature and decreasing precipitation in the Mediterranean environments is causing substantial impacts on forest resilience, threatening their health. Climate not only influences the quantity and availability of resources essential for the growth of trees, but also the competitive interactions for these resources of single trees within the tree communities. The influence of climate variations and competitive interactions on mixed-species stands are often less severe than on pure stands, thanks to different functional traits, stand density, site quality and spatial arrangement of trees. However, this is not always true, particularly in harsh environments. The objectives of the work were to identify and understand the influence of climate variations and competitive interactions on stem radial growth of beech and silver fir in mixed and pure stands of mountain forests. Three sites along the Italian Peninsula were sampled for tree growth analysis (Trentino, Molise, Calabria). Climate-growth analysis and the identification of pointer years allowed to evaluate species responses to climate variation. Competitive interactions were carried out through the identification of competition indices (global and inter-intra-specific). Our results showed that: i) the influence of summer drought decreases for both species along the latitudinal gradient; ii) mild winters favored the growth of silver fir in Trentino, not for Calabria; iii) basal area increment was negatively affected by the competition in mixed stands of Molise; iv) more negative inter-specific interactions than intra-specifications.

Session 2: Ecosystem services from mixed forests

Key-note talk: Lars GAMFELDT, Department of Marine Sciences, University of Gothenburg, Sweden

Biodiversity and ecosystem multifunctionality: which measure of multifunctionality, which species, which scale?

Biodiversity is generally an important driver of ecosystem functioning. It has been proposed that the relationship between biodiversity and function should be stronger if we simultaneously consider multiple functions or services. Furthermore, it is also suggested that the relationship is stronger if we consider larger, compared to more local, spatial scales. These two claims may, however, not necessarily be true. It all depends on which analytical approach we use. How do we define multifunctionality? What do we mean by biodiversity being more important? For example, are we interested in the slope of the relationship between biodiversity and function, or is it rather the extent to which biodiversity provides overyielding or not? To advance our understanding of these topics, explicit definition of terms and concepts is imperative. I also want to stress the importance of moving beyond generic studies of biodiversity and functioning. If we want functional biodiversity research to be relevant for policy and management of ecosystem services in production systems, we should study the composition of specific species mixtures. We need to ask ourselves which combinations of species will maximise which services. Drawing from examples in forests and other ecosystems, the presentation will explore different aspects of multifunctionality across spatial scales. The aim is to provide a critical perspective on broad claims when it comes to the role of biodiversity at higher dimensions of scale and functioning.

	Lars Gamfeldt is a senior lecturer at the Department of Marine Sciences at University of Gothenburg, Sweden. He is broadly interested in questions related to the multifunctional consequences of changes in biodiversity across ecosystems and scales. While his background is mainly marine, he has worked with a range of organisms and ecosystems, including bacteria, coastal rock pool communities, and temperate forests. Lars uses a range of approaches, including analyses of time-series of monitoring data, field- and laboratory experiments, simulation modelling and meta-analyses. His interest in ecosystem multifunctionality started with the publication of a paper in Ecology 2008. The main message of that article was that multifunctionality is more susceptible to species loss than are single functions. The Ecology paper was followed up by a paper on mixed forests and multiple ecosystem services in 2013, a methods paper 2014, and a meta-analysis in 2015. The claim that the value of biodiversity becomes more important if we consider more functions and services was questioned in a recent perspectives paper (Gamfeldt and Roger 2017). Lars is currently working with international colleagues to reach consensus on this issue.

Is multifunctionality greater in mixed than in pure forests? A metaanalysis of a latitudinal network of European forest triplets

Charlotte Poeydebat[1], Quentin Ponette[2], Felipe Bravo[3, 4], Anna Barbati[5], Admir Avdagic[6], Ignacio Barbeito[7, 8], Kamil Bielak[9], Gediminas Brazaitis[10], Jakub Černy[11], Lluís Coll[12, 13, 14], Catherine Collet[15], Miren del Río[16], Aksel Granhus[17], Michael Heym[18], Līga Jansone[19], Āris Jansons[19], Nicola La Porta[20, 21], Magnus Löf[8], Marek Mestlaid[22], Renzo Motta[23], Arne Nothdurft[24], Cristóbal Ordoñez[25, 26], Maciej Pach[27], Marta Pardos[28], Ricardo Ruiz-Peinado[29, 30], Hans Pretzsch[18], Roman Sitko[31], Miroslav Svodoba[32], Mary Kate Ugrekhelidze[33], Tzvetan Zlatanov[34], Hervé Jactel[1]

[1] French National Institute for Agricultural Research (INRA), UMR Biogeco, 33612 Cestas, France
[2] Université catholique de Louvain, 1348, Louvain-la-Neuve, Belgium
[3] Escuela Técnica Superior de Ingenierías Agrarias, Universidad de Valladolid, Palencia, Spain
[4] Sustainable Forest Research Institute UVa-INIA, Palencia, Spain
[5] University of Tuscia, 01100 Viterbo, Italy
[6] University of Sarajevo, Faculty Forestry, Zagrebačka 20, 71000 Sarajevo, Bosnia & Herzegovina
[7] AgroParisTech, INRA, SilvaUniversité de Lorraine, Nancy, France
[8] Swedish University of Agricultural Science, 23053 Alnarp, Sweden
[9] Department of Silviculture, Warsaw University of Life Sciences, 02-878 Warsaw, Poland
[10] Faculty of Forest Science and Ecology, Vytautas Magnus University, Akademija, Kauno r., Lithuania
[11] The Forestry and Game Management Research Institute, Opočno, Czech Republic
[12] Department of Agriculture and Forest Engineering, University of Lleida, 25198Lleida, Spain
[13] Forest Sciences Centre of Catalonia (CTFC), Solsona 25280, Spain
[14] CREAF, Autonomous University of Barcelona, Spain
[15] LERFoB, UMR 1092, INRA-AgroParisTech, 54280 Champenoux, France
[16] Department of Silviculture and Forest Management, INIA-CIFOR, Madrid, and iuFOR, University of Valladolid, Valladolid, Spain
[17] Norwegian Institute of Bioeconomy Research, P.O. Box 115, NO-1431 Ås, Norway
[18] Chair for Forest Growth and Yield Science, Technische Universität München, München, Germany
[19] Latvian State Forest Research Institute “Silava”, Rīgas str. 111, Salaspils, Latvia, LV2169
[20] IASMA Research and Innovation Centre, Fondazione Edmund Mach, 38010 Trento, Italy
[21] MOUNTFOR Project Centre, European Forest Institute, 38010 Trento, Italy
[22] Institute of Forestry and Rural Engineering, Estonian University of Life Sciences, 51014 Tartu, Estonia
[23] Department of Agricultural, Forest and Food Sciences (DISAFA), University of Torino, Italy
[24] Institute of Forest GrowthUniversity of Natural Resources and Life Sciences (BOKU), Vienna, Austria
[25] E.T.S. de Ingenierías Agrarias, Universidad de Valladolid, Palencia, Spain
[26] Sustainable Forest Management Research Institute Universidad de Valladolid-INIA, Palencia, Spain
[27] Department of Silviculture, University of Agriculture in Krakow, 31-425 Krakow, Poland
[28] Department of Forest Dynamics and Management, INIA-CIFOR, Madrid 28040, Spain
[29] Forest Research Centre, INIA, Madrid, Spain
[30] iuFOR, Sustainable Forest Management Research Institute University of Valladolid & INIA, Spain
[31] Faculty of ForestryTechnical University in Zvolen, Zvolen, Slovakia
[32] Faculty of Forestry and Wood Sciences, Czech University of Life Sciences, Prague, Czech Republic
[33] School of Natural Sciences and Medecine, Ilia State University, Tbilisi, Georgia
[34] Forest Research Institute, 1756 Sofia, Bulgaria

The biological simplification of managed ecosystems often leads to reduced functionality and greater vulnerability to biotic and abiotic disturbances. By contrast, some mixed forests have proven to be more productive and resistant than monospecific forests. However, different compositions of mixed forests can have contrasting effects on multiple ecosystem services (provisioning, supporting, regulating and cultural), making it difficult to find the best compromise. In the meantime, climate change is likely to affect the ability of forests to provide ecosystem services in a sustainable manner. It is therefore important to better understand how mixed forests can improve multifunctionality under a wide range of climatic conditions. We set up a network of more than fifty forest triplets (monoculture of species A, monoculture of species B and mixture of A+B) from Spain to Scandinavia. To characterize forest functionality, we measured tree productivity, stem quality and resistance to defoliation, as well as tree-related microhabitats as indicators of the capacity to support biodiversity. We produced a quantitative index of multifunctionality and applied a meta-analytical approach to analyse the data synthetically. Overall, multifunctionality tended to be similar in pure and mixed stands. However, the effect of species mixing on multifunctionality varied greatly depending on the composition of the mixed stands. There were trade-offs between functions, in particular between wood production (in quantity and quality) and habitat provision. Finally, we found that climate was also an important driver of the multifunctionality of forests in Europe.

Tree species diversity and identity as drivers of soil carbon stocks in European mixed forests

Lars Vesterdal[1], Seid Muhie Dawud[1], Karsten Raulund-Rasmussen[1], Sophia Ratcliffe[2], Timo Domisch[3], Leena Finér[3]

[1] Dept. of Geosciences and Natural Resource Management, University of Copenhagen, Frederiksberg C, Denmark
[2] Institute of Biology, University of Leipzig, Leipzig, Germany
[3] Natural Resources Institute Finland (LUKE), Joensuu, Finland

Studies of mixed forests have reported positive effects on aboveground carbon (C) sequestration, but the question remains whether higher soil C stocks could result from belowground niche differentiation driven by more efficient root exploitation of soils. We studied soil C stocks and fine root biomass in tree species diversity gradients in six major European forest types within the FunDivEurope project. We found consistent modest effects of species diversity on soil C stocks in the forest floor and 0-10 cm layer across the regions. Carbon stocks increased with tree species diversity, but there was no effect on fine root biomass. In contrast, there was a strong effect of species identity on soil C, root biomass and root distribution. In Poland we sampled soils to 40 cm and here tree species diversity increased soil C stocks in deeper soil layers (20-40 cm), while species identity influenced C stocks within forest floors. Root biomass increased with diversity in 30-40 cm depth, and a positive relationship between C stock and root biomass suggested that belowground niche complementarity could be driving higher root C input and deeper distribution of C in mixed forests. We conclude that soil C stocks are mainly driven by tree species identity while modest positive diversity effects were detected at the European scale. Stronger positive effects on subsoil C stocks in Poland were associated with higher subsoil root biomass. Targeted selection of tree species would be a stronger management approach for soil C sequestration than increasing tree species diversity per se.

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Tree species identity and site conditions have stronger impact on soil organic carbon storage than species diversity in European forests.

Richard Osei[1], Hugues Titeux[1], Jean-Thomas Cornelis[2], Kamil Bielak[3], Felipe Bravo Oviedo[4], Michael Heym[5], Nathalie Korboulewsky[6], Magnus Löf[7], Arne Nothdurft[8], Maciej Pach[9], Hans Pretzsch[5], Ricardo Ruiz-Peinado Gertrudix[10], Quentin Ponette[1]

[1] Earth & Life Institute, Université catholique de Louvain, Louvain-la-Neuve, Belgium.
[2] Gembloux Agro-Bio Tech, TERRA Teaching and Research Centre, University of Liège, Gembloux, Belgium.
[3] Department of Silviculture, Warsaw University of Life Sciences, Warsaw, Poland.
[4] Sustainable Forest Management Research Institute, University of Valladolid, Valladolid, Spain.
[5] Chair of Forest Growth and Yield Science, TUM School of Life Sciences Weihenstephan, Technical University of Munich, Freising, Germany.
[6] Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture, Domaine des Barres, France.
[7] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Alnarp, Sweden.
[8] Institute of Forest Growth, Department of Forest and Soil Sciences, University of Natural Resources and Life Sciences, Vienna, Austria.
[9] Department of Forest Ecology and Silviculture, Faculty of Forestry, University of Agriculture in Krakow, Krakow, Poland.
[10] Forest Research Centre, INIA, Madrid, Spain.

Mixed forests are usually associated with increased aboveground carbon storage but information on the impact of mixing on soil organic carbon (SOC) is still limited. Yet, this soil contribution is crucial for long-term carbon storage under climate change. This study used a triplet approach (i.e. two-species mixed stand and respective pure stands) to assess the impact of species identity and diversity on SOC storage in eight pine-oak, eight pine-beech and five oak-beech triplets along an ecological gradient in Europe. We sampled the forest floor (FF) and 0-40cm in the mineral soil per 10cm interval. For each triplet type, we fitted basal area (BA) proportion of one species (for species identity), BA-based plot-level Shannon Diversity index, and site (as main effect and in interaction with species identity and diversity) as explanatory variables for SOC in multiple linear regression models that also included stone content and plot BA as covariates. Considering the whole soil profile (FF+0-40cm layer), species identity effect was only significant for pine-beech and pine-oak triplets; conversely, species diversity effect was site-dependent in pine-beech and oak-beech triplets but was not detected in pine-oak triplets. While species identity effect was consistently more pronounced in the superficial soil layers across the triplet types, species diversity effect was limited to deeper soil layers. When significant, the diversity effect was either synergistic or antagonistic. The results show that species identity and site conditions are stronger drivers of SOC storage than species diversity, especially in the upper soil layers.

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Identifying the tree species compositions that excel in the provision of multiple benefits

Jillian Mayberry[1], Lesley Lancaster[1], Joan Cottrell[2], Nadia Barsoum[3]

[1] Institute of Biological and Environmental Sciences, University of Aberdeen, Aberdeen, UK
[2] Centre for Ecosystems, Society and Biosecurity, Forest Research, Northern Research Station, Roslin, Midlothian, EH25 9SY, UK
[3] Centre for Ecosystems, Society and Biosecurity, Forest Research, Alice Holt Lodge, Farnham, Surrey, GU10 4LH, UK

Increasingly, international forest policy is encouraging the establishment of mixed tree species plantations, in preference to monocultures, in order to improve resilience and gain multiple ecosystem services, including enhanced woodland biodiversity. Many studies comparing monoculture and polyculture effects on woodland biodiversity have revealed the importance of tree identity, but the relative benefits of specific tree species combinations in mixtures is still poorly understood. The Gisburn experimental trials, Lancashire, UK offer a unique opportunity to gain greater understanding of not only the commercial viability, but also the biodiversity benefits of specific tree species combinations. We used this trial to study tree species compositional effects on the taxonomic and functional diversity of ground-dwelling Carabids (*Coleoptera*: *Carabidae*) and vascular plants in monocultures and two-species mixtures of Scots pine, Norway spruce, common alder and sessile oak. We consider the relative biodiversity value (in terms of carabid beetles and vascular plants) and tree growth performance of the range of monocultures and polycultures in our study to identify the crop types that provide maximum combined benefits.

Effects of spruce budworm outbreaks and suppression on carbon dynamics in forest soils

Michael Stastny[1], Louis-Pierre Comeau[2], Cameron Wagg[2], Stephen Heard[3]

[1] Atlantic Forestry Centre, Canadian Forest Service
[2] Agriculture and Agri-food Canada
[3] Department of Biology, University of New Brunswick, Canada

Multi-year outbreaks of spruce budworm (*Choristoneura fumiferana*), a lepidopteran defoliator of fir and spruce, are the most important natural disturbance in mixed and conifer forests of eastern Canada. Canopy loss and tree morality over millions of hectares reduce photosynthesis and presumably change microclimate and microbiota of forest soils. In the short term, defoliation also may increase carbon inputs through insect frass and litterfall. Yet, the magnitudes of these contributions to carbon cycling are poorly understood. The regional management of spruce budworm using aerial application of biological insecticides (*Btk*) offers an opportunity to understand and manage spruce budworm's effects on carbon cycling in one of the most extensive forest biomes.

We have begun a multi-year experiment in eastern Quebec, Canada, to quantify soil carbon processes in 12 forest watersheds at the onset of an outbreak, by manipulating defoliation in half of the watersheds through spraying with *Btk*. We are sampling soils for litter, carbon, nitrogen, and mycorrhizal colonization, measuring soil temperature, in-situ soil metabolism and decomposition rates, and quntifying frass and needlefall inputs to soils. Together, these data will reveal how defoliation influences soil biota and their role in carbon flux and storage. Preliminary results reveal patterns in frass- and litterfall among sites differing in baseline defoliation, but only subtle differences in soil parameters, including decomposition rates. These findings are consistent with our pilot work in nearby sites with longer defoliation histories, and suggest that carbon cycling effects are likely cumulative time during the multi-year outbreaks of spruce budworm.

Effects of tree species mixing on ecosystem carbon and nitrogen stocks in a Swedish boreal forest

Róbert Blaško[1], Benjamin Forsmark[1], Michael Gundale[1], Tomas Lundmark[1], Annika Nordin[2]

[1] Department of Foret Ecology and Management, Swedish University of Agricultural Sciences, Umeå, Sweden
[2] Department of Forest Genetics and Plant Physiology, Umeå Plant Science Center, Umeå, Sweden

Targeted selection and mixing of particular tree species with a potential to promote C storage in tree biomass and soil is one of the management tools for climate change mitigation. Majority of the research has focused on the diversity-productivity relationship, but far less is known about how tree species mixing impacts on belowground C stocks, as well as the whole ecosystem C stocks. We used 60-year-old experiment in boreal Sweden with adjacent monoculture and mixed stands of the two dominant coniferous species in Sweden: Norway spruce (*Picea abies* (L.) Karst) and Scots pine (*Pinus sylvestris* (L.). The aim of the study was to evaluate the species mixing effects on ecosystem C and N stocks.
We measured total standing volume, total tree biomass, C and N stocks in tree biomass and soil, litterfall inputs, fine-root biomass, and soil CO_2 efflux. Our results show major differences in C allocation and growth patterns between spruce and pine that were enhanced in the mixed stands. Our results do not suggest significant mixing effect and the idea of higher productivity and C sinks in mixed stands, given the levels of the measured variables did not exceed levels of the most productive monoculture, in our case pine monoculture. Hence, our results suggest that Norway spruce and Scots pine are not complementary tree species from the forest management perspective. However, the mixed stands performed equally well as the best monoculture indicating that mixed-stands management may not result in any loss in C uptake and storage.

Species-specific deadwood density and its driven factors in a virgin European beech-silver fir mixed forest in the Southern Carpathians

Any Mary Petritan[1], Victor Vasile Mihaila[1,2], Ioan Cosmin Braga[1], Ion Catalin Petritan[2]

[1] National Institute for Research-Development in Forestry ‘Marin Dracea‘, Brasov, Romania
[2] Transilvania University Brasov, Romania

Deadwood is a fundamental structural and functional component of natural forests contributing to the forest biodiversity and to the natural nutrient and carbon cycling. For a better understanding of the dynamics of deadwood in a natural forest, it is important to achieve deeper information about decay rate of wood and how it is influenced by environmental factors. In this study, we attempted to estimate dry deadwood density for two species and three for snags and five for logs decomposition classes and to assess the influence of its related factors (moisture, rottenness, position of the sampling along piece, the contact with the ground, elevation, slope, aspect) in a virgin mixed beech-fir forest in the Southern Carpathians. For snags the mean dry density showed a reduced variability within decomposition classes (484-326 kg.m^{-3} for beech and 374-319 kg.m^{-3} for fir), comparing to the logs (486-151 kg.m^{-3} for beech and 359-161 kg.m^{-3} for fir). The mass moisture varied slowly in the first three decay classes (around 60-80%), while it increased sharply in the last two decay classes of logs (> 140% in the fourth classes and > 350% in the last one). The rottenness increased with the decay degree in a similarly way for both species. The logs contact with the ground influenced positively the moisture, while the position of the sampling along piece didn’t play any role in the variation of mass moisture or density. The determined densities per decay class will be used in estimating the amount of carbon sequestrated in deadwood.

Session 2: Ecosystem services from mixed forests.

Key-note talk: Anna BARBATI, University of Tuscia, Department for Innovation in Biological, Agro-food and Forest systems (DIBAF), Viterbo, Italy.

Can mixed forests play the jack-of-all-trades in ecosystem services provision?

Mixed-species forests have long been regarded to be better able to deliver multiple ecosystem services (ES) than single-species ones. The ‘Jack-of-all-trades’ has been proposed as an intuitively well-grounded assumption, arguing that a diverse forest community (‘Jack’), would have moderate levels of most ecosystem functions (‘trades’), but would hardly reach the highest possible levels of any function (‘master-of-none’). On this ground, an observational study has been conducted in the framework of the REFORM project based on real-world forest communities growing in different European Biogeographical Regions. Main study goal was to compare ES provision between stands dominated by one tree species (Sp1, Sp2) with mixed stands of the two species (Sp1xSp2) over large forest areas, characterized by relatively homogeneous environmental conditions. Sampling plots were pooled from National and Regional forest inventories. Plots were assigned to mixed stands when the basal area percentage of 2 (or 3) species exceeds (or is equal to) 15 percent of total plot basal area. Provisioning and regulating ES were quantified at plot-level using the following parameters: growing stock, timber production, carbon sequestration and biodiversity indicators for habitat provision (density of large trees, tree size diversity, richness of not dominant trees). For each case study, the level of provision of single ES was standardized at plot-level (0, 1). Multiple ES provision was then quantified as the number of ES in a plot that had a value above a given threshold. Multiple thresholds levels were considered (0.2, 0.4, 0.6, 0.8). Findings from statistical non-parametric tests show that the ‘Master’ in the provision of single ES are generally single species coniferous stands for timber provision, while mixed stands can show better performance for carbon sequestration and habitat provision. Mixed stands perform better than single species in providing low to moderate level of multiple ES, thus confirming the ‘Jack-of-all-trades’ hypothesis.

Prof. Anna Barbati, PhD, is Associate Professor at the University of Tuscia (Viterbo, Italy), where she teaches “Geomatics & Forest Inventories” and “Research support for sustainable forest management”. She has developed her research experience in the field of forest management and planning, gaining a specific expertise on the following topics: geomatics applications to forest monitoring, with a focus on forest productivity and structural and compositional biodiversity variables and implementation of forest types classifications to monitor sustainable forest management at European level. Her recent research interests lie in the area of application of remote sensing-based and/or forest sampling strategies, to study interactions between compositional and structural heterogeneity at stand scale and supply of multiple ecosystem services (wood and non-wood products, forest biomass, carbon sequestration, habitat provision).

Tree Species Composition and Diversity Influence Provision of Multiple Ecosystem Services in Pacific Northwest US Plantation Forests

Austin Himes[1]

[1] Oregon State University

Trends in landcover and demand for ecosystem services suggest plantation forests will be expected to provide a larger quantity and diversity of ecosystem services. Higher tree species diversity has been suggested as one way of increasing the provision of multiple ecosystem services to meet future demand. However, trade-offs between different ecosystem services are well documented in forest systems. We rely on the results of a study in intensively managed forest plantation in the Coast Range of the US Pacific Northwest to discuss linkages between tree species diversity, ecosystem components, forest management and ecosystem services.

We collected data from trees and understory plants in 43 plots in 35 to 40 year-old (late rotation) industrial stands with similar management history. The tree species composition of plots included monocultures and all possible two and three species mixtures of western hemlock, Douglas-fir, and red alder. We derived proxies for nine ecosystem services from the field data and used a response surface model and simple optimization process to determine species compositions that maximized potential ecosystem service output under four sets of hypothetical management objectives. We further compared the response of the nine ecosystem service proxies to two common indicators of ecosystem function in forests: above ground biomass of trees and plant species diversity of the understory. Our results highlight trade-offs between individual ecosystem services, suggest compatibility between some forest management strategies and demonstrate potential limitations to relying on a single response variable (e.g. tree biomass/productivity) in forest biodiversity ecosystem function (BEF) studies.

How do sessile oak and Scots pine admixtures affect carabid beetles in the eastern part of the German lowlands?

Alexandra Wehnert[1] , Franka Huth[1], Sven Wagner[1]

[1] Institute of Silviculture and Forest Protection, Department of Forest Sciences Tharandt, TU Dresden

Scots pine forests account for 70 % of the forest cover of the eastern part of the German lowlands, compared to only 6.7 % sessile oak forests. Oak trees of a comparable age are typically admixed in pine forests as single trees or in small groups. In four different forest types comprising (i) pure oaks, (ii) pure pines, (iii) equal oak-pine mixtures and (iv) single tree admixtures of oak in pine forests, we analysed the effects of the stand composition on the representatives of larger carabid beetles (*Carabus coriaceus, C. violaceus, C. arvensis, C. hortensis, Calosoma inquisitor*). These carabid beetles are known for their function as environmental indicators and predators of pest insects. In a six months study period, pitfall traps were established on a grid. The samples focussed on gender-specific analyses of carabid beetles. The results showed that *Calosoma inquisitor, Carabus coriaceus* and *C. hortensis* were non-existent in the pure pine forest type. Individuals of *Calosoma inquisitor* were only present in pure oak forests with activity densities per hectare of 8.6 (females) and 32.1 (males). The highest activity density in the pure pine forest type was documented for C. violaceus males. In the two mixed forest types, both genders of *C. arvensis* exhibited the highest activity densities, between 9.6 and 20.0 individuals per hectare. *C. coriaceus, C. violaceus* and *C. hortensis* also demonstrated high activity densities. The statistical analyses of species-specific body parameters revealed that females were significantly larger than males, especially in the mixed forest types.

Retaining border zones for the benefit of conservation: a case study from southern Sweden

Isak Lodin[1], Ljusk-Ola Eriksson[2], Adam Felton[1]

[1] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, P.O. Box 49, SE-230 53 Alnarp, Sweden
[2] Department of Forest Resource Management, Swedish University of Agricultural Sciences, SE-901 83 Umeå, Sweden

Swedish forestry is characterized by relatively intensive silvicultural practices which have been, and still are, strongly focused on managing Norway spruce and Scots pine. More diversified management including *inter alia* the increased use of mixed forest and broadleaves have been suggested as suitable future alternatives to promote biodiversity conservation and reduce climate change related risks. One complementary and perhaps partly overlooked pathway to increase the diversity of the forest landscape is to increase the ecological quality of retention patches at final felling. Recent studies indicate that border zones towards water and other land uses have a higher share of broadleaves and therefore should be prioritized for retention. This presentation will focus on showing results from a study investigating the benefits of prioritizing the retention of border zones at final felling. Our study is based on investigations initiated in a collaborative project in nature conservation between the research project ALTERFOR and the county administrative board in Kronoberg County. Our results are based on projections over 100 years for typical southern Swedish landscapes in the decision support system Heureka. Our results indicate that retaining border zones towards water and open land seems to be a promising strategy. On average the border zones have twice as high standing volume of broadleaves compared to the average on productive forestland. In the presentation I will also discuss the prospects of retaining these broadleaf rich zones in practical forestry.

Disentangling the relationship between tree biomass yield and biodiversity in Mediterranean Mixed Forests

Felipe Bravo[1], Narangarav Dugarsuren[1], Ana Martín Ariza[1], Cristóbal Ordóñez[1]

[1] iuFOR, Universidad de Valladolid. Spain

Tree biomass and diversity relationship in mixed forest is a hot topic in due to its impact on ecosystem services provisions. By comparing pure and mixed forests and within mixed forests diverse degrees of mixture we can insight on the ecosystem services provision level and dynamic. 3 monitoring sites in the Castilian Northern Plateau (Spain) have been analyzed in order to disentangling the relationships betwee biodiversity levels and biomass yield. In this sites a set of permanent plots, located in Llano de San Marugan, Ampudia and Celadilla del río, were established accounting for a total of 2,8 ha were every tree was measured (diameter and height), georeferencied and its species identity defined. Species presents in the 3 monitoring sites were *Pinus sylvestris, Pinus nigra, Pinus pinea, Pinus halepensis, Quercus pyrenaica, Quercus ilex, Quercus faginea, Juniperus thurifera* and *Cupressus arizonica*. From these datasets 10 diversity indices that falls in 3 categories: species richness indices, species compositional/mingling indices (Mi, MS, S) and vertical structural indices (W, A, TH) were used as predictor variables for the models to characterize different structure of diversity in the stands. Several linear models were fitted. Models were ranked on the Akaike Information Criterion (AIC) basis and finally the best one for each species and site selected. Our results revealed that tree biomass and diversity relation varies among species and sites. Different simulations and sensitive analysis are presented.

Mixture-effects on tree biomass production and soil organic C quality in a temperate plantation forest

Iftekhar Ahmed[1], Andrew Smith[2], Douglas Godbold[1]

[1] Universität für Bodenkultur (BOKU)
[2] Bangor University

Forest restoration and afforestation on degraded lands are receiving tremendous research efforts globally as a climate change mitigation option. There is a growing interest in mixed species plantation to ensure sustainable ecosystem services and biodiversity. However, successful mixture of achieving these potential benefits is rare. We studied the polyculture of two pioneer fast growing species (i.e. *B. pendula*, and *A. glutinosa*- of which *A. glutinosa* is N-fixing) and one shed tolerant species with slow juvenile growth (i.e. *F. sylvatica*) to examine the effects of species mixture on biomass production and quality of soil organic C stock following the replacement series approach. Standing woody biomass in polyculture demonstrated no over-yielding, presumably due to concurrent impacts of suppression of *F sylvatica* by two fast growing species and competitive reduction benefits in *A. glutinosa*. Similarly, standing fine root biomass production and turnover showed no significant mixture effect. Although the quantity of soil organic C stock was unaffected by tree mixture, the vertical distribution of biodegradable C fractions was differed between mono and polyculture stands, most probably due to slow decay rate of mixed litter. We found that species mixture decreased soil C lability in the upper soil layers, and increased recalcitrant C in deep soil (>40 cm) that has enormous potential for long-term sequestration. We concluded that contrasting growth responses can result in no biomass over-yielding in polyculture stands but the mixed litter can affect soil C quality.

A simulation-based study to explore the impact of climate change on pure and mixed forests across Europe

Xavier Morin[1], Maude Toigo[1], Rafael Calama[2], Felipe Bravo[3], Markus Engel[4], Hervé Jactel[5], Antonio Tomao[6], Carlo Trotta[6], Mathias Steckel[7], Arne Nothdurft[4], Hans Pretzsch[7], Sonja Vospernik[4], Anna Barbati[6]

[1] CNRS
[2] CIFOR-INIA
[3] Universidad de Valladolid
[4] University of Natural Resources and Life Sciences, Vienna (BOKU)
[5] INRA
[6] University of Tuscia
[7] Technische Universität München

Ongoing and future climate change puts forests at risk by strongly impacting forest composition and functioning. Yet, large uncertainties remain regarding how climate change will affect forest dynamics, notably because forests have slower dynamics than other terrestrial ecosystems. In this context, forest models represent a key tool to explore the links among species composition, forest functioning and climate, complementing former experimental and empirical approaches. Furthermore, some models allow to take in account the possible adaptive role of forest management in maintaining forest functioning. Part as the REFORM project, we explored how climate change differentially affect pure and mixed stands across several forest types in Europe (from Mediterranean to alpine forests). To do so, we relied on simulations performed with a range of forest models, from semi-empirical gap models to ecophysiology-based models. We have considered several climatic scenarios from various climate models.

We found that the impact of climate change of EU forest types may greatly vary depending on species composition and site location. Yet, our simulations show how species mixing may promote ecosystem resistance to harsher climatic conditions, although some mixtures may be difficult to maintain in future conditions, especially for drought-sensitive species. We further discuss our results in the light of the models' comparisons, and the implications of our findings about forest management. This study opens key perspectives regarding our ability to predict the future of European forests while taking into account the role of species composition in mitigating the impact of climate change and in preserving ecosystem services.

Mixed longleaf, slash, and loblolly pine plantations in southern Georgia, USA

Thomas Harris[1], Bronson P. Bullock[1], Cristian R. Montes[1]

[1] Warnell School of Forestry and Natural Resources, University of Georgia, Athens, GA, USA

As a commercial timber species, longleaf pine (*Pinus palustirs* Mill.) has a commonly understood history of exploitation and extirpation from its native range. However, in the past few decades, US federal government agencies have subsidized landowners to restore longleaf pine forests for biodiversity and conservation. Now, there are more than 100,000 hectares of old-field sites have been planted with longleaf pine across Georgia and the southeastern US. Currently, longleaf pine seedlings are being produced at the same rate as slash pine (*Pinus elliottii* Engelm.), a commercial tree species, across the Southeastern US. However, low initial survival rates for longleaf pine in the first or second growing seasons results in partial plantation failures. To ameliorate that, landowners return to newly established longleaf pine stands and interplant to loblolly pine (*Pinus taeda* L.) or slash pine seedlings, which are less expensive compared with longleaf pine seedlings. Without the government incentives to offset the cost of planting the more expensive longleaf seedlings, many landowners fill in the area with poor survival with the relatively cheaper alternative.
We will evaluate the scope of the problem and possible impacts on yield resulting from the introduction of other pine species into the longleaf pine plantations. The impacts of this initial review will be useful for the existing longleaf pine stands and newly established stands across Georgia and the southeast US on old-field and cut-over sites.

Above ground tree biomass, carbon stocks and tree diversity in a mixed forest plantation in Northern Vietnam

Thi Nhat Minh Doan[1], Van Manh Vu[1], Irene Ruano[2], Felipe Bravo[2]

[1] VNU University of Science, Vietnam National University, Hanoi (Vietnam)
[2] iuFOR, Universidad de Valladolid (Spain)

Biomass research and plantation in the tropics have long been recognized as an effective solution in reducing the rate of increase in CO_2 in the atmosphere. Most of the forest plantations included only one tree species nevertheless, the use of two or more tree species during the planting phase and the plantation diversification are becoming more and more frequent. In this research, carbon stocks and above ground tree biomass by compartments were calculated from a one hectare marteloscope established in the framework of BioEcoN project (http://bioecon.eu/) in Vietnam, using different developed biomass equations. The relationship between above ground tree biomass and species diversity was examined using model selection approach by ranking linear models through Akaike Information Criterium where predictor variables considered are a set of parameters for the characterization of mixed stand structure include stand density and species proportion, species intermingling and horizontal and vertical tree distribution pattern. The results show that the study area embraces 110.66 tons/ha of tree biomass and 55.33 tons/ha of carbon in the aboveground compartments. Furthermore, results from the calculation of indices for characterizing species richness and diversity indicates high diversity and high evenness in the community. Although the study area is said to be a plantation, the results from a set of measures, indices, and methods for characterization of tree distribution patterns illustrate random distribution patterns. Sensitivity analysis indicates that above ground biomass and carbon concentration decrease as the species diversity increase.

Session 2: Ecosystem services from mixed forests. Poster presentations

Ecological mechanisms for mixture and diversity effects on ecosystem services

Jan Bengtsson[1]

[1] Swedish University of Agricultural Sciences

Ecological mechanisms for mixture (or diversity) effects on biomass production have been studied for a long time in basic ecology, agriculture and forestry, both from theoretical and applied perspectives. Intercropping effects on yield have been studied in especially agricultural research. However, effects of mixtures on ecosystem services (ES) other than yield are still rare. Recent focus on managing production ecosystems for multifunctionality highlights the need to understand mixture effects on multiple ES. There are basically approximately five main categories of mechanisms behind positive mixture effects, i.e. transgressive overyielding in which the mixtures produce more of the ES than the best monoculture.

- Niche differences in resource use.
- Increasing amounts of resources, e.g. mixtures with N-fixing components.
- Lower pest levels or herbivory.
- Higher resistance to disturbances, e.g. storms or fire.
- Higher stability in ES production over time.

The two latter are versions of insurance effects based on species differences in response to environmental variation over time. Obviously, understanding and utilisation of mixtures based these mechanisms require a knowledge of which species are combined in mixtures, not just observations of a diversity effect. Previous results on mixture effects based on the Swedish NFI support the view that positive mixture effects on forest ES – production of tree biomass as well as other ones – are based on niche differences in tree species resource use. However, the other mechanisms are more difficult to evaluate using the plot-based data in the NFI, and may require approaches that account for landscape effects on forest ecosystem services.

Short-time effects of forest harvesting on soil carbon stocks and fluxes in a former virgin mixed forest

Cosmin Braga[1], Any Mary Petritan[1], Victor-Vasile Mihaila[1,2], Vlad Crisan[1], Catalin Ion Petritan[2], Elena Deleanu[1], Jorge Curiel Yuste[2, 3]

[1] National Institute for Research and Development in Forestry "Marin Dracea"
[2] TRANSILVANIA" University of Brasov, Faculty of Silviculture and Forest Engineering
[3] BC3-Basque Centre for Climate Change

In this study we compared two old beech - silver fir forests: a virgin forest (VF) and a former virgin forest (FVF) with similar tree composition and growing conditions, in the southern Carpathian. In the FVF the first silvicultural interventions were carried out ten years ago. For each forest type, we investigated the variability of soil carbon stocks, soil respiration rates (Rs) and soil environmental conditions. Using an infrared gas analyzer (IRGA), Rs was monitored during the growing season (from May to November) of 2017, together with the microclimatic parameters (soil temperature and soil moisture) that can modulate it. Reduction of the stand density by silvicultural interventions influenced positively rates of Rs, especially during summer when the soil perturbation and intensity of light (both variables associated with FVF) were the main factors that best explained the variability of Rs and the soil microclimate. The results obtained showed that the mean value of Rs was 2,72 $\mu\ m^{-2}\ s^{-1}$ in VF compared to 3,68 $\mu\ m^{-2}\ s^{-1}$ in FVF. The rates of Rs ranged from 1,99 $\mu\ m^{-2}\ s^{-1}$ in November (VF) to 5,43 $\mu m^{-2}\ s^{-1}$ in August (FVF). Within site variability of Rs was highest in FVF during the summer (CV=47%) and in VF during fall (CV=56%). Further, the experimental results indicated more soil carbon content in FVF site compare with VF site. Our data suggest that the forest management interventions can increase stocks and emissions of soil carbon, but for long term this trend can be modify.

Assessing soil Phosphorus availability under mixed stands of *Quercus* sp. and *Pinus sylvestris* vs pure stands.

Marina Getino Álvarez[1, 2], Luisa Fernanda Velasquez Camacho[1, 2], Javier de Dios García[3], Valentín Pando Fernández[1, 2], Felipe Bravo Oviedo[1, 2], Mª Belén Turrión Nieves[1, 2]

[1] Escuela Técnica Superior de Ingenierías Agrarias, Universidad de Valladolid, Palencia, Spain.
[2] Sustainable Forest Management Research Institute, UVa-INIA. Palencia, Spain.
[3] Centro de Ciencia y Tecnología Forestal de Cataluña (CTFC), Solsona, Spain.

An increasing number of forest managers have focused their work on mixed rather than pure stands due to the strong evidences that mixed forests provide several ecosystem services more efficiently. Nevertheless, is still necessary to intensify the studies to assess the effect of mixed stands on soil nutrients availability. It is widely known that phosphorus - P- is an essential element for life and vegetation development. But it is also known that its presence is not always in easily available forms, what can be a big limitation in the ecosystems. In this study we assess whether oak-pine (*Quercus* sp. and *Pinus sylvestris*) mixed forests influence differently than pure ones on the state and availability of soil P. To this end, the superficial soil horizon of the soil was studied within three experimental triplets located in the Cantabrian Mountains and the Pyrenees. Each group was formed by two monospecific plots and a mixed one. Soil samples were taken in specific points covering a wide range of percentage of species mixture, as well as different stand densities. At each sample, organic P, inorganic P, as well as P in soil microbial biomass phosphorus and enzymatic phosphatase activity were measured. Data was analyzed using a two factors linear mixed model. Results suggested that the mixture of species do not affect significantly the status and availability of P in these soils in comparison to the monocultures. Location and the edaphic and environmental characteristics seem to be the ones determining P behavior on these soils.

Influence of Agroforestry on Rural Income and Livelihood of Smallholder Farmers in the Semi Arid Region of Sub Saharan Africa

BENJAMIN KINYILI[1], Ezekiel Ndunda[2], Esther Kitur[3]

[1] Benjamin Mutuku Kinyili, Kenya Forest Services, PO Box 2501-30100, Eldoret, Kenya
[2] Ezekiel Ndunda, Department of Environmental Science, Kenyatta University, PO Box 43844–00100, Nairobi, Kenya
[3] Esther Kitur, Department of Environmental Science, Kenyatta University, PO Box 43844– 00100, Nairobi, Kenya

Semi arid lands typically suffer from sustainable land use challenges including climate variability, declining agricultural productivity, low economic prowess and poor livelihood conditions. In order to sustainably address these challenges, agroforestry has been fronted as a critical entry point allowing for the integration of trees on farms and diversification of production in agricultural landscapes. Nevertheless, the contribution of agroforestry to socio-economic and rural livelihood in several developing countries remains debatable. This study determined the influence of agroforestry on rural income and livelihood of smallholder farmers in Machakos County (Kenya). The study was conducted using survey research design from a sample of 248 individual farmers, selected using stratified, random sampling. Data were collected using questionnaires and interviews. Results showed that agroforestry was adopted by 82% of the respondents as a strategy for livelihood improvement in the region. Total income was higher among adopters from timber, fuel wood, posts/poles and fodder. Adopters also had more money to spend on food, clothing, education, medicine and basic needs as a result of revenues from agroforestry. The overall gross revenue, net returns above variable costs and total costs were also higher among adopters compared to the non-adopters due to sales of agroforestry products. The study recommends adoption of agroforestry as a strategy to boost rural income and livelihood. The policy makers can create awareness for adoption of agroforestry for increase of tree cover, ecosystem goods and services.

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Responses of functional diversity in forest understory to canopy structural heterogeneity

Sara Klingenfuss[1], Jan Helbach[1], Michael Scherer-Lorenzen[1]

[1] Department of Geobotany - Faculty of Biology, University of Freiburg, Freiburg, Germany

In plant communities, species can be arranged in the multidimensional space of their functional traits. Shifts in the environmental conditions to which a community is exposed might also entail shifts in their functional space. The volume of this trait space might furthermore be extended by changing environmental conditions, which allow for more coexisting species. Habitat heterogeneity, therefore, influences functional diversity, and ultimately biodiversity. Declines in biodiversity are frequent in managed landscapes, especially in economically utilized environments. Forest management, for example, is one factor introducing heterogeneity into a plant community's environment. However, little is known about the influence of management-induced structural heterogeneity in forests on the functional diversity of the understory. We hypothesize that the functional diversity of the forest understory is higher in structurally rich environments with a high degree of temporal and spatial variability in resource availability.

We will present results from our study, which combines vegetation surveys and measures of canopy structure from the Black Forest, Germany with functional trait values from the TRY database. The project aims to provide evidence-based recommendations for forest management and conservation, in order to deal with the challenges of improving and maintaining biodiversity in managed forests in Central Europe.

How tree mixture and diversity affects soil fauna diversity?

Nathalie Korboulewsky[1], Matthieu Chauvat[2]

[1] Irstea, UR EFNO Ecosyst emes Forestiers, 45290 Nogent-sur-Vernisson, France
[2] Ecodiv URA/EA-1293, Normandie Université, 76821 Mont Saint Aignan Cedex, France

In the context of sustainable forest management and climate change, increasing tree richness has been proposed as a possible strategy to reach both ecological and productivity goals. This review focuses on the effects of mixed stands and increasing tree richness on soil fauna in temperate forests. Effects on earthworm and microarthropod (Collembola and Oribatid Mites) species diversity and abundance and community structure are examined. Our statistical analyses showed no evidence of any general trend for the effect of mixture either on earthworm or microarthropod diversity or on their abundance. Indeed, positive, negative and nonsignificant effects have all been reported. Nevertheless, the majority of the studies did find that increased tree richness or the introduction of broad-leaves had a positive effect. In addition, our review shows that soil organism abundance and diversity can be strongly affected by the presence of certain tree species and that the soil organism community structure is, in most cases, significantly affected by an increase in tree richness or by a mixing effect. Litter features appear to be important drivers of soil fauna community composition, while mixture effect seems to have less impact on soil biota. Soil fauna are directly affected by the physical characteristics (microhabitats) and chemical composition (resource quality) of the litter specific to each tree species. Soil communities are then indirectly affected by the subsequent humus characteristics. We conclude our review with some guidelines for forest management and further research.

Mixed pine stands conserve the understory richness under worse water soil conditions and improve soil fertility

Daphne López-Marcos[1, 2], María-Belén Turrión[1, 2], Felipe Bravo[2, 3], Carolina Martínez-Ruiz[1, 2]

[1] Dpto. de Ciencias Agroforestales, E.T.S. de Ingenierías Agrarias, Universidad de Valladolid, Campus La Yutera, Avda. Madrid 50, 34071 Palencia, Spain.
[2] Sustainable Forest Management Research Institute, Universidad de Valladolid & INIA, Avda. Madrid 50, 34071 Palencia, Spain.
[3] Dpto. de Producción Vegetal y Recursos Forestales, E.T.S. de Ingenierías Agrarias, Universidad de Valladolid, Campus La Yutera, Avda. Madrid 50, 34071 Palencia, Spain.

Many studies highlight the role of mixed forests to provide ecosystem services more efficiently than monospecific forests. Most report of the positive mixture effect on biodiversity focus on mixtures that combine tree species with contrasting traits, but little is known about the relationship overstory-understory-soil in coniferous tree mixtures. Thus, 6 triplets of Scots pine and Maritime pine were selected in North-Central Spain to assess the effects of mixed vs monospecific stands in the understory richness and composition and its relationship with the soil status. The cover of every understory vascular plant species was estimated visually and data were codified according to Raunkiær's life-forms in ten one square meter quadrats randomly located per plot. One soil pit of 50 cm depth was dug in each plot to determine the soil´s water-holding capacity and fertility (carbon and exchangeable cations stocks) status. The overstory and understory respond to a waterstress gradient: Maritime pine tolerates lower soil´s water holding capacity than Scots pine. Secondarily, a soil fertility gradient defined by organic carbon and exchangeable magnesium stocks was identified. Mixed stands under greater water stress than Scots pine stands maintain the same level of understory richness. Hemicryptophytes, whose abundance is greater in mixed stands, were the only understory life-form positively correlated to soil fertility. We conclude that the mixture of both *Pinus* species should continue to be favored in the study area because it helps to maintain understory richness, similar to *Pinus sylvestris* stands, under greater water-stress conditions and improves soil fertility.

Do mixed versus pure pine forests show a different pattern of carbon accumulation in the soil profile?

Daphne López-Marcos[1,2], Carolina Martínez-Ruiz[1,2], María-Belén Turrión[1,2], Mathieu Jonard[3], Hugues Titeux[3], Quentin Ponette[3], Felipe Bravo[2, 4]

1 Dpto. de Ciencias Agroforestales, E.T.S. de Ingenierías Agrarias, Universidad de Valladolid, Campus La Yutera, Avda. Madrid 50, 34071 Palencia, Spain.
2 Sustainable Forest Management Research Institute, Universidad de Valladolid & INIA, Avda. Madrid 50, 34071 Palencia, Spain.
3 ELIE, Université catholique de Louvain, Croix du Sud 2, Louvain-la-Neuve, Belgium.
4 Dpto. de Producción Vegetal y Recursos Forestales, E.T.S. de Ingenierías Agrarias, Universidad de Valladolid, Campus La Yutera, Avda. Madrid 50, 34071 Palencia, Spain.

Many studies highlight the role of mixed versus monospecific forests to supply numerous ecosystem services like carbon sequestration. The positive effect of tree mixtures on carbon storage (Cstock) is already known, but little is known about the underlying mechanisms in tree mixtures of the same genus. In this study, we assessed the effect of mixed vs. monospecific stands of Scots and Maritime pine on carbon storage along the soil profile, based on research with six triplets in the northern Iberian Peninsula (Spain). One soil pit of at least 30 cm depth was dug at each plot for soil characterization: the percentage of fine roots (%FR) and the Cstock were analyzed every 10 cm. Also, a 25x25 cm quadrant was used to collect the forest floor (FF) and its Cstock, and carbon-nitrogen ratio (C/N) were analyzed. Two trends were found: in the topsoil (0-10 cm), higher values of Cstocks soil were found in Scots pine stands, lower in Maritime pine stands and intermediate in mixed stands; this pattern was related to the C/N of FF. In the intermediate soil layers (10-30 cm), Cstock tends to be higher in mixed stands and is related to the %FR and to the greater thickness of the first mineral horizon. These results improve our understanding of the mechanisms underlying soil carbon accumulation in mixed stands and emphasize the use of mixtures as a strategy to combat climate change, due to the advantage in the accumulation of carbon in the subsoil layers that hinders its mineralization.

Does mixed pine forest conserve the understory richness through the native oak regeneration?

Daphne López-Marcos[1,2], María-Belén Turrión[1, 2], Felipe Bravo Bravo[2,3], Carolina Martínez-Ruiz[1,2]

[1] Dpto. de Ciencias Agroforestales, E.T.S. de Ingenierías Agrarias, Universidad de Valladolid, Campus La Yutera, Avda. Madrid 50, 34071 Palencia, Spain.
[2] Sustainable Forest Management Research Institute, Universidad de Valladolid & INIA, Avda. Madrid 50, 34071 Palencia, Spain.
[3] Dpto. de Producción Vegetal y Recursos Forestales, E.T.S. de Ingenierías Agrarias, Universidad de Valladolid, Campus La Yutera, Avda. Madrid 50, 34071 Palencia, Spain.

The relevance of mixed forest management has increased due to their more efficiently supply of ecosystem services like biodiversity. Most reports of the positive effects of mixtures on biodiversity conservation focus on coniferous–deciduous combinations, but little is known about the tree regeneration role on understory biodiversity in mixtures combining coniferous species. In northern Spain, 6 triplets of Scot pine and Maritime pine were selected to assess the effects of mixed vs monospecific stands to tree regeneration relationship with the niche amplitude and richness of the understory. In ten one square meter quadrats randomly located per plot, the cover of every understory vascular plant species, including tree regeneration and bryophytes, and the number of individuals of the tree regeneration were estimated. The understory composition and tree regeneration were explained by a gradient in the percentage of basal area of both *Pinus* species: Scots pine monospecific stands host species characteristics of humid zones, including *P.sylvestris* regeneration, whereas typical Mediterranean species of well-drained areas, including *P.pinaster* regeneration, dominates in *P.pinaster* monospecific stands. In mixed stands, the highest regeneration of the native Pyrenean oak was accompanied by typical species that share the same regeneration niche and contributed to maintaining the understory richness under worse environmental conditions.

Understanding pastoralists medicinal plants use in Kirisia Forest Reserve

Lucy Muithui[1]

[1] Doctoral School of Biology, Szent Istvan University, Hungary

Tropical forests in sub Saharan African are known to be a key source of medicinal plants important to the community living close to these forests. Among the Samburu people, the use of medicinal plants is part of their culture and traditions. Medicinal plants are preferred because they are affordable, easily available and believed to be safe than the conventional medicine. We interviewed vendors and elders in Maralal town to assess what plant and specifically what part of the plant (root, bark, leaves, seeds, fruit and flower) is used from Kirisia Forest Reserve. Forty-eight plants from thirty-two families were found to be used to treat different ailments among the Samburu. We also noted that most of the plant part sold by the vendors was dried barks, roots and seeds. The study highlights the importance of medicinal plants as an important forest ecosystem services contributing to livelihoods and the need to promote for sustainable utilization of the plant species.

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Studies on physico- chemical properties of soil under different forest communities in Col. Sher Jung National Park, Himachal Pradesh, India

S. Balaji Naik[1], Dr. Vimal Kumar Chauhan[1]

[1] Department of Silviculture and Agroforestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, India

The present investigation was carried out in Sirmour district of Himachal Pradesh, India, during the year 2018-19 with the aim to assess soil physico-chemical properties of major forest communities. The composite soil samples were collected from different layers 0- 20cm and 20-40cm for studying the soil physical and chemical analysis and depth–wise distribution of nutrient elements from eight sites. The Eight major forest communitie selected were as following: *Shorea robusta, Eucalyptus tereticornis, Syzygium cumini, Shorea robust + Terminalia tomentosa, Shorea robusta+ Eucalyptus tereticornis, Shorea robusta+ Syzygium cumini, Shorea robusta+ Diospyros melanoxylon*, and Mixed forest. Soil bulk density, soil organic carbon, pH, and soil electrical conductivity in soil at 0-20cm depth in different forests varied from 1.17 (Mixed forest) to 1.49 (*Eucalyptus tereticornis*) g/cm^3, 2.52 (*Eucalyptus tereticornis*) to 2.81 (Jamun forest) % , 5.28 (Sal+ Jamun forest) to 6.84 (Sal+ Eucalyptus) pH, 0.17(*Eucalyptus tereticornis*) to 0.23(Sal+ Sain and Sal+ Eucalyptus) dSm^{-1} respectively whereas, in 20-40 cm depth of soil their values were: 0.14 (*Eucalyptus tereticornis*) to 0.20 (Sal+ Tendu forest) g/cm^3, 2.34 (*Eucalyptus tereticornis*) to 2.67 (Jamun forest) %, 6.08(Jamun forest) to 7.67 (*Eucalyptus tereticornis*) pH, 0.14(*Eucalyptus tereticornis*) to 0.20 (Sal+ Tendu forest) dSm^{-1}. The per cent organic carbon and electric conductivity showed a decreasing trend with the increase in soil depth. Alternatively, soil pH and bulk density showed a reverse trend.

Establishment of Multifunctional Forest Garden: A Solution through Mixed Garden; A case study from Sri Lanka

Thavananthan Sivananthawerl[1]

[1] University of Peradeniya

Sri Lanka is an island with 6.6 million ha of land area of which 21% is covered with the natural forest. Two third of the island is with less than 1750 mm per annum of precipitation and creating enormous pressure to the periphery of the natural forest with the intrusion of slash and burn (*Chena*) cultivation. A trail study as well as a model was established in the north-central part of Sri Lanka called Maho. To reduce the pressure on natural forest, numbers of villagers at the periphery were given the support to establish a mixed garden with trees (forest trees such as teak, mahogany and multipurpose trees such as jak, coconut, and mango) in their premises. Due to the long gestation period of trees, farmers were supported with the annual crop cultivation with the minimum use of water using different water harvesting systems.

Different training sessions (water harvesting, soil conservation, etc.) were conducted to uplift their knowledge). Non-woody perennials such as papaw and banana started giving yield from 2nd year onwards where as coconut gave the production in three years. In 10-12 years of period the income has increased almost more than 10 folds on a sustainable basis (annually). Proper land use planning; forest zonation from strict conservation to forest plantations and agroforestry, awareness programs are the most successful remedies which leads to implement the mixed species forest garden to overcome the loss of natural forest in Sri Lanka.

Tree reaction to climate and neighbourhood: a partitioned response between twig and stem growth.

Maude Toigo[1], **Gael Ledoux**[1], Soline martin-blangy[2], Xavier Morin[1]

[1] Centre d'Ecologie Fonctionnelle et Evolutive, UMR CEFE CNRS 5175, 1919 route de Mende, 34293, Montpellier cedex 05, France
[2] Université de Lorraine, AgroParisTech, INRA, UMR SilvaNancyFrance

Diversity-productivity relationships in forests are largely apprehended via simple measures of tree dimension. Thus, the above-ground productivity of a tree is estimated via allometric relationships that do not take into account a possible mixture effect on tree crowns. Yet the consideration of a specific effect of tree mixture on branch growth could contrast the results obtained from stem growth. We studied the effects of climate and tree species mixture on the annual growth of twigs and stems in beech, fir and oak in the French Alps. The sample design was organized in 10 triplets of pure and bi-specific plots (oak-beech and fir-beech) along an altitudinal gradient ranging from 725m to 1431m.
We found that beech was generally not sensitive to tree species mixture. However, it affected its companion species both in terms of branch and radial growth: oak had a branch volume and a radial growth decreased in mixture, whereas the effect of beech on the radial growth of fir was more site-specific. Twig volume of the coniferous species responded more to climatic conditions than to species mixture. Twigs and radial growth generally increased with precipitation. Our results showed that the effects of climate and tree species mixture act differently according to the tree compartment considered. The marker of the mixture effect remains primarily the radial growth whereas branchs respond more to climatic conditions. This underline the interest of jointly considering different compartments of tree to apprehend in a more integrative way the tree's response to biotic and abiotic factors.

Forest management to promote a sustainable and diversified use of the mixed second-growth forests dominated by Amomyrtus spp. In Southern Chile, taking the production of wood for furniture production as a main ecosystem service.

Gustavo Torres[1], Marcos García[2]

[1] Social Sciences Department, Universidad de Los Lagos
[2] Architecture and Arts Faculty, Universidad Austral de Chile

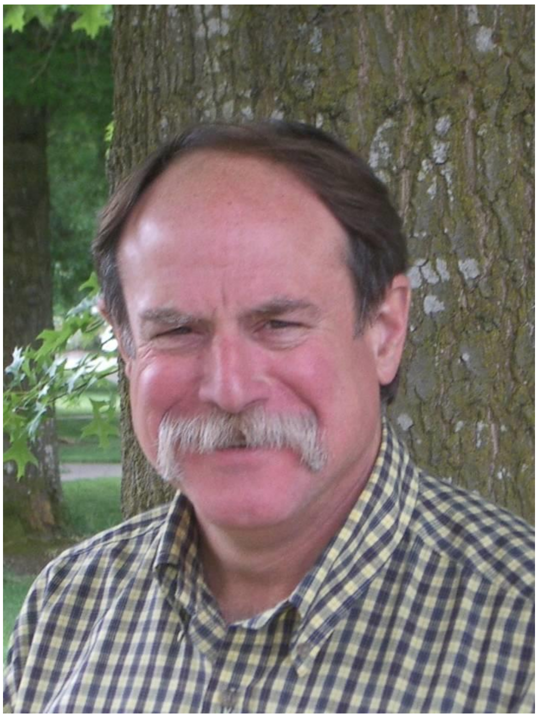
The temperate forests of southern Chile, particularly in the Cordillera de la Costa, are considered an international hotspot because of its high degree of endemism and threat level that represents the unsustainable use that this forest has had during the last 200 years. Currently the driver that reduces forest cover is the extraction of wood for firewood. This use does not discriminate between the type of forest species or its successional status. Therefore, mixed second-growth forests that today exist as a resilient forest response are in serious threat. An alternative to promote its sustainable use is to enhance the ecosystem services of these second-growth forests by visualizing a use that represents a greater economic value than firewood. In the case of the present work, mixed second growth formations dominated by species of the genus Amomyrtus were studied in Los Lagos Region, Chile. The social component of the rural communities of the Huilliche ethnic group that co-evolve with the temperate forest was also studied, demonstrating the current traditional uses and ecosystem services. In addition, through an interdisciplinary proposal, the potential of Amomyrtus spp. wood as a furniture raw material was evaluated and validated with quality certification standards. This new knowledge, in conjunction with local communities, allowed us to propose forest management measures that promote the sustainable and diversified use of the Amomyrtus formations, taking as a main ecosystem service the production of wood for furniture production in this rural communities. The contributions of the project FONDEF IDeA ID16i10303 are gratefully aknowledged.

Session 3: Dynamics and management of mixed forests

Key-note talk: Douglas MAGUIRE, Oregon State University, Corvallis, USA.

Evidence from controlled experiments for interaction effects of spacing and species mix on productivity, stand dynamics and vertical structure

The productivity, stand dynamics and ecosystem processes characterizing mixed species forests have been inferred from a mix of observational studies and designed experiments. The richest source of information to date has been observational studies of various types, the most prevalent being comparison of adjacent triplets of pure and mixed plots. Results from replicated mixed-species spacing trials in 45-yr-old *Pinus ponderosa/Abies grandis* plots and 52-yr-old *P. ponderosa/P. contorta* plots demonstrate the interaction effects of spacing and species composition on growth and stand structure, as well as the change in interaction effects over time. Initial spacing in these trials ranged from 1.8 m to 5.5 m on a square grid. Juvenile height growth, potential crown width, and relative shade tolerance of the constituent species dictated the growth and stand structural patterns over time. Mixtures of *P. ponderosa* and *A. grandis* at wide spacings offered *A. grandis* the opportunity to achieve cumulative height growth nearly equal to P. ponderosa and thereby form a uniform mixed canopy. The same species mixture at closer spacing resulted in increasingly stratified mixtures with *A. grandis* persisting in the understory and *P. ponderosa* dominating the overstory. A similar pattern emerged in the mixtures of *P. ponderosa* and *P. contorta*, but with more subtle gradients in vertical structure attributable to less extreme differences in juvenile height growth and shade tolerance and to much lower site quality. By the end of 2018, slight relative overyielding occurred in the mixed species plots of the *P. ponderosa/P. contorta* trials but not in the mixed species plots of the *P. ponderosa/A. grandis* trials. Relative and absolute mixing effects changed over time. No transgressive overyielding was yet evident in these mixed species spacing trials at ages 52 and 45 total plantation age.



Doug Maguire is currently Giustina Professor of Forest Management and Director of the Center for Intensive Planted-forest Silviculture (CIPS) at the College of Forestry, Oregon State University. Since 1996, he has taught undergraduate courses in forest mensuration and forest models, and several graduate courses on advanced silvicultural topics, currently Silvicultural Influences on Forest Ecosystem Dynamics. His research has involved forest understory vegetation, growth impacts of Swiss needle cast, foliage age-class distribution and crown structural dynamics of managed coniferous forests and, most recently, empirical and mechanistic components of models for simulating net primary production and growth responses to silvicultural treatments in Douglas-fir plantations. He previously served on the faculty at the University of Washington where he led the Silviculture Project within the Stand Management Cooperative and initiated a long-term research program on functional links between stand density regime, site productivity, crown dynamics and wood quality. He received his B.S. in Forest Management from the University of Maine, M.S. in Botany from Rutgers University, M.S. in Applied Statistics from Oregon State University, and Ph.D. in Forest Biometrics from Oregon State University.

Gisburn mixtures experiment: a new analysis of stand dynamics for the first 25 years of the second rotation

Gary Kerr[1], Jack Forster[1], Victoria Stokes[1]

[1] Forest Research

The Gisburn mixtures experiment compares the performance of pure and mixed plots of four species: Norway spruce (*Picea abies*), Scots pine (*Pinus sylvestris*), sessile oak (*Quercus petraea*) and common alder (*Alnus glutinosa*); in the second rotation planted in 1991 Sitka spruce (*Picea sitchensis*) was added to the design. A previous paper by Mason and Connolly (2014) summarized the results up to 20 years of the second rotation and reported results of analysis of mean data for each plot and species component. This paper will present a new analysis of results up to 25 years of the second rotation based on modelling of the growth and development of individual trees in the pure and mixed plots. This more detailed analysis gives greater clarity to the stand dynamic processes contributing to the challenging results from this iconic experiment.

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Restoring American Chestnut in Mixed-Species Forests: What Can We Learn from New Stocking Approaches?

Mark Ducey[1], Ethan Belair[1]

[1] University of New Hampshire

American chestnut (*Castanea dentata*) was once a dominant timber tree in mixed-species hardwood forests of eastern North America. However, by the mid-20th century it was eliminated as a mature tree in the region by an introduced fungus (*Cryphonectria parasitica*) and root pathogen (*Phytophthora cinnamomi*). Recent progress in breeding blight-resistant cultivars suggests the time may be approaching to restore chestnut on appropriate sites in its native range. The ecology of chestnut indicates this should be done in mixed-species stands rather than monocultures, but an absence of data on pre-blight chestnut stands limits our understanding of appropriate enrichment planting densities and other silvicultural strategies. Here, we suggest how a mixed-species density measure based on functional traits (e.g. Ducey and Knapp 2010) can be used to design tentative restoration strategies for chestnut within mixed-species stands. The development of climate-sensitive density measures for the region will help anticipate the robustness of such strategies to a shifting climate in the mid- to late 21st century.

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Spacing effects in spruce-pine plantations: trade-offs between yield, size and damage

Ignacio Barbeito[1], Bianca Eskelson[2]

[1] Southern Swedish Forest Research Center, Sweden
[2] University of British Columbia, Canada

Monocultures tend to yield higher total stand volumes and are simple to manage, yet mixed species-stands may result in similar stand volumes while providing benefits such as reductions in damages due to insects and disease. To understand the effects of density and species mixture on damage proportions and stem and crown size distributions in pure- and mixed species plots, we analyzed a 25-year-old mixed lodgepole pine—interior hybrid spruce experimental trial across three densities—1000, 1500, and 2000 stems per hectare —and five species mixtures—1:0, 3:1, 1:1, 1:3, and 0:1 pine:spruce. The study site is located in British Columbia, in Western Canada, at an elevation of 1560m. We asked: (1) What is the effect of mixture on tree size, yield, and damage? (2) Do mixture effects change with density? Results showed that at all densities volume was larger with an increasing proportion of pine. At the highest densities, pine showed larger diameters when mixed with spruce due to a spacing effect resulting from lower competition in the mixture. Damage increased over time and no differences in damage were observed across densities. Mixture did not influence western gall rust infection in pine, but mixed species stands had significantly less spruce weevil damage than pure spruce stands. Although based on a single site, our results highlight the importance of planting density when designing mixtures to balance the trade-offs between yield, growth and damage.

Effects of mixture forms on the early growth performance and survival of sessile oak (*Quercus petraea* (Matt.) Liebl.) and Scots pine (*Pinus sylvestris* L.) in central Poland

Kamil Bielak[1], Tadeusz Andrzejczyk[1]

[1] Department of Silviculture, Institute of Forest Sciences, Warsaw University of Life Sciences

Successful tree regeneration is a key process in ensuring forest diversity and one of the most crucial investments made in silviculture. This study compares the effects of three main horizontal mixture forms (by individual stems, rows and by small groups of 25 m^2), including also control treatment (monocultures), on biometric parameters and survival of very important two tree species in Europe, i.e. sessile oak and Scots pine in the first 12 years of growth. We used data collected under 4 inventories performed on the randomly block design experiment located in Central Poland and established in 2005. To quantify all effects (height, diameter and biomass growth as well as survival rate) depending on the different mixture forms over time, we employed the mixed effects models. While in case of pine the best growth and survival rate was characterized by group admixture forms, oak was performed better in the individual mixture forms. Both species were characterized by balanced and comparable growth rate, however the survival rate of pine was significant lower in case of single mixture form. The diameter increment for selected dominant trees was lower in case of oak monoculture. The obtained results confirmed that species interactions in mixed-species forests are dynamic, and can change over the time. Finally, we discuss the importance of results obtained for ecology and management of mixed Scots pine-sessile oak stands and we compare our results with the results obtained in more mature stands described by Pretzsch et al. (2019).

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Mixedwoods enhance northeast British Columbia's boreal forest resilience and carbon storage in a changing climate

Christopher Hawkins[1], Christopher Maundrell[1], Jeffrey Beale[1]

[1] Association of Peace River Woodlots

Post-logging, management of northeast British Columbia's complex conifer–broadleaf boreal forest (54-60° latitude), about 15 M ha, results in simple even-aged conifer stands. The rationale is to enhance growth of more valuable conifers by broadleaf removal, but this reduces species and structural diversity, carbon storage and resilience. Regional climate projections suggest a different future by 2050, increased; mean annual temperature (MAT, 1.9–4.7C), precipitation (11–19%), and frost-free days (25–40). MAT ranges from +3C to -0.4C in a south to north traverse, extremes -52C to +36C. Regional annual precipitation is about 450 mm. The frost-free period varies independent of latitude, 90 to 125 days. Given projected changing climate and decreased managed stand diversity, trials were initiated across the region in five to 18-year-old post-logging stands. The design was a single crop tree plot with various levels of broadleaf competition. The objective was to investigate the impact of broadleaf (aspen (*Populus tremuloides*) or birch (*Betula papyrifera*)) competition on crop tree white spruce (*Picea glauca*) or Lodgepole pine (*Pinus contorta latifolia*) growth.
Two to five-year results indicated, except at extreme broadleaf densities (>7000 sph), conifer growth was not impacted and often was enhanced by broadleaves. Productivity was greater in the mixedwoods resulting in greater carbon sequestration. The early results are biologically important and suggest the need and cost of much of the broadcast broadleaf removal was unnecessary and reduced needed ungulate forage. Sites were remeasured after the 2019 growing season and these results have not changed appreciably and support earlier observations.

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The potential of mixed plantations with local species to reforest the Sudanese area in West Africa

Brahima Coulibaly[1], Dominique Louppe[2], Anatole Kanga N'Guessan[1], N'klo Ouattara[3], ForestInnov Consortium[1, 2, 3, 4, 5], Bruno Hérault[2,4]

[1] CNRA, Abidjan, Ivory Coast
[2] Cirad, Université de Montpellier, Montpellier, France
[3] Université Péléforo Gbon Coulibaly, Korhogo, Ivory Coast
[4] Institut National Polytechnique Félix Houphouët-Boigny (INP-HB), Yamoussoukro, Ivory Coast
[5] Sodefor, Abidjan, Ivory Coast

In West Africa, the Sudanese region is characterized by an alternation of open forests, wooded and grassy savannas and lateritic plateaus. After the partial failure of large industrial plantations of exotic species in the late 1970s in Sahelo-Sudanian countries, tentative research has been initiated on the forestry potential of local species in plantations. In northern Côte d'Ivoire, the Kamonon Diabate station was created in 1988 in Lataha (Korhogo). This station, protected until now, has allowed the long-term study of the behaviour of nearly 90 species in plantations over 100 ha of trials, a unique experiment in the Sudanese region of West Africa. We present here an updated assessment of these longterm tests by analysing the productivity and the 25-30 year survival of trees from local species planted in the 1990s. We propose a classification of the local species according to their potential to produce (i) timber, (ii) fuel wood and (iii) non-timber forest products. Finally, we highlight the most promising species mixtures for reforesting the Sudanese sector of West Africa.

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Mixedwood silviculture: the science and art of managing for complex, multi-species forests of eastern North America

Patricia Raymond[1], Bethany Munoz Delgado[2], Benjamin Knapp[3], Laura Kenefic[2], John Kabrick[2]

[1] Ministere des Forets, de la Faune et des Parcs
[2] U.S. Forest Service, Northern Research Station
[3] University of Missouri, School of Natural Resources

Mixedwoods are a type of mixed-species forest specifically defined as a mixture of hardwoods and softwoods, with neither component exceeding 75 to 80 percent of stand stocking. In eastern North America, mixedwoods have garnered recent interest due to ecological and economic benefits, including diversification of timber products and adaptability to forest health issues. Although there are a variety of naturally occurring mixedwood forest types with different constituent species across the region, management of mixedwoods shares common challenges due to different silvics of the primary species. We consider six of the major temperate mixedwood forest types that occur within eastern North America, from the Central States region of the United States through the Atlantic Provinces of Canada. Based on natural disturbance patterns and management approaches, we classify these mixedwood types into two overarching groups: late-successional mixedwoods of the temperate-boreal ecotone and early successional mixedwoods in firedependent ecosystems. With few exceptions, softwood species were the ‘limiting species’ that created silvicultural challenges for deliberately managing mixedwoods. Common problems for regeneration of the limiting species included: 1) a lack of seed source due to land use legacies; 2) improper substrate for germination and early survival of seedlings; and 3) interspecific competition, often from abundant hardwoods. Although specific silvicultural recommendations vary across the mixedwood types, prescriptions must include practices that target the regeneration of the limiting species. Our synthesis provides a conceptual framework for identifying silvicultural practices for mixedwood management across forest types of eastern North America.

Model projections of mixed-species stands for two climate scenarios in the Netherlands

Meike Bouwman[1], Jan den Ouden[1], Frits Mohren[1]

[1] Forest Ecology and Forest Management Group, Wageningen University and Research, Wageningen, the Netherlands

Adapting forests to climate change is one of the major challenges for forest management in the near future. Mixed forests may provide more resilience and resistance to various climate related disturbances, depending on species and admixture proportion. Since the impacts of climate change may differ between species and hence may also vary per mixture and proportion, the direction of interspecific competition may change under climate change. Climate-sensitive models designed for mixed stands are a useful tool to provide insight in the interspecific competition under different growing conditions. The process-based forest growth model 3-PGmix is such a model, and it used for Dutch conditions. In this study, 3-PGmix is used to predict growth and yield of monocultures and mixtures of 4 combinations of two species: *Pseudotsuga menziesii* + *Fagus sylvatica*; *Pinus sylvestris* + *Quercus robur*; *Q. robur* + *F. sylvatica* and *Q. robur* + *Betula pendula*. Model predictions were compared with long-term growth and yield data of mixtures and monocultures, and mixing effects for each combination were analysed. The model was able to predict stem biomass, basal area and diameter with reasonable accuracy for all species, but was less accurate in predicting foliage and root biomass components. Subsequently, model projections over a period of 50 years were carried out under two different climatic scenarios for stands of *P. menziesii* + *F. sylvatica* and *P. sylvestris* + *Q. robur* to analyse effects of climate change on competition between these species, to provide information for adaptive management strategies.

Long-term changes in tree species composition of mixed forests in Swiss natural forest reserves

Amanda Mathys[1], Martina Hobi[1], Harald Bugmann[2], Jonas Stillhard[1], Peter Brang[1]

[1] Forest Resources and Management,Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf, Switzerland
[2] Forest Ecology, Institute of Terrestrial Ecosystems, ETH Zurich, Zürich, Switzerland

Forest dynamics and demographic rates of mixed forests can be observed through longterm monitoring networks in natural forests. The natural forest reserve network in Switzerland has been collecting inventory data on stand dynamics and tree species composition over the past 60 years on 205 permanent plots distributed in different forest types across the country. The purpose of this study was to determine long-term changes in species composition within the reserves and to identify what driving factors caused these changes. The occurrence and abundance of tree species was compared between the first and last inventory along an environmental gradient to determine where changes in species composition have been most abundant. Annual species gains and losses were estimated separately as a function of stand structural attributes and climate. Species gains were influenced by growth and climate variables whereas species losses were additionally affected by stand density. An increase in species richness was observed at lower elevations in mixed forests located in the colline, submontane, and lower montane belts, while the abundance of major tree species declined. Results from this study improve our understanding of naturally occurring species dynamics over large temporal scales, which can contribute to developing forest management strategies in mixed forests.

Natural diversification processes in Mediterranean forests: an analysis using forest typologies and forest inventory data

Lluís Coll[1, 2], Martina Sánchez-Pinillos[2], Miquel De Cáceres[2]

[1] Department of Agriculture and Forest Engineering, University of Lleida, Lleida, Spain
[2] Joint Research Unit CTFC-AGROTECNIO, Solsona, Lleida, Spain

In the northern Mediterranean basin, forests are expanding and densifying in last decades in response to the generalized abandonment of traditional agro-silvo-pastoral activities. More recently, some of these forests (mainly pinewoods) are also undergoing important natural diversification processes, through the progressive development of late-successional species in their understory. Notwithstanding these processes are known to be important for the resilience of forest stands, we still lack large-scale analyses about when and where they occur (i.e. their spatiotemporal variation) and the factors underlying them. In this study, we addressed this issue using the data from three consecutive surveys (1990, 2001, 2015) of the Spanish National Forest Inventory in Catalonia (NE Spain). We first classified every plot and survey into forest typologies based on dissimilarities in stand composition and structure. Then, we assessed the changes in forest types between consecutive surveys (i.e. transition matrices) and classified the plots according to their dynamic trajectories (identifying the ones showing progressive diversification processes from the others). Finally, we analyzed the potential role of different environmental variables at both the stand and landscape level in driving the reported diversification trajectories. Overall, the results of our study showed a progressive diversification of Mediterranean forests during the last twenty-five years. However, these processes were importantly modulated by environmental conditions and the stand composition and structure at the initial state considered. Our results suggest that future climatic trends can significantly impair tree diversification processes in Mediterranean areas, affecting their resilience capacity to upcoming disturbances.

Forecasting the future of forests and the importance of mixed stand management in the Alps under climate change.

Marion Jourdan[1], Thomas Cordonnier[2], Catherine Riond[3], Philippe Dreyfus[4, 5], François de Coligny[6], Xavier Morin[7]

[1] Université Paris-Sud, CNRS, AgroParisTech, Laboratoire Ecology systematique et Evolution, Faculté de Sciences d'Orsay, France
[2] Université Grenoble Alpes, IRSTEA, UR LESSEM, 2 rue de la Papeterie, BP76, Saint-Martind'Hérès Cedex, France
[3] ONF, Office National des Forêts Département R&D, Chambery, France
[4] ONF, Office National des Forêts Département R&D, Avignon, France
[5] INRA, UR 0629 URFM Ecologie des Forêts Méditerranéennes, Centre de Recherche PACA, Avignon, France
[6] INRA, UMR 931 AMAP, Botany and Computational Plant Architecture, TA A-51/PS2, Boulevard de la Lironde, 34398 Montpellier Cedex 5, France
[7] Centre d'Ecologie Fonctionnelle et Evolutive, CNRS, UMR 5175, FORECAST, Montpellier, France

Climate change affects forest ecosystem processes and related services due to increasing temperature and increasing extreme drought event frequency. This effect can be direct through changes altering the physiological responses of trees, but also indirect, driving changes in communities' composition. Numerous studies have confirmed that species richness may modify ecosystem functioning, especially productivity (for observation-based study see Forrester et al., 2016, for modelling approach see Morin et al., 2018), but it is necessary to go further. Regarding management issues, mixed stands seem unavoidable alternatives to maintain forest cover and ecosystem services under climate change (particularly in mountain context, with avalanche and block fall risks). We asked following questions: (1) Are monospecific stands vulnerable to climate change? and (2) Would mixed stand management significantly mitigate climate change effects on forest productivity and wood production? With modelling approach, we try to quantify the effect of climate change (using RCP 8.5) compared to present climate and managements effect in North French Alps. We used a "gap-model" (ForCEEPS, derived from ForClim, Bugmann 2001) which allowed testing several silvicultural scenarios on different stands (i.e. with various composition, structure or environmental conditions) under climate change. These simulations first showed that monospecific stands currently under stressful conditions would be too vulnerable to climate change to be maintained. Management by mixing species or conversion from pure to mixed stands would make it possible to maintain higher productivity and higher wood production in the long-term scale.

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Thinning responses of individual trees in mixed stands of Norway spruce and Scots pine

Silke Houtmeyers[1], Andreas Brunner[1]

[1] Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences, Ås, Norway

The effects of thinning and species mixture on productivity have previously been studied separately. We combined both and examined the individual tree thinning response of Norway spruce and Scots pine trees growing in mixture. For this purpose, data was collected from temporary sample plots that cover the full range of species proportions in mixed stands of Norway spruce and Scots pine in South-Eastern Norway that have been thinned about 10 years before. Growth of individual trees after thinning was derived from increment cores. Individual tree level models were fitted for two variables describing the dynamics of the thinning response: the maximum growth after thinning and the number of growing seasons to reach this maximum (response time). Density in a 6-m radius neighborhood was described by a distance-dependent competition index (CI) and the species proportion is the share of competition from a species to the total competition. In the sampled stands, the thinning from below did not only decrease the stands density, but also lowered the spruce proportion. The change in competition is the main factor affecting both thinning response variables of Scots pine and the maximum growth after thinning of Norway spruce. The species identity of the competitors only had a minor effect on the response time of Norway spruce. The low stand density after thinning and the weak mixture effects for this species mixture reported in previous studies at higher densities might be off help to explain the lack of mixture effects in this analysis.

Simulating the effects of thinning and species mixing on stands of oak (*Quercus petraea* (Matt.) Liebl. / *Quercus robur* L.) and pine (*Pinus sylvestris* L.) across Europe

Markus Engel[1], Sonja Vospernik[1], Maude Toïgo[2], Xavier Morin[2], Antonio Tomao[3], Carlo Trotta[3], Mathias Steckel[4], Anna Barbati[3], Arne Nothdurft[1], Hans Pretzsch[4]

[1] Institute of Forest Growth, Department of Forest- and Soil Science, University of Natural Resources and Life Sciences Vienna, Austria
[2] Systèmes d'Information en Ecologie, Centre D'Ecologie Fonctionelle et Evolutive, Montpellier, France
[3] Department of Innovation in Biology, Agro-food and Forest Systems, University of Tuscia, Italy
[4] Chair of Forest Growth and Yield Science, Technical University of Munich, Germany

This study investigated the effects of thinning and species mixing of oak (*Quercus petraea* (Matt.) Liebl. / *Quercus robur* L.) and pine (*Pinus sylvestris* L.) on the long-term stand volume productivity by means of model simulation. In total four different growth simulators were applied on a set of 23 triplets of oak and pine across Europe: the distance-independent single-tree simulator PROGNAUS, the distance-dependent single-tree simulator SILVA, the process-based gap model ForCEEPS, and the process-based simulator 3D-CMCC. Thinning was applied from the upper and lower end of the diameter distribution by reducing the stand basal area to 50 and 80 % of the maximum stand basal area. In addition, an unthinned control variant was simulated. We compared simulated results of the relative volume productivity of mixed versus pure stands and of thinned versus unthinned stands to empirical results previously obtained on the same set of triplet plots. Simulations showed both over- and underyielding and long-term predictions lay within empirical ranges reported in Pretzsch et al. (2019). Contrary to our expectations, relative volume productivity did not increase with the annual water supply on the triplet locations. The simulators achieved contrary results on which thinning application is best suited for maximizing long-term productivity. We hypothesize that the influence of climate and its interaction with other site variables and stand structure is not yet sufficiently represented by the models. The results revealed a need to further improve the existing growth models to be able to reflect thinning and mixture effects adequately.

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Growth and development of young mixed Scots pine and Norway spruce stands

Saija Huuskonen[1], **Simone Bianchi**[1], Jari Hynynen[1]

[1] LUKE

Mixed-species stands could integrate a wider array of environmental services. In the Nordic countries, a common mixture includes pine (either planted or seeded) and spruce (planted). However, there is still lack of information on how the two components would develop in the seedling and young stand stages with the current silvicultural managenent, and if there are species-specific differences in the growth patterns. The aims of our study were: 1) to assess if both species are still viable future components of young pine-spruce mixed stands; 2) to investigate species-specific growth differences. Ten such stands were selected in Finland, each with three sample plots. In each plot, all trees were recorded; soil properties were analyzed; stem and growth ring analyses were carried out on ten trees (five pine and five spruce) to measure past diameter and height growth. All stands had received juvenile stand management activities.

Results from non-linear mixed models showed that pine and spruce had developed evenly until now. Considering only last year growth, there were species-specific differences related to the effect of the stand characteristics. Competition reduced growth more in pine, while structural diversity enhanced growth more in spruce. The spatial distribution of the two species was even across the stands, and browsing damage limited only on pine. Our results showed that it is possible to establish and grow single storied pine and spruce mixed stands when the juvenile stand management practices have been properly taken care, but forest managers should consider specific some species-specific growth differences.

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Approaches to restoring and regenerating shortleaf pine-oak mixedwoods in the Ozark Highlands, USA

Daniel C. Dey[1], John M. Kabrick[1], Benjamin O. Knapp[2], Steve Lyczak[2], Scot Robinson[3], Michael Stevens[3]

[1] U.S. Forest Service, Northern Research Station
[2] The School of Natural Resources, University of Missouri
[3] U.S. Forest Service, Mark Twain National Forest

Shortleaf pine was once a dominant species throughout the southern US occurring in pure stands and mixedwoods with hardwoods dominated primarily by oak species. Since European settlement, 90% of the original pine-oak forests have been lost through conversion to hardwood forests, loblolly pine plantations, or agriculture. Despite the growing widespread interest in restoring pine-oak forests and woodlands, managers continue to suffer the loss of pine throughout much of its range, regardless of the management approach. New silvicultural systems are needed to regenerate and recruit shortleaf pine in pine-oak forests. Forest managers need new approaches and silvicultural prescriptions for restoring pine-oak mixedwood forests.

There are several barriers to regenerating pine and restoring pine-oak mixedwoods including deep hardwood litter, infrequent pine seed crops, aggressive hardwood advance reproduction, and dense hardwood overstory. New combinations of silvicultural practices are necessary to secure pine regeneration and to ensure its development into the overstory. Combinations of prescribed fires and harvesting are needed to prepare the site for natural pine regeneration and to control competing hardwoods as natural or artificial pine reproduction establishes and develops. Strategies for restoring pine-oak mixedwoods may range from intensive even-aged approaches using clearcutting and herbicides with artificial regeneration to developing large pine advance reproduction under shelterwoods using natural or artificial regeneration. We are evaluating novel sequences and timing of practices to restore pine-oak forests in the Missouri Ozark Highlands.

Management alternatives of spontaneously regenerated mixed stands of Birch and Norway spruce in Sweden.

Felicia Lidman[1], Nils Fahlvik[2], Emma Holmström[3], Tomas Lundmark[1]

1 Department of Forest Ecology and Management, Swedish University of Agricultural Sciences.
2 Skogforsk, The forestry Reaserch institute of Sweden
3 Southern Swedish Forest Reaserch Centre, Swedish University of Agricultural Sciences.

More than 75 % of clearcuts in Sweden are regenerated by planting coniferous tree species followed by subsequent pre-commercial thinnings to secure growth on the main crop trees. However, areas on clearcuts without active regeneration methods, tend to be spontaneously forested with a mixture of naturally regenerated Birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) and Norway spruce (*Pices abies* (L.) Karst.) The aim of this study is to compare the alternatives and effect of first thinning and extraction of forest fuel on stand development and future tree species composition, in areas with low investment regeneration. A long term experiment with a randomized block design was established 2007 (22 years after clearcutting) on two naturally regenerated sites, on the east-central coast of Sweden. Treatments included thinning of forest fuel leaving (1) 1300 stems ha-1 of Norway spruce, (2) 1200 stems ha-1 of birch, (3) a tree-wise mixture with 1200 stems ha-1 of birch and 1300 stems ha-1 of Norway spruce and (4) an unthinned control. A second thinning was made 2016 in treatment (2) and (3), to favor the main crop trees. Treatment (1) created a stand suitable for a longer rotation period, (2) for a medium length rotation period, (3) for two harvests of crop trees during a longer rotation period and (4) for a short rotation period. All treatments had different levels of forest fuel outtake and management intensity. These results can be used to optimize the different silvicultural practices strategically towards the goal of the forest owner.

The birch-spruce mixed forest of southern Sweden in contemporary forestry.

Emma Holmström[1]

[1] Swedish University of Agricultural Science

Two different forest surveys was used to investigate the status of birch-spruce mixed forest in contemporary forest in southern Sweden. Permanent sample plot data from the Swedish national forest inventory was used to evaluate the proportion of birch admixture in Norway spruce plantations and relative change over time and over stand development. Temporary sample plots in a randomized stand survey, designed and performed by the authors, was used to evaluate stand variation in the same type of mixtures. In addition, the birch timber quality was assessed over a gradient of admixture proportion. The survey material shows that birch proportion in the planted spruce forest is in general low, less than 30 %, but with no dramatic decrease after first commercial thinning. Although the reason for the birch admixture often is stated as provisioning increased biodiversity, the timber quality of the retained birch in stands 40-60 years old, was on average sufficient for saw log production.

Session 3: Dynamics and management of mixed forests

Key-note talk: Hans PRETZSCH, Chair for Forest Growth and Yield Science, Technical University of Munich, Freising, Germany.

Mixed-species forest stands. From understanding to design

Monospecific stands, especially when cultivated beyond the species' natural range, are often susceptible to disturbances. Disturbances and damages may reduce growth and the provision of other ecosystem services. This talk will first provide examples of how tree species mixture can increase the resilience and stability of tree and stand growth. It will be shown that mixing can reduce the vulnerability against windthrow, drought stress, and improve the recovery after disturbances.
The second part of the presentation will outline the design of mixed species stands including species selection and combination, design of spatial and temporal patterns, density regulation, and stand regeneration.
The third part of the presentation will stress that the available knowledge of mixing effects and silvicultural regulation of tree species mixtures needs to be implemented in management models in order to provide forest management with quantitative information, guidelines and prescriptions for management of mixed-species stands.
A conclusion is that tree species mixing has great potential of risk reduction and growth stabilization but that there is still a significant lack of knowledge and suitable silvicultural prescriptions for the design and steering of mixed-species stands. Finally, perspectives are drawn how to improve the state of knowledge by innovative experiments, further developed models, and new guidelines.

Hans Pretzsch is Professor of Forest Growth and Yield Science at Technical University of Munich, Germany, since 1994 and responsible for the network of long-term experimental plots in Bavaria which date back to 1860. For the past 25 years he focused on general rules of tree and stand growth, tree and stand dynamics under stress, mixed-species stands, and forest modelling.

Proportion of mixture influences overyielding in a long-term nursing mixtures experiment in northern Scotland.

Bill Mason[1], Victoria Stokes[1]

[1] Forest Research, Northern Research Station, Roslin, Midlothian, EH25 9SY

In Great Britain and Ireland, 'nursing mixtures' of pines (*Pinus contorta*, *P. sylvestris*) have been used to establish Sitka spruce (*Picea sitchensis*) dominated forests on infertile soils without nitrogen fertilisation. Although this effect has been known for several decades, there is little evidence on the most effective design of nursing mixture. We provide information from an experiment established in 1988 with five proportions of a Scots pine: Sitka spruce mixture (from 75:25 to 25:75 pine: spruce) plus pure Scots pine and Sitka spruce; the latter was with or without nitrogen application. These eight treatments were replicated four times in a randomised block design and have been assessed for 30 years. We examined the occurrence of overyielding (the difference between the actual basal area of a mixture and that predicted from the weighted average perfromance of the component species in pure plots) at 10, 15 and 30 years. When unfertilised pure Sitka spruce was a baseline, overyielding occurred in some treatments at year 10, and was evident in all treatments at the later dates. At year 30, it was significantly greater in the 67:33 pine: spruce mixture than in the other treatments. When Sitka spruce with nitrogen was a baseline, overyielding was not found at 10 and 15 years. However, at 30 years it was present in two treatments and was again highest in the 67:33 pine: spruce mixture. Thus mixture design will affect overyielding in Sitka spruce forests with implications for timber production and profitability.

Productivity-diversity relationships in mixed-hardwood plantations

Madeline Montague[1], Kliffi Blackstone[2], John Couture[1,3], Brady Hardiman[1,4], Gordon McNickle[2], Douglass Jacobs[1]

[1] Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN, USA
[2] Department of Botany and Plant Pathology, Purdue University, West Lafayette, IN, USA
[3] Department of Entomology, Purdue University, West Lafayette, IN, USA
[4] Department of Environmental and Ecological Engineering, Purdue University, West Lafayette, IN, USA

Higher species diversity in natural forests generally leads to increased overall stand productivity. However, this diversity-productivity relationship (DPR) has not been well studied in plantation settings, limiting capacity to develop plantation prescriptions for species mixtures that maximize productivity for timber and other ecological services. We are investigating the DPR using a 14-year-old experiment of hardwoods planted in varying species mixtures and densities. American chestnut (*Castanea dentata*), northern red oak (*Quercus rubra*) and black cherry (*Prunus serotina*) were planted as monocultures and polycultures at 1, 2 or 3-meter spacing treatments in a full-factorial design in the Midwestern, USA. Annual DBH measurements, basal diameter cores, litter traps, photosynthesis measurements, soil coring (reflecting standing root biomass) and mesh ingrowth cores (representing annual root productivity) provide data on wood, canopy, and root productivity. Our results suggest that increased diversity of these species is not positively related to aboveground plantation productivity, in contrast to most analyses in natural forest stands. To explain this contradictory response, we evaluated species occurrence data in natural forest plots from throughout the eastern US and discovered that the inter-planted species in our experiment rarely co-occur in nature. Taken together and interpreted through modern coexistence theory, these findings suggest that our species mixtures have overlapping, rather than complementary niche adaptations. We posit that to fully exploit site resources and realize maximum stand productivity, it is essential to plant mixtures with species that are known to have niche complementarity.

Tree species mixture effects on growth vary with stand density – an analysis based on individual tree responses

Andreas Brunner[1], David Forrester[2]

[1] Faculty of Environmental Sciences and Natural Resource Management, Norwegian University of Life Sciences
[2] Swiss Federal Institute for Forest, Snow and Landscape Research

Overyielding in mixed species stands is expected to vary with stand density, but only a few studies have quantified this. We used individual-tree growth data from permanent sample plots on 83 sites in Switzerland representing a three-species mixture between Norway spruce, Silver fir, and European beech. Basal area growth models for all three species indicated significant interactions between a competition index (CI) and species composition in the neighborhood. The distance-dependent CI indicates stand density in a 10-m radius neighborhood, and the contribution of individual species to the CI indicates the species composition. Given the rich vertical stand structure in the sample plots, which were often managed by single tree selection cutting, it is not surprising that interactions between CI and species proportion varied with relative tree height. We used the individual tree growth models to simulate stand growth with and without species composition effects. A sample plot with its real stand structure in terms of tree size and position was homogenized in terms of species composition at the tree level. By varying the stand density of this plot, we demonstrate how overyielding increases with stand density. In the given mixture, it is mostly beech contributing to the observed overyielding in dense mixed stands. Stand density therefore needs to be considered more explicitly when studying growth and yield of mixed species stands.

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Inter- and intra-specific mode of competition of Scots pine in pure and mixed stands along an environmental gradient in Europe

Andrés Bravo-Oviedo[1], Hans Pretzsch[2], Ricardo Ruiz-Peinado[3], Michael Heym[2], Magnus Löf[4], Christian Ammer[5], Jorge Aldea[4], Kamil Bielak[6], Felipe Bravo[7], Gediminas Brazaitis[8], Jakub Cerný[9], Lluis Coll[10], Catherine Collet[11], Lars Drössler[12], Aksel Granhus[13], Stig-Olof Holm[14], Aris Jansen[15], Nathalie Korboulewsky[16], Thomas Lardson[17], Marek Metslaid[18], Arne Norhtdurft[19], Maciej Pach[20], Quentin Ponette[21], Roman Sitko[22], Miroslav Svoboda[23], Barbara Wolf[24], Miren del Río[3]

1 Dpt. Biogeography and Global Change, National Museum of Natural Sciences – National Research Council (MNCN-CSIC), Spain
2 Technical University of Munich (TUM), Germany
3 Spanish Institute for Agriculture and Food Research and Technology (INIA)-CIFOR & iuFOR, Spain
4 Swedish University of Agricultural Sciences (SLU), Sweden
5 Georg-August-Universität Göttingen (GAU), Germany
6 University of Life Sciences (SGGW), Poland
7 Sustainable Forest Management Research Institute (iuFOR) University of Valladolid, Spain
8 Vytautas Magnus University Agriculture Academy (VDU), Lithuania
9 Forestry and Game Management Research Institute (FGMRI), Czech Republic
10 University of Lleida (UdL), Spain
11 Université de Lorraine, AgroParisTech, (INRA), France
12 Ilia State University (USI), Georgia
13 Norwegian Institute of Bioeconomy Reseach (NIBIO), Norway
14 Umeå University (UMU), Sweden
15 Latvian State Forest Research Institute (SILAVA), Latvia
16 Institut national de Recherche en Sciences et technologies pour l'Environnement et l'Agriculture (IRSTEA), France
17 University of Copenhagen (KU), Denmark
18 Estonian university of Life Sciences (EMU), Estonia
19 University of Natural Resources and Life Sciences (BOKU), Austria
20 University of Agriculture in Krakow (UAK), Poland
21 Université Catholique de Louvain (UCL), Belgium
22 Technical University Zvolen (TUZVO), Slovakia
23 Czech Univeristy of Life Sciences (CZU), Czech Republic
24 Eberswalde University for Sustainable Development (HNEE), Germany

Mixed forests are considered more productive and resilient to perturbations than monospecific stands. Mechanisms explaining this outperformance are usually related to complementary use of resources over time through reduced competition. The amount of secondary growth allocated can be (i) constant through tree size, reflecting complete symmetric competition; (ii) proportional to the tree size (symmetric competition), (iii) more than proportional, where the observed growth of large trees is higher than proportional (asymmetric competition) or (iv) inversely proportional, where small trees growth proportionally more than larger trees (inversely size-asymmetric competition). These modes of competition can vary with changes in nutrient and climatic conditions. We hypothesize that the response is also modulated by the species at contest. Data from three transect of triplets across Europe were used to test if Scots pine mode of competition change in pure stands or mixed with European Beech, Norway Spruce and Oak. A triplet is a set of three plots representing two pure stands and one mixed stand of the corresponding species. We use a size-growth relationship to test the existence of mixing effects across environmental gradients and time. We started testing if symmetric competition is dominant in dry years and if mixing effects can modulate the response. Previous results indicated that the mode of competition is site specific with divergent mixing effects across Europe.

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Individual tree growth for coexisting Norway spruce and Scots pine as function of competition of neighbouring tree species

Jorge Aldea[1], Ignacio Barbeito[1], Kamil Bielak[2], Gediminas Brazaitis[3], Aksel Granhus[4], Michael Heym[5], Stig-Olof Holm[6], Gro Hylen[4], Aris Jansons[7], Marek Metslaid[8], Thomas Nord-Larsen[9], Arne Nothdurft[10], Hans Pretzsch[5], Miren del Río[11,12], Ricardo Ruiz Peinado[11,12], Roman Sitko[13], Magnus Löf[1]

[1] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Sweden.
[2] Faculty of Forestry. Department of Forest Silviculture. Warsaw University of Life Sciences, Poland
[3] Institute of Forest Biology and Silviculture, Faculty of Forest Sciences and Ecology, Aleksandras Stulginskis University, Lithuania
[4] Norwegian Institute of Bioeconomy Research (NIBIO), P.O. Box 115, N- 1431 Ås, Norway
[5] Chair of Forest Growth and Yield Science, Technical University of Munich, Freising, Germany
[6] Department of Ecology and Environmental Sciences, Umeå University. Sweden.
[7] Latvian State Forest Research Institute Silava, Salaspils, Latvia
[8] Institute of Forestry and Rural EngineeringEstonian University of Life Sciences(EMU),Tartu,Estonia
[9] Department of Geosciences and Natural Resource Management. University of Copenhagen. Denmark
[10] Institute of Forest Growth, University of Natural Resources and Life Sciences, Vienna. Austria
[11] Department of Forest Dynamics and Management, INIA-CIFOR, Madrid, Spain
[12] Sustainable Forest Management Research Institute, University of Valladolid - INIA, Palencia, Spain
[13] Tehnical University in Zvolen, Faculty of Forestry, Zvolen, Slovakia

Trees in mixed forest can experience a competition reduction due to niche complementarity (spatial and temporal partitioning of resources) and/or facilitation between species. These positive interactions can take place at belowground (size symmetric) and/or aboveground levels (size asymmetric), among intra or inter-specific competitors. Here we aim to further understand the interactions between Norway spruce and Scots pine to detect possible causes of competition reduction in mixed stands composed by both species along a wide ecological gradient throughout Europe. Five different competition index and structures (size-symmetry, size-asymmetry, combined, and splitting the competition indices into intra- and inter-specific components) where included in basal area growth models fitted for each species using data from REFORM triplets.

The results showed that there is a slightly negative effect of Scots pine on Norway spruce basal area growth, while Scots pine clearly was benefitted from the admixture with Norway spruce. Size-asymmetric is stronger than size-symmetric competition in these mixtures, highlighting the importance of light in competition. In addition, tree size and site conditions also modulated species competition along Europe. In general, competitive reduction in mixed forest involved greater advantages for Scots pine growth, although Norway spruce could also be beneficiated increasing resilience follow abiotic disturbances.

Stand density and growth in mixed compared with monospecific stands

Eric Andreas Thurm[1], Hans Pretzsch[2]

[1] Research Unit Silviculture & Forest Growth, LandesforstMV, Zeppelinstrasse 3, Schwerin 19061, Germany
[2] Chair of Forest Growth and Yield Science, TUM, Hans-Carl-von-Carlowitz-Platz 2, 85354 Freising, Germany

Forest management mainly controls growth in forests by the regulation of stand density. Numerous papers deal with the relationship between stand density and growth in monospecific stands. In times of forest adaption monospecific stands transformed to mixed stands. However, works about the density regulation of mixed species stands and their growth reactions are very rare. Here we use 128 long-term experiments from the networks of Bavaria and Mecklenburg-Western Pomerania in order to analyze: (i) the effect of the stand density in a given period on the periodical annual volume growth; (ii) the development of this density-growth relationship with progressing stand development (age and mean diameter); (iii) the dependency of the addressed relationships on the species-specific functional traits (light-shade, evergreen-broadleaved, high-low morphological plasticity). Finally, we discuss the implications of the revealed relationships for forest ecology and management.

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Mixture effects on Scots pine and Norway spruce productivity along a climatic gradient in Europe

Ricardo Ruiz-Peinado[1,2] , Hans Pretzsch[3], Michael Heym[3], Magnus Löf[4], Jorge Aldea[4], Kamil Bielak[5], Ignacio Barbeito[4], Gediminas Brazaitis[6], Lars Drössler[7], Aksel Granhus[8], Stig-Olof Holm[9], Aris Jansons[10], Marek Metslaid[11], Arne Nothdurft[12], Ditlev Otto Juel Reventlow[13], Roman Sitko[14], Miren del Río[1,2]

[1] Spanish Institute for Agriculture and Food Research and Technology (INIA)-CIFOR, Spain
[2] Forest Management Research Institute (iuFOR, UVa-INIA), Spain
[3] Technical University of Munich (TUM), Germany
[4] Swedish University of Agricultural Sciences (SLU), Sweden
[5] Warsaw University of Life Sciences (SGGW), Poland
[6] Vytautas Magnus University Agriculture Academy (VDU), Lithuania
[7] Ilia State University (ISU), Georgia
[8] Norwegian Institute of Bioeconomy Reseach (NIBIO), Norway
[9] Umeå University (UMU), Sweden
[10] Latvian State Forest Research Institute (SILAVA), Latvia
[11] Estonian University of Life Sciences (EMU), Estonia
[12] University of Natural Resources and Life Sciences (BOKU), Austria
[13] University of Copenhagen (UCPH), Denmark
[14] Technical University in Zvolen (TUZVO), Slovakia

Growing in mixed stands has been recognized to achieve several ecosystem services in a better way than monocultures. For example, higher productivity of mixed forests has been identified for several two-species mixtures in European forests. The mixtures of *Pinus sylvestris* and *Picea abies* have been studied in Europe for their importance in wood production and geographical distribution, but a systematic analysis with homogenous sampling covering the distribution of this mixture along a climatic gradient was lacking. Thereby, as part of an European project (REFORM), 22 triplets has been established in 10 European countries covering the distribution of this mixtures. Each triplet comprises one monospecific *Pinus sylvestris* plot, one monospecific *Picea abies* plot and the mixed species plot in fully stocked stands, with no management in the last 8-10 years. The age range between 45-80 years, however, within each triplet the age between the three plots is comparable. The results show that mixed stands are slightly more productive than monospecific stands (+3% in terms of volume increment and +9% of basal area increment). Quadratic mean diameter of pine in mixtures is higher than in monocultures (+17%) and the opposite was found for spruce (-5% in mixtures than in monocultures). The trend is similar for mean height: +7% higher in mixtures for pine and -2% lower in mixtures for spruce. For the majority of triplets stand productivity was higher in mixtures compared to monospecific stands, with both species being promoted jointly in mixtures in a 38% of the cases.

Effects of tree diversity, fine-root traits and (micro-) climate on the decomposition of absorptive fine roots of 13 European tree species

Janna Wambsganss[1], Friderike Beyer[1], Grégoire Freschet[2], Jürgen Bauhus[1], Michael Scherer-Lorenzen[3]

[1] Chair of Silviculture, University of Freiburg, Germany
[2] Centre for Biodiversity Theory and Modelling (CNRS), Moulis, France
[3] Institute of Geobotany, University of Freiburg, Germany

Decomposition of organic matter is a key ecosystem process for carbon and nutrient cycling. Despite the fact that the majority of the world's forests consists of tree species mixtures and that most of the organic matter entering the forest soil originates from decaying fine roots, little is known about tree diversity effects on the decomposition dynamics of fine-root litter. Therefore, the objective of this study was to assess the effects of tree diversity, fine-root traits and environmental conditions on decomposition rates. We hypothesized that decomposition rates

(1) are non-additive, i.e. higher for mixed-species stands than corresponding monospecific stands
(2) increase with functional diversity of root litter mixtures
(3) are largely explained by fine-root traits, more than (micro-)climate or tree diversity

To test these hypotheses, absorptive roots (representing the first three orders of fine roots starting from the tips) of 13 European tree species were incubated using litter bags for 12 months in mature, semi-natural mixed-forest stands and corresponding monospecific stands at four study sites across Europe. The four study sites represent four major European forest types ranging from boreal forest in Finland to thermophilous deciduous forest in Italy. Initial fine-root traits including chemical, architectural and morphological traits were measured. First results indicate that decomposition rates are more related to fine-root traits and site conditions rather than tree diversity. Nevertheless, this study will provide new insights in decomposition dynamics of mixed-species forests that may be relevant for overall ecosystem functioning.

Tree mixture modify the nutrient cycling: evidence from foliar diagnosis and litterfall in oak-pine stands?

Nathalie Korboulewsky[1], Maude Toigo[1,2], Thomas Pérot[1]

[1] Irstea, UR EFNO, Nogent-sur-Vernisson, Domaine des Barres, 45290 Nogent-sur- Vernisson, France
[2] CEFE, UMR 5175, 34090 Montpellier

Mixed stands are often considered an asset for stand productivity, but some studies are contradictory and most of the mechanisms are unknown. One of the key factors of stand productivity is the mineral nutrition of trees, which is modulated by soil fertility and the level of intra and interspecific competition. We studied how mixture modify the nutrient cycle. We chose 8 triplets in the Orléans state forest, France, in mature stands of similar soil conditions for a total of 24 plots of either oak (*Quercus petraea*), pine (*Pinus sylvestris*) or mixed oak-pine stands. Dendrometric measurements were taken, tree litterfall was collected for 3 years every month, and fresh leaves and needles were analysed. Foliar diagnosis showed nutrient limitations which confirms the low fertility of the site: deficiency in P for both species, and also in Mg for the pine. Mixture ameliorates significantly the pine Mg nutrition. We also found that in the mixed stands, there were a greater production of leaves and needles, probably due to space complementarity of crown. Calculus of nutrient return to the soil showed an increase by 45% and 80% in mixed stands compared respectively to oak and pine stands. Mixture significantly modified the nutrient cycle. More litter fall and richer provides nutrients easily assimilated by trees and benefits to the nutritional status of mixed stands. These findings can partly explain the overyielding of mixed stands.

Facilitation and competition in regeneration in mixed-conifer forests of the southern and central Rocky Mountains

W. Keith Moser[1], John Shaw[2], Jaroslaw Paluch[3]

[1] USDA Forest Service, Rocky Mountain Research Station, Flagstaff, Arizona, USA
[2] USDA Forest Service, Rocky Mountain Research Station, Ogden, Utah, USA
[3] Faculty of Forestry, University of Agriculture, Cracow, Poland

The Dry Mixed-Conifer Forest is a prominent forest type in the southwestern United States. Comprised of various combinations of *Abies concolor*, *Pinus ponderosa*, *Pseudotsuga menziesii*, *Populus tremuloides*, and *Pinus strobiformis*, this system has historically relied on fire to maintain structure and composition. With the changes in fire regimes, there has been a long-term progression toward more shade tolerant species such as *Abies concolor*, a trend that has been amplified by the relative unpopularity of *Abies* species for utilization. Using data from the USDA Forest Service Forest Inventory and Analysis program, this study focused on relative proportions of each species in the seedling, sapling, and overstory tree cohorts. The hypothesis was that regeneration and subsequent development by species were proportional to the species in the overstory, accounting for shade tolerance. Transitions to a different future forest combination, if that transition was occurring, was related to the time since the previous disturbance, usually fire, and the relative proportion of *Abies* in the overstory mix. We found evidence of lessened competition and even potential facilitation at lower latitudes (warmer climate) and greater competition at higher latitudes, considerably mediated by topography, however.

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Effect of spatial distribution on forest growth as function of species composition in Fagus sylvatica (L.) mountain forests across Europe

Giustino Tonon[1], Francesco Giammarchi[1], Pietro Panzacchi[1, 2], Hans Pretzsch[3], Enno Uhl[3], Michal Bosela[4,5], Tzvetan Zlatanov[6], Kamil Bielak[7], Jerzy Skrzyszewski[8], Soraya Versace[2], Michal Bellan[9,10], Alvaro Rubio-Cuadrado[11], Miren del Rio[12,13], Lluis Coll[14,15,16], Lucian Dinka[17], Branko Stajic[18], Admir Avdagic[19], Aida Ibrahimspahic[19], Roberto Tognetti[20]

[1] Faculty of Science and Technology, Free University of Bolzano-Bozen, Bolzano, Italy
[2] Dipartimento di Bioscienze e Territorio, Università degli studi del Molise, 86090 Pesche (IS), Italy
[3] Chair for Forest Growth and Yield Science, Technical University of Munich, Freising, Germany
[4] Department of Forest Management and Geodesy, Technical University in Zvolen, Zvolen, Slovakia
[5] National Forest Centre, Department of Forest Landscape and Ecology, Zvolen, Slovakia
[6] Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia, Bulgaria
[7] Department of Silviculture, Warsaw University of Life Sciences, Warsaw, Poland
[8] Department of Forest Ecology and Silviculture, Faculty of Forestry, University of Agriculture in Krakow, Krakow, Poland
[9] Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Forest Ecology, Brno, Czech Republic
[10] Global Change Research Institute of the Czech Academy of Sciences, Bělidla 4a, 603 00 Brno, Czech Republic
[11] Departamento de Sistemas y Recursos Naturales, Escuela Técnica Superior de Ingeniería de Montes, Forestal y del Medio Natural, Universidad Politécnica de Madrid, Madrid, Spain
[12] Department of Forest Dynamics and Management, INIA, Forest Research Centre, Madrid, Spain
[13] Sustainable Forest Management Research Institute, University of Valladolid - INIA, Palencia, Spain
[14] Joint Research Unit CTFC – AGROTECNIO, Solsona, Spain
[15] Center for Ecological Research and Forestry Applications (CREAF), Cerdanyola del Vallès E, Spain
[16] Department of Agriculture and Forest Engineering (EAGROF), University of Lleida, Lleida E, Spain
[17] National Institute for Research and Development in Forestry (INCDS) "Marin Drăcea", Voluntari, Romania
[18] Faculty of Forestry, University of Belgrade, 11000, Belgrade, Serbia
[19] Department of Forest Management and Urban Greenery, Faculty of Forestry, University Sarajevo, Bosnia and Herzegovina
[20] Department of Agricultural, Environmental and Food Sciences, University of Molise, Campobasso, Italy

There are evidences that mixed forests are more resistant and resilient than mono-specific ones. Higher biodiversity was associated with higher productivity and ability to adapt to climate change. The positive interactions (facilitation) among different species and the higher use efficiency of resources linked to the niche complementary concept was suggested to be the main reason for the higher performance of mixed forests. However, the mechanistic understanding of ecological processes and tree-tree interactions that underpin the higher functionality of mixed forests is far to be reached. Even if the spatial distribution of trees is fundamental to understand how the interactions among individuals take place and how they affect the ecosystem productivity, its role was neglected in the previous studies. In this study we used data of a newly established network of pure and mixed beech stands across Europe (52 stands) to study the effect of spatial distribution on forest growth in the 20-year period between 1997 and 2016. We used Ripley K function to analyze the spatial distribution of trees. The results show that the random distribution is the most frequent point pattern in the analyzed beech stands. Spatial distribution has a stronger effect than mixture on the recent growth rate, with dispersed-distributed stands showing the highest growth rate. Finally, beech trees do not show any attraction behavior toward other species, while the repulsion prevails in both dispersed- and clumped-distributed stands, questioning the theory that facilitation is the prevailing mechanism behind the higher productivity of beech mixed forests.

Admixing other tree species to European beech forests: Effects on soil organic carbon and total nitrogen stocks. A review.

Stephanie Rehschuh[1], Michael Dannenmann[1]

[1] Institute of Meteorology and Climate Research–Atmospheric Environmental Research (IMK-IFU), Karlsruhe Institute of Technology (KIT), Kreuzeckbahnstr. 19, 82467 Garmisch-Partenkirchen, Germany

Drought-sensitive European beech forests are increasingly challenged by climate change. Admixing other, preferably more deep-rooting, tree species has been proposed to increase the resilience of beech forests to summer drought. This might not only alter soil water dynamics and availability, but also soil organic carbon (SOC) and total nitrogen (TN) storage in soils. Since information of these effects is scattered, our aim was to synthesize results from studies that compared SOC/TN stocks of beech monocultures with those of mixed beech stands as well as of other monocultures. We conducted a meta-analysis including 32 studies with 202, 210 and 152 observations for forest floor, mineral soil and the total soil profile, respectively. Pure conifer stands had higher SOC stocks compared to beech in general, especially in the forest floor with up to 200% (larch forests). Other broadleaved tree species showed in comparison to beech lower SOC storage in the forest floor, with little impact on total stocks. Similarly, we found significantly increased SOC stocks of >10% and a small increase in TN stocks of ~4% for mixed beech-conifer stands compared to beech monocultures, which means a potential SOC storage increase of >0.1 t $ha^{-1}yr^{-1}$. In contrast, mixed beech broadleaved stands did not show a significant change in total SOC stocks. Currently, the influence climatic and soil parameters on SOC changes due to admixture of other tree species is analyzed based on this dataset. This is expected to facilitate an assessment which mixtures with beech have the largest potential towards increasing SOC stocks.

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Spatial nitrogen and water uptake strategies of mature Norway spruce and Scots pine in monocultures and in the two species mixed stands

Reimo Lutter[1], Nils Henriksson[1], Ruth-Kristina Magh[1], John D Marshall[1], Annika Nordin[2], Tomas Lundmark[1]

[1] Department of Forest Ecology and Management, Swedish University of Agricultural Sciences, Skogsmarksgränd 17, SE-901 83 Umeå, Sweden
[2] Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Skogsmarksgränd 17, SE-901 83 Umeå, Sweden

Historically, the composition of tree species in Nordic forests has been directed towards the preference of monocultures. However, mixed forests are considered to be more resilient to negative climate change consequences compared to monocultures. Therefore, mixed forests are a realistic part of future silvicultural programs in Northern Europe (NE) and they should meet the demand of wood for the industry. However, the knowledge about mixed forest ecology, functioning and management is not so clear in NE and several aspects needs to be clarified. Mixed forests are considered to use these resources more efficiently than monocultures. However, the functioning of the root system, site occupancy and resource acquisition distance of pine and spruce, the two most important tree species in NE, are not well understood. The existing knowledge gaps in nutrient and water uptake are explained by the complexity of sampling where the traditional destructive methodologies would create direct disturbances in root functioning. In the summer of 2019, a water and nitrogen labeling experiment was started in Central Sweden (Främlingshem) where the aim was to describe nitrogen and water uptake patterns in mature spruce, pine and the two species mixture. Novel stable-isotope tracing techniques using a solution of $K^{15}NO_3$ and $^{2}H2$-labeled water were used to describe trees spatial belowground root functioning without any soil disturbance. The project will give new insights about the fundamental processes of spatial nitrogen and water uptake for both species. Based on the results, new silvicultural practices can be implemented to both species management.

Mixing has limited impacts on the foliar nutrition of European beech and Scots pine trees across Europe

Géraud de Streel[1], Christian Ammer[2], Peter Annighöfer[2], Ignacio Barbeito[3], Kamil Bielak[4], Andres Bravo-Oviedo[5], Gediminas Brazaitis[6], Catherine Collet[7], Vaclav Hurt[8], Viktor Kurylyak[9], Jan den Ouden[10], Maciej Pach[11], Hans Pretzsch[12], Jerzy Skrzyszewski[11], Vit Sramek[13], Katarina Strelcova[14], Miroslav Svoboda[15], Kris Verheyen[16], Tzvetan Zlatanov[17], Quentin Ponette[1]

[1] Earth and Life Institute, Université catholique de Louvain, Louvain-la-Neuve, Belgium
[2] Abteilung Waldbau und Waldökologie der gemäßigten Zonen, Georg-August-Universität, Göttingen, Germany
[3] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Alnarp, Sweden
[4] Department of Silviculture, Warsaw University of Life Sciences, Warsaw, Poland
[5] Dept. Biogeography and Global Change. National Museum of Natural Sciences, Madrid, Spain
[6] Vytautas Magnus University, Kaunas, Lithuania
[7] Université de Lorraine, AgroParisTech, INRA, UMR Silva, Nancy, France
[8] Department of Silviculture, Mendel University, Brno, Czech Republic
[9] Forestry Academy of Sciences of Ukraine, Lviv, Ukraine
[10] Forest Ecology and Forest Management Group, Wageningen University & Research, Wageningen, The Netherlands
[11] Department of Forest Ecology and Silviculture, University of Agriculture in Krakow, Krakow, Poland
[12] Chair for Forest Growth and Yield Science, Technische Universität München, Munich, Germany
[13] Forestry and Game Management Research Institute, Opocno, Czech Republic
[14] Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Zvolen, Slovakia
[15] Faculty of Forestry and Wood Sciences, Czech University of Life Sciences, Praha, Czech Republic
[16] Forest & Nature Lab, Department of Environment, Ghent University, Melle-Gontrode, Belgium
[17] Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia, Bulgaria

The mineral nutrition of major broadleaved and coniferous tree species is deteriorating in Europe. In that context, species-mixing could be an efficient management tool to improve stand nutrition through effects of species interactions on the availability, uptake or use efficiency of nutrients. We analyzed the current foliar nutrient (N, P, K, Ca, Mg) quantities and balances of 260 beech and 248 pine trees from 15 pure and two-species stands across a gradient of environmental conditions throughout Europe. We hypothesized an overall positive effect of mixing on tree nutrition, and that this mixing effect would be stronger on nutrient-poor sites. Using linear mixed models, we first tested for the effects of species (beech/pine) and composition (pure/mixed) across all sites; we then investigated whether mixing was related to site fertility. The composition of beech leaves and pine needles differed significantly for all balances. For both species, significant mixing effects were detected for some nutrients and balances; those effects could however not be related to interspecific differences in foliar nutrient composition. For most nutrients and balances, the mixing effect was affected by the site nutritional status; however, the magnitude of this effect was low, and no consistent pattern could be detected. The contrasting foliar elemental composition of pine and beech trees, and the difference in nutrient status between sites proved insufficient to explain the mixing effects on tree nutrition. While our results suggest limited impact of mixing for those two species, they claim for a better understanding of nutrient-related mechanisms associated with complementarity.

Session 3: Dynamics and management of mixed forests. Poster presentations

Short-term thinning effect on radial increment of a Scots pine and Mediterranean oak mixed stand

Jorge Aldea[1], Miren del Río[2,3], Nicolás Cattaneo[4], Jose Riofrío[5], Cristobal Ordóñez[3,5], Sara Uzquiano[3,5], Felipe Bravo[3,5]

[1] Southern Swedish Forest Research Centre, SLU, Sundsvägen 3, SE-23053 Alnarp, Sweden.
[2] Department of Forest Dynamics and Management, INIA-CIFOR, Madrid, Spain
[3] Sustainable Forest Management Research Institute, University of Valladolid - INIA, Avda. Madrid, s/n, 34004, Palencia, Spain
[4] Chaire de recherche sur la forêt habitée, Département de Biologie, Chimie et Géographie, Université du Québec à Rimouski (UQAR), Canada
[5] Departamento de Producción Vegetal y Recursos Forestales, ETS de Ingenierías Agrarias. Universidad de Valladolid, Palencia, Spain

Thinning treatment and mixed forest stands have been suggested as possible adaptation strategies to cope to climate change but there is scarce knowledge about the combination of both subjects. In this study, we aim to better understand the thinning effect and the growth differences on inter- and intra-annual cumulative radial increment patterns between two coexisting species. We studied radial increment of Scots pine-oak (Pinus sylvestris-Quercus pyrenaica) Mediterranean mixed stands during two climatically contrasted years (2016-2017) in north-western Spain. A thinning trial was carried out, consisting in a randomized block experimental design with a control and two thinning treatments from below: a moderate and heavy thinning removing 25% and 50 % of initial basal area respectively focused on both species. Radial increment was analysed based on readings from band dendrometers installed in 90 oak and pine trees. Scots pine leaded the tree and stand growth, and have also a better respond to early spring drought compared to oak. Heavy thinning increased tree radial increment for both species at the expense of decreased stand basal area increment for Scots pine and for total stand, but does not for oak at stand level. Heavy thinning has been proved to be a suitable management proposal to ensure the stability and persistence for the Scots pine-oak mixed stand, which could play an important role to cope to ongoing climate change.

Impact of the mixture on stand density management diagram for Mediterranean pines

Ali Askarieh[1], Felipe Bravo[1], **Irene Ruano**[1]

[1] iuFOR, Universidad de Valladolid

Stand density management diagrams (SDMDs) are robust decision-support tools available to forest managers under limited information. SDMDs which are empirical models at stand level, graphically represent the temporal relationships among stand density, and different stand variables. They are used to define initial planting spacing or thinning interventions in pure even-aged stands but there is still a lack of knowledge on how to develop and use in mixed stands. The aim of this study is to develop an SDMD for Pinus sylvestris and Pinus pinaster mixed stands in the Sierra de la Demanda, an elongated mountainous massif rising in the extreme northwest of the Iberian system located in Soria and Burgos provinces (Spain), using data from the third Spanish National Forest Inventory. Linear models including quadratic mean diameter, dominant height, total stand volume, density, Reineke index, and species proportion were used to model a simultaneous fit. The results of the fitting showed the new variable representing the proportion of both species was not significant indicating that the considered variable does not capture the impact of the mixture. So the SDMD was constructed using fitted models including stand density, dominant height and stand total volume and without including mixture degree.

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Crown size and niche partitioning in Nothofagus alpina and Nothofagus obliqua (Nothofagaceae) trees of the mixed subantartic forest

Hernán Attis Beltrán[1], **Alejandro Dezzotti**[2], Georgina Sola[1], Luis Chauchard[3], Marcelo González Peñalba[4], Renato Sbrancia[3]

[1] Consejo Nacional de Investigaciones Científicas y Técnicas, San Martín de los Andes, Argentina
[2] Departmento de Ecología, Universidad Nacional del Comahue, San Martín de los Andes, Argentina
[3] Departmento Forestal, Universidad Nacional del Comahue, San Martín de los Andes, Argentina
[4] Administración de Parques Nacionales, Parque Nacional Lanín, San Martín de los Andes, Argentina

The crown size, although been subjected to less mensuration studies, is a key component for controlling the performance of a tree given the close relation with its photosynthetic capacity (Hemery et al. 2005). Trees usually exhibit a linear relationship between crown diameter (*k*) and stem diameter (*d*) for d ≈ 0.2 - 0.5 m. *k/d* interaction is used not only for growth models and silviculture, but also for ecological studies because of the existence of higher *k/d* ratios in more shade tolerant trees (Blanchard et al. 2016). The forests composed of *N. alpina* (Na) and *N. obliqua* (No), two evolutionarily closely related species, develop on the eastern slopes of the Andes between 39°-41°S (CIEFAP 2016). Nothofagus exhibits intolerance to shade and gap-dependent regeneration. However, immature trees also show divergences associated to light with Na being more shade tolerant than No, a feature which in turn explains niche partitioning and species coexistence (Dezzotti and Ponce 2018). In mature virgin stands, healthy dominant individuals originated from seed ($d \leq 0.5$ m) were measured for *d* and *k*. *k/d* followed a significant linear function k = a + b d for Na (b = 0.173, R2 = 0.624, n = 46) and No (b = 0.143, R2 = 0.580, n = 36) ($p < 0.001$). Although *k/d* was better represented by a straight line, the comparison of b did not reveal any interspecific difference in shade tolerance (p = 0.368). Other crown features (shape, position) could be related to the existing divergences in species temperament.

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Business scenario analysis for native-exotic mixed forest plantations: a case study in the Brazilian Atlantic Forest

Remo Augusto Padovezi Filleti[1], Hilton Thadeu Zarate do Couto[2], Francesco Bosello[3, 4, 5], **Felipe Passos Caffaro**[6]

[1] Department of Economics, Ca'Foscari University of Venice
[2] Department of Forestry Sciences, "Luiz de Queiroz" College of Agriculture, University of São Paulo
[3] Eni Enrico Mattei Foundation - FEEM
[4] Euro-Mediterranean Center on Climate Change - CMCC
[5] Department of Environmental Science and Policy, University of Milan
[6] School of Forest Sciences, University of Eastern Finland

Most forest plantations in tropical regions are composed of monocultures of fast-growth exotic species, with well-known economic return rates. Although the capacity of mixed species forests to enhance biomass productivity and resilience have been attested by science, such projects are still incipient. This work analyzed eight business scenarios for a native-exotic case study in the Brazilian Atlantic Forest biome using discounted cash flow approach (discount rate = 8%), considering a common product (sawn wood) combined with: biofuel (debris/pellets), carbon credits (present/absent) and target markets (local/external). The production system considers 20 native (high commercial value) and 6 exotic tree species, four thinnings and the clearcut at age 48. The volumetric increment has been estimated by individual tree growth models. A sensitivity analysis has simulated both sawn wood and carbon credit price variations. Results show that tax exemptions granted for external market scenarios increased 2,15 percentile points the project's IRR and 60% the NPV. Biofuel selection and carbon credits have a small impact on economic returns. The project has remained economically robust regarding sawn wood price variations. The scenario targeting the external market, carbon credits and wood pellets has obtained the greatest economic results: NPV (US$3.279.377,56), IRR (15,83%) and payback period (18 years). Business scenario analysis has proven to be a useful tool to support forest investors' decision making. The most profitable scenarios have presented competitive IRR when compared to long-term rotation Pine plantations (25 years) in Brazil, validating the potential of mixed tropical forest investments in similar conditions.

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Incorporating climate change adaptation strategies to a fire-adapted mixed conifer landscape

Mike Battaglia[1], Lance Asherin[1], Matthew Tuten[2], Linda Nagel[3]

[1] USDA Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado, USA
[2] USDA Forest Service, San Juan National Forest, Colorado, USA
[3] Colorado State University, Department of Forest and Rangeland Stewardship, Fort Collins, CO, USA

Forest managers need robust examples of integrating climate change adaptation into silvicultural planning and on-the-ground actions. To address this need, the Adaptive Silviculture for Climate Change (ASCC) project is translating various adaptation concepts into on-the-ground, operational-scale research through a network of replicated sites testing ecosystem-specific climate change treatments across a gradient of adaptive approaches. In this presentation, we focus on the dry-mixed conifer forest site on the San Juan National Forest, CO, USA. Climate in this area is expected to get warmer with longer growing seasons, longer fire seasons, and cycles of drought conditions. Furthermore, much of the dry mixed conifer forest structure is outside its historical range of variability due to fire exclusion, grazing, and harvesting. These activities have resulted in dense forests that contain an excessive amount of non-fire adapted trees compared to historical densities when fire helped regulate forest structure. Three adaptation treatments were developed to demonstrate a gradient of accommodating change: Resistance, Resilience, and Transition. Each of the treatments focused on reducing forest density and manipulating species composition and spatial structure to increase resiliency to fire. This replicated study will contribute to the broad understanding of adaptive management strategies designed to address the uncertainty of climate change while testing site-specific effects on forest resiliency to increased wildfire potential, drought, disease, insects, and other disturbance factors relevant to dry mixed conifer forests in the Rocky Mountain region.

Dynamic of the mixed oak stands in the south side of the Mediterranean

Kada Bencherif[1]

[1] Department of forest resources, University of Tlemcen, Algeria

The exiting coppices and shrub-lands in the national park of Tlemcen (Algeria) are dominated by 3 oak species: *Quercus rotundifolia, Quercus faginea* and *Quercus suber*. These opened-fragmented structures, don't seem enough strong so to hope durable protection against climate change. Field observations across the park show certain dynamism in favor of *Quercus faginea* and *Juniperus oxycedrus* compared to *Quercus rotundifolia* and *Quercus suber*. In view of the expected climate changes, this dynamism could worsen more, and forest management is brought to keep interest in the causes and the consequences of this trend, providing rules for forest planning (choice of species, forest regime) in line with the current landscape context and especially with the future climatic context. On the sylvicultural plan, the invasion of *Quercus faginea* form in some places pure stands and as for the holm and pubescent oaks in north Mediterranean, where it's possible the replacement one another, this invasion must be considered as a natural tendency where *Quercus faginea* becomes the structuring specie. It's also the case of juniper that overruns holm oak stands. The purpose of this paper is to bring answers to questions in relation with the evolution of the climate in the region and its possible impact on the oak woods of the national park of Tlemcen on one side, and questions in relation with planning modalities of these stands in a context of climate change and anthropogenic pressure on the other side.

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Sensitivity of the growth of conifer and deciduous species to longterm climatic forcing in a drier western continental climate within the mixedwood forests zone of Québec, Canada

Emmanuel Amoah Boakye[1], Daniel Houle[2,3], Yves Bergeron[1], Igor Drobyshev[1,4]

[1] Institut de Recherche Sur Les Forêts, Université du Québec en Abitibi-Témiscamingue, Canada
[2] Ministère des Forêts, de la Faune et des Parcs, Direction de la recherché forestière, Québec, Canada
[3] Ouranos Climate Change Consortium, Montréal, Canada
[4] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Alnarp, Sweden

Climate warming trend since the inception of the 20th century could be impacting on boreal and temperate forests areas, where trees growth rates are limited by cold temperatures. To enhance sustainable forest management, there is a need to monitor the response of tree growth to the climatic variability. We analyzed the influence of the variability in climate on the growth rates of three conifers and four deciduous trees (~2300 trees), which co-occur in a drier western continental climate within the mixed forests bioclimatic zone of Québec, Canada. We used moving window correlations to analyze the changes in the relationships between seasonal climatic variables and tree-ring growth patterns. To enhance climate signal in the regional species-specific growth patterns, we removed the periods of growth suppression in the respective tree chronologies. *Abies balsamea*, *Thuja occidentalis*, *Acer rubrum* and *Populus tremuloides* displayed an upward growth trend since the mid of the 1900 suggesting that they experienced more favorable climatic conditions. In contrast, *Picea glauca*, *Acer saccharum* and *Betula papyrifera* displayed a decreasing growth trend. Although we observed a diversity of relationships between climatic variables and the growth of the species, consistently positive correlations with tree growth rates were observed for summer and fall temperatures and precipitation of the year of growth and for the summer and fall temperatures of the previous year. The study documents long-term changes in the growth rates of trees in mixed forests of eastern Canada and emphasizes a considerable variability in species growth response to long-term climatic changes.

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Stand Volume, Stability and the Richness of Tree Species, how it Associated in Hemiboreal Forest of Lithuania?

Gediminas Brazaitis[1], Ramūnas Mažėtis[1], Hans Pretzsch[2], Miren del Río[3], Gintaras Kulbokas[4], Remigijus Žalkauskas[1]

[1] Institute of Forest Biology and Silviculture Vytautas Magnus university, Studentu 11 Akademija LT-53361, Kaunas dist. Lithuania
[2] Chair for Forest Growth and Yield Science, Technical University of Munich, 85354, Freising, Germany
[3] Department of Forest Dynamics and Management, INIA-CIFOR, 28040, Madrid, Spain
[4] Institute of Environment and Ecology Vytautas Magnus university, Studentu 11 Akademija LT-53361, Kaunas dist. Lithuania

Mixed-species forests are getting a new forest management paradigm. This study aims to answer the question how does Tree Species Richness affects the Stand Stability and Volume in mixed stands? This study was performed in south-west Lithuania. Field surveys were conducted using 586 systematically dispersed circular plots ($500 m^2$) in mature stands. Per plot we recorded 1-10 tree species. Stand stability was estimated by mortality, recorded with the presence of fresh deadwood. Tree species richness and the volume of shade tolerant species showed no clear association with stand volume. Stand age and stand density show strong positive effect. Tree species richness was positively associated with the proportion of fresh deadwood, i.e. diverse stand with more tree species showed less stability. Finally, the proportion of shade tolerant tree species showed strong positive impact to stand stability.
A.glutinosa showed highest preference in formation of pure stands, *F.excelsior, S.caprea, A.platanoides, S.aucuparia* – affiliation to maximal richness of tree species. Other tree species highest abundance showed in a whole gradient: *P.sylvestris* (2-3 tree species), *T.cordata* (3-7), *P.abies, Q.robur* (4-6), *U. minor* (7-8), *P.tremula* (7-9). Finally, *Betula* spp. showed lowest preference in 4-6 tree species plots. Highest mortality (least stability) showed *P.sylvestris* in pure stands as well as *F.exelsior, P.tremula, A.glutinosa , U.minor* in mostly rich tree species stands. *Q.robur* and *Betula* spp. were least stable in the stands with 6-8 and *T.cordata, C.betulus* –7-9 tree species. *P.abies* showed relatively high unstability in a whole range of tree species diversity with slight more stability in least diverse stands.

Demographic approach to stocking control in multi-species forests: a case study in Białowieża Forest

Bogdan Brzeziecki[1], Stanisław Drozdowski[1], Kamil Bielak[1], Marcin Czacharowski[1]

[1] Department of Silviculture, Institute of Forest Sciences, Warsaw University of Life Sciences

It is widely recognized that mixed forest stands have several important silvicultural and ecological advantages over pure stands. That is why, in many countries, increasing the share of mixed tree stands in total forest area is an important goal of the modern-day forest policy. In the forestry practice, however, creating and sustainable management of multi-species stands is hampered, among others, by a lack of suitable planning tools, analogous to the stocking control methods, most of which were developed for singlespecies stands (like the BDq method, for example). We use species-specific, so called ‘demographic equilibrium curves’, as a tool enabling controlling and regulation of the long-term development of forest stands composed by several different tree species. The curves were developed and calibrated for major tree species occurring in Białowieża Forest using long-term data on basic demographic processes (tree growth and mortality) (Brzeziecki et al. 2016). We describe an example of practical application of the equilibrium curves, using for this purpose the stand inventory data collected on three occasions (2002, 2011 and 2018) in the ‘Experimental Control Unit Browsk 26C’ (occupying an area of ca. 30 ha and consisting of ca. 10 different tree species), located in the managed part of the Białowieża Forest. We demonstrate that a comparison of con-specific theoretical equilibrium curves with the actual diameter distributions can significantly help to elaborate silvicultural prescriptions aimed at the long-term maintaining of a ‘balanced’ composition and structure of multispecies tree stands occurring within the analyzed control unit.

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White spruce growth responses to climate variability in pure and mixedwood stands

Jéssica C. Cardoso[1], Ché M. Elkin[2]

1 Natural Resources and Environmental Studies Graduate Program, University of Northern British Columbia, Prince George, British Columbia, Canada
2 Department of Forest Ecology and Management, University of Northern British Columbia, Prince George, British Columbia, Canada

Novel climatic conditions will likely pose challenges for forest management and conservation, and will influence tree growth. To better project how forests will develop, we need to advance our understanding of how they grow, particularly under novel future climate scenarios. This study aims to evaluate how the growth of individual white spruce trees (Picea glauca (Moench) Voss) is influenced by climate variability over short (daily) and intermediate (monthly, annually) time periods in pure and mixedwood stands located at the Inga Lake site, north-eastern British Columbia, Canada. This study includes an evaluation of 30 years of site microclimate data, individual tree growth high-resolution measurements using electronic dendrometer bands, dendrochronology studies, and sap flux measurement. Our first findings indicated that the response of annual white spruce growth to microclimate variability depends on the stand structure. Our study suggests that seasonal and monthly climate predictor variables might be more suitable to understand annual tree growth responses to climate than annual climate variables. In both stands warm spring increased spruce growth and warm summer decreased spruce growth. Spruce growth in the pure stand showed a positive relationship with soil water potential during spring and summer, while spruce growth in the mixed stand showed a negative relationship. Spruce growth in both stands may suffer from drought stress as the climate warms. Our study provides information that will be useful in modeling and managing pure and mixed stands across western Canada in a current and future climate condition.

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Influence of thinning, litter type and canopy on litter decomposition in a Scots pine and European beech mixed forest

David Candel-Pérez[1], J. Bosco Imbert[1], Maitane Unzu[1], Juan A. Blanco[1], Federico J. Castillo[1]

[1] Department of Sciences, Public University of Navarre, Pamplona, Spain

Leaf litter decomposition is an essential process in biogeochemical cycles and the release of nutrients available to plants (Gartner and Cardon, 2004), especially in mixed forests where a conifer and a broadleaved share the habitat but have different ecological requirements. Forest management can affect decomposition factors differently and produce significant changes in productivity and other ecosystem functions (Blanco et al., 2011). Therefore, it is necessary to understand the factors controlling decomposition rates and nutrient cycles in mixed forests. A litter decomposition experiment was carried out in a Scots pine and European beech mixed forest in the south-western Pyrenees (province of Navarre, Spain). The effects of different thinning intensities (0%, 20% and 40% removal of basal area), leaf litter types (pine needles, beech leaves or a mixture of both) and tree canopy (pure pine or mixed) on mass loss and chemical composition in such decomposing litter were studied over a period of three years. A higher decomposition rate was observed in litter from the pine needles and beech leaves mixture, as well as under mixed tree canopy. Incubation time of the litter in the decomposition bags affected the concentration of nutrients and significant differences in chemical composition were observed between the different litter types. Thinning had no appreciable effect on decomposition rates. These results suggest that there are positive synergies between both pine and beech litter types and that mixed stands favour decomposition. The combined effect of these mixed-stands factors on decomposition rates is greater than the influence of thinning.

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Crown level modifications. The case of pine mixtures in Mediterranean environments

Nicolas Cattaneo[1], Felipe Bravo[2,3], Andrés Bravo-Oviedo[4], Robert Schneider[1]

[1] Chaire de recherche sur la forêt habitée, Département de Biologie, Chimie et Géographie, Université du Québec à Rimouski (UQAR), Rimouski , Canada.
[2] Sustainable Forest Research Institute, University of Valladolid and INIA, Palencia, Spain.
[3] Departamento de Producción Vegetal y Recursos Forestales, E.T.S de Ingenierías Agrarias, Universidad de Valladolid, Palencia, Spain.
[4] Department of Biogeography and Global Change, National Museum of Natural Sciences, MNCN-CSIC, Madrid, Spain.

Canopy structure is a main determinant of productivity changes observed in mixed forests. It can be defined as the sum of the size, shape and relative position of individual tree crowns. Although most studies of mixture effects focused on combinations of species with contrasting traits, the increasing in species diversity have shown an improving of both productivity and canopy assembly even in homogeneous forest types or in closely related species mixtures. Using data from a triplet trail, we analyzed the crown structure of trees growing in pure and mixed stands of *Pinus pinaster* Ait. and *Pinus sylvestris* L.. Analysis were based on dataset series of crown metrics derived from terrestrial laser scanner. Changes in the crown dimensions of *P. pinaster* in response to *P. sylvestris* mixing were observed. In addition, we were able to quantify different aspects of crowns in trees growing in pure and mixed stands, which allowed us to inspect the way these two species tend to occupy the space in the canopy, and discuss potential crown complementarity mechanisms behind the changes previously found in productivity.

Biological attributes of compositionally contrasting natural forests in a single geomorphological area from a temperate ecoregion

Alejandro Dezzotti[1], Ariel Mortoro[2], Andrea Medina[3], Renato Sbrancia[2], Hernán Attis Beltrán[4]

[1] Departmento de Ecología, Universidad Nacional del Comahue, San Martín de los Andes, Argentina. Present address: Instituto Universitario de Gestión Forestal Sostenible, Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria - Universidad de Valladolid, Palencia, España.
[2] Departmento Forestal, Universidad Nacional del Comahue, San Martín de los Andes, Argentina.
[3] Departmento de Botánica, Universidad Nacional del Comahue, San Martín de los Andes, Argentina.
[4] Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina.

Changes of land use represent a significant and immediate threat to biological diversity (Titeux et al. 2017). Forest plantations is a land cover conversion that may implicate substantial effects on diversity (Overbeek et al. 2012, Greene et al. 2016). In north-western Patagonia from Argentina, afforestation of *Pinus* is integrated into a matrix of natural vegetation, in the transition between the semiarid Patagonian and the humid Subantarctic ecoregions (MAGyP 2014). In the context of a comprehensive evaluation of the ecological sustainability of forestry (Frugoni et al. 2016), the diversity of two contiguous and compositional divergent mature forests surrounded by pines, were assessed in Aguas Frías (38°46´W, 70°54´S). The monospecific stand was composed of the broadleaved *Nothofagus pumilio*, whereas the mixed stand included also the conifer *Araucaria araucana*. We carried out univariate, bivariate and multivariate analysis from incidence data of vascular plants including 52 variables. The N. pumilio stand showed larger values of taxonomic and lifeform diversity, species density and frequency of shrubs, herbs, rare and unique species. The similarity between both communities was intermediate, and the Principal Component Analyses clearly split them into separated groups. The observed dissimilarities would be related to the greater efficiency of mixed stands to occupy the aerial space, therefore limiting the amount of light that reach the forest floor. The assessment permitted to characterise the diversity of two contrasting stands. This information can be used to prevent and mitigate eventual deleterious effects of forestry, and consequently to attain a greater compatibility concerning conservation and wood production.

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Restoring forests biodiversity: the example of the Life Integrated Project "Gestire 2020"

Patrizia Digiovinazzo[1], Mattia Bertocchi[1], Giuliana Cavalli[2], Gherardo Fracassi[2], Marco Torretta[2], Bruna Comini[2]

[1] Technical Facilitator of Life Project Gestire 2020
[2] Regional Authority for Agriculture and Forestry Services – Lombardy Region (E.R.S.A.F.)

Lombardy regional government is currently running the EU-funded, 8 years long Life Integrated Project *Gestire 2020*, aiming to improve management effectiveness of Natura 2000 sites and their linking Green Networks. Mixed forests represent relevant Habitats both in plains, hills and mountains and the Life Project seeks to improve biodiversity and ecosystem resilience through specific restoration projects. The aim of our contribution is to show the most significant forest improvements projects conducted through the Life Project by now: A) restoration of the undergrowth inside Riserva Naturale Bosco dei Bordighi by reduction of alien invasive species (e.g. *Impatiens glandulifera*) and restoring with native ones; B) interventions to improve the forests composition and the suitability for species of conservation interest (e.g. *Dryocopus martius*); C) restoration of riparian woods to improve spontaneous undergrowth; D) interventions to improve production of ecotypes and resistant phenotypes of oak (*Quercus robur*). Each project has been preceded by releves to assess the state of the art. Some of these projects have already been completed, while others will be completed soon. Life Project *Gestire 2020* plans ex ante and ex post surveys to monitor the effectiveness of the interventions in terms of biodiversity improvement: in progress results are already able to provide some important informations

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Underyielding in mixed stands of pedunculate oak depends on the admixed tree species and the pattern of admixture: a case study for European aspen, small-leaved lime, Norway spruce and hybrid larch in Sweden

Lars Drössler[1], Jens Peter Skovsgaard[2]

[1] School of Natural Science and Medicine, Ilia State University, Kakutsa Cholokashvili Ave 3/5, 0162 Tbilisi, Georgia
[2] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Box 49, 23053 Alnarp, Sweden

Mixing pedunculate oak with European aspen, small-leaved lime, Norway spruce or hybrid larch on a fertile glacial till site in south Sweden consistently resulted in increased stand volume growth (stem volume for conifers, stem and branch volume for broadleaves) during 15 years after planting, but less so than expected based on the proportion of admixture (Drössler et al. 2015). Underyielding was less for broadleaved tree species than for conifers. Group mixtures resulted in larger productivity than row mixtures. Ecological indicator values describing common traits of each tree species could explain a part of the observed variation in stand growth.

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Long-term dynamics of protected mixed forests as a contribution to development of close to nature silviculture

Karolina Gabrysiak[1], Rafał Paluch[1]

[1] Department of Natural Forests, Forest Research Institute, Białowieża, Poland

One of the important demands of "close to nature" silviculture is the widest possible use of natural regeneration. Understanding the course and evaluation the effectiveness of renewal in the absence of human influence is essential to forestry practice. The main objective of the study was determining the directions of changes in species composition and structure of stands covered by reserve protection, and natural regenerations appearing in them. The possibility of using renewals in silviculture was also assessed. Research was carried out on permanent research plots (size 0.25 ha) located in Augustów, Knyszyn, Białowieża Forest (NE Poland), established in the 70s and measured systematically. The thickness measurement included all trees reaching breast height, and also saplings were counted. Over analyzing period of 40yr we state that renewals are unsatisfactory from the point of view of the concept of multifunctional forest and sustainable forest management. There were no Scots pine (*Pinus sylvestris* L.) regeneration, and the renewal of the oak (*Quercus robur* L.) occurred sporadically. The number of saplings of other species was often small, except hornbeam (*Carpinus betulus* L.) and maple (*Acer platanoides* L.). It was found that the expansion of hornbeam and / or hazel (*Corylus avellana* L.) was the most important factor directly affecting the direction and pace of changes in many of analyzed forest communities, which has intensified in the last decade. Control of renewal processes and creation mixed, multi-generational stands are necessary to provide a forest biodiversity.

Tree size and diversity relationships in a tropical forest in Vietnam

Yusif Habib[1], Manh Hung Bui[2], Felipe Bravo[1]

[1] Instituto Universitario de Investigacion Gestion Forestal Sostenible (iuFOR), Universidad de Valladolid, Palencia, Spain
[2] Vietnam National of Forestry, Xuan Mai, Hanoi, Vietnam

In tropical forests tree species, diversity underlines productivity. By modelling mixed forest stand dynamics, we introduced biodiversity parameters to derive insight on its relationships and simulate alternative management strategies. In this study, tree size and diversity relationship models were adjusted for six (6) species and three (3) different species groups in Northern Vietnam tropical forests. Species with higher observations/distribution in the analyzed one-hectare plot were considered individual candidate whiles, those with less observations were grouped according to their respective wood density values. Height-Diameter relationships were adjusted by species and class. Crown Width was modelled using the Diameter at Breast Height and Crown Ratio as independent variables. In order to examine the influence of diversity on size, diversity indices were included as independent variables in the previous models. Candidate models were ranked according to Akaike Information Criterion (AIC), R-adjusted (R^2) and Mean Squared Error (MSE) Values. The analysis revealed best-fitted model for tree size and diversity with an R^2 value of 0.69 and MSE value of 0.05 respectively with inclusion of Shannon index for the overall distribution in the Marteloscope. Further, Shannon diversity index on Crown Width revealed an R^2 of 0.52 and MSE of 2.71. It was therefore established that, species diversity in Vietnamese tropical forests affected the size of Crown and Height-Diameter growth. Consequently, these models set the basis for understanding the dynamics of tropical forest growth for sustainable forest management in South-East Asia.

Gap Regeneration and Dynamics: The Case Study of Mixed Forests at Krtiny in the Czech Republic

Maame Esi Hammond[1], Radek Pokorny[1]

[1] Department of Silviculture, Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic.

For decades, mixed forests at Krtiny have had long-standing silviculture records of sustainable natural regeneration as the main form of forest management practice. Hence, this study aimed to examine the dynamics of natural regeneration in gaps at different forest types (i.e. coniferous, broadleaved and mixed) from 2013 to 2016. Habruvka forest unit was the study area. Within each ten studied gaps, four transects towards the cardinal directions were demarcated and then, along each transect, ten 1m^2 circular sampling areas were created. Data on light conditions before and after gap creation and regeneration census from 2013 to 2016 were gathered. Results indicated that gap sizes (226 - 1291m^2); small and big influenced light conditions in gaps. From these quantified light conditions, Indirect site factor (ISF) was the significant condition in 2013 and 2014 due to permanent shading emitted from geographic characteristics at the study sites. Tree species densities were higher in 2014 but poor in 2016 following drought and game activities in 2015. Regeneration density of shade-tolerant beech under broadleaved forest in 2013 while that of intermediate spruce under coniferous forests in 2016, both in small gaps were significantly higher than other species in these respective years. Beech, spruce, fir, larch ash, sycamore maple, and willow were present in all gaps during the studied period while hornbeam was exclusively absent in 2014. Gap creation enhanced microclimatic conditions which facilitated the coexistence of different tree species. Forest types, gap sizes, and species were the main variability factors that caused regeneration dynamics.

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Dendrometric parameters estimation from terrestrial laser scanner data: adaptation of a methodology for mixed forests in central Mexico

José Antonio Hernández-Moreno[1], Valentín Jose Reyes-Hernández[1], Alejandro Velázquez-Martínez[1], Aurelio Manuel Fierros-González[1], Armando Gómez-Guerrero[1], José Armando Gil Vera-Castillo[2], Felipe Bravo[3].

[1] Colegio de Postgraduados
[2] Universidad Autónoma Chapingo
[3] iuFOR, Universidad de Valladolid

Terrestrial laser scanning (TLS) is a fast developing technology worldwide, owing to its usefulness as a remote sensing tool to acquire three-dimensional data and assess forests structure, among other uses; nevertheless, it still remains a hardly explored approach in Mexico's forestry, remaining as a compelling research opportunity for further use in forest inventories and forest ecology. In this research, we used TLS data to estimate dendrometric characteristics and compared them with traditional field measurements, to develop a methodology combining TLS and free access software, for inventories in mixed forests of Central Mexico. Also, the application of TLS data in describing and characterizing the available growing space of the coexistent species was explored. The study was performed in an *Abies religiosa* (Kunth) Schltdl. & Cham and *Pinus pseudostrobus* Lindl. mixed plot, located in the Monarch Butterfly Biosphere Reserve, in Michoacán, Mexico. Our results showed no significant differences ($p > 0.05$) between TLS and inventory data, with RMSE=1.67 cm and R^2=0.99 for diameter at breast height (DBH), RMSE=2.67 m and R^2=0.93 for total height (HT), and RMSE=0.351 m3 and R^2= 0.95, for stem volume. The results demonstrated that TLS is an efficient and reliable technique that can provide precise and detailed information of individual tree attributes, and to characterize available growing space in mixed stands. The results also showed that TLS represents a powerful and robust non-destructive method, based on digital dendrometry, widely used in forest ecology, with emphasis on forest inventories, to assess forest stand dynamics.

Long-term research of the dynamics of structure and productivity of mixed uneven-aged European beech (*Fagus sylvatica* L.), Silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* Karst.) forests in Bosnia and Herzegovina

Aida Ibrahimspahic[1], Ahmet Lojo[1], Besim Baloć[1], Azra Čabaravdić[1], Admir Avdagić[1]

[1] Faculty of Forestry, University of Sarajevo, Bosnia and Herzegovina

During the period from 1954 to 1957 on the Igman mountain (near Sarajevo), 5 permanent experimental plots were established in both mixed uneven-aged forests of fir and spruce and in forests of beech, fir, and spruce. The experimental plots were established at different altitudes, expositions and terrain slopes. Selection felling, based on the positive selection principle was conducted on them. Analyzing of the data collected by the 6 periodic measurements revealed the following:

- unimodal or bimodal diameter structures of stands at the beginning of the observation period gradually developed into digressively decreasing ones, with the dropping of mean diameter and stand homogeneity,
- the number of trees (threshold of 10 cm) varied from 230 to 870 trees/ha, greater in worse site conditions and with smaller mean diameter,
- changes in the proportion of tree species in the number of trees were caused by changes in the proportion of tree species in the number of ingrown trees,
- the basal area varied from 17.0 to 51.0 m2/ha, depending on the number of trees and diameter structure,
- different changes in the tree diameter-height ratio, the smallest displacement of the height curves was for dbh = 50 cm,
- growing stock (merchantable wood) varied from 159.0 to 615.0 m3/ha, positively correlated with the basal area and site quality,
- volume increment varied from 3.0 to 13.0 m3/ha/year, greater in better site conditions, with smaller mean diameter of stand and a greater amount of precipitation during the growing season.

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Nemoralization process of mesotrophic and meso-eutrophic pine *Pinus sylvestris* forest stands in a changing environment in Latvia

Dārta Kaupe[1]

[1] LVMI "Silava", Salaspils, Latvia

In Latvia, 76.5% of pine stands (with more than 40% of pine in the tree layer) grow in mesotrophic and meso-eutrophic sites. For 30 years, we have carried out long-term observations and studies in extensively managed old (older than 100 years) pine stands in mesotrophic and meso-eutrophic conditions. The study revealed significant changes in the species composition of forest stands (main stand, advance growth and seedlings) during this time, which allowed two lines of transformation of pine forest stands to be identified. In an urban environment, urban forests tend to form composite pine stands, where the overstorey is composed of old pines, while the second storey consists of maple *Acer platanoides* with small admixture of broad-leaved species. The number of pine individuals in the forest stands has decreased to 30-35%, the number of maple individuals is 70-65%.
In urban forests, semi-natural mature and over-mature pine stands are intensively permeated by Norway spruce (*Picea abies*), as individuals of varying ages and heights, gradually replace pine in the tree layer. At the same time in older forests, under the overstorey of 120-180-year-old pine and spruce stands, an understorey of broad-leaved trees is gradually developing along with the spruce. In Latvia, both in urban and rural environments, intensive invasion of indigenous (in urban forests – also introduced) broad-leaved tree species is currently taking place in old pine and mixed pine and spruce forest stands. These changes are related to the nemoralization process of vegetation, which reflects trends of transformation of coniferous forest stands.

Reducing uncertainty in the site index modeling of mixed hardwoods using a data assimilation approach

Anil Koirala[1], Cristian R. Montes[1], Bronson P. Bullock[1]

[1] Warnell School of Forestry and Natural Resources, University of Georgia, GA, USA

Naturally regenerated hardwood forests are extremely important to preserve regional biodiversity as well as to support regional timber supplies. Decision support tools, such as growth and yield models, are needed to better manage these forests. However, comprehensive growth and yield models for hardwoods in the southern US are still scarce. Predicting growth and yield of hardwoods is difficult because of the multi-species and typically uneven age structure of the stands, leading to growth rates that largely differ between individuals. Past studies developing site index curves for southern hardwoods have incorporated a species grouping variable to tackle multiple species problem. The downside of the 'group' modeling approach is that there is a large amount of variability present in such data due to the heterogeneous nature of the different growth rates of the species present in stands. Therefore, we developed a data fitting methodology to calibrate a dominant height equation using a data assimilation approach that filters out much of the variation. The concept of data assimilation is based on the assumption that neither model nor measurements can perfectly describe a system, but an analysis that combines both model and data will provide a better estimate of system dynamics. This approach is well suited for site index data that includes height at the current age. For this study, we used permanent sampling plot data from even-aged mixed-species stands measured all over the southern US. Site index models developed with this approach will reduce uncertainty in dominant height projection for mixed hardwood fore.

How does tree species mixture affect ecosystem processes? – Results from OPTMix, Oak-Pine tree Mixture experiment.

Nathalie Korboulewsky[1], Philippe Balandier[1], Marion Gosselin[1], Bello Jordan[1], Anders Mårell[1], Thomas Pérot[1]

[1] Irstea, UR EFNO, Nogent-sur-Vernisson, Domaine des Barres, 45290 Nogent-sur- Vernisson, France

Solutions for more resilient and resistant forests, while maintaining ecosystem services such as wood production, carbon stock and biodiversity conservation. OPTMix, a unique tree experiment, makes it possible to study the effects of climate, silvicultural management (mixed species and density) and the presence or absence of large herbivores, as well as their interactions, on the functioning of lowland forests. The network covers 40 ha and comprises 33 plots of sessile oak (*Quercus petraea*) and Scots pine (*Pinus sylvestris*) in monospecific and mixed stands. The plots are heavily instrumented for continuous measurements: microclimate, growth, undergstorey dynamics including stand regeneration, resources (water, light, nutrients) and biodiversity are monitored through standardized protocols. We propose to give an overview of the major results obtained since 5 years, dealing with growth and water uptake during summer drought, nutrient cycle, tree species regeneration and moss diversity. The first results show that tree species mixture is not always better than monospecific stands for all the different processes and services studied. Further, these preliminary results show that the tree species identity determines both the magnitude and the sense of the effects observed. This work and future results make it possible, from an applied point of view, to optimize the supply of services while continuing to adapt the forest to future constraints.

OPTMix - Oak Pine Tree Mixture - A long-term experimental site in temperate oak-pine forest

Nathalie Korboulewsky[1]

[1] Irstea, UR EFNO, Nogent-sur-Vernisson, Domaine des Barres, 45290 Nogent-sur-Vernisson, France

OPTMix (https://optmix.irstea.fr) is an experimental site composed of 33 plots (of 0,5 ha) selected in even-aged lowland temperate forest stands of 60-80 years old (Orleans state forest in Central France). We combine factors rarely done at once and on the same forest, which makes this site unique. The objective of the field experimental site OPTMix (https://optmix.irstea.fr) is to study the cross effects of:

- stand composition (pure oak, pure pine, mixed pine-oak) and
- stand density (number of trees/ha) combined with
- presence of wild ungulates (roe deer, wild boar, red deer),

on the ecosystem functioning such as tree productivity, resource use and allocation (including water and nutrients), biodiversity and understory vegetation dynamics including regeneration. Each stand is equipped with a sensor network (temperature, light, relative humidity, rainfall, soil water content, soil water table depth) connected to a datalogger. We study various parameters on soil (physico-chemical parameters, water, nutrient cycle), plants (diversity, cover, litter quantity and chemistry) and animals (diversity, predation) in order to understand:

- the functioning of mixed stands vs monospecific stands,
- the role of biotic and abiotic factors on forest dynamic including biodiversity and tree regeneration,
- benefits and limits of managements practices to face the climate change and
- the vulnerability of forests towards global change.

We welcome teams and researchers to participate with new measurements or data analyses. This experiment will benefit to forest managers and industry players to meet the socio-eco-environmental challenges.

Two-storied mixed plantations for forest restoration

Magnus Löf[1] , Jorge Aldea[1], Lars Rytter[2]

[1] Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre, Alnarp, Sweden
[2] Forestry Research Institute of Sweden, Ekebo, Sweden

Two-storied mixed plantations for afforestation or reforestation can be designed to meet climate-, economic-, environmental- and social objectives during forest restoration. The temporary inclusion of pioneer trees (native or non-native) as nurse crops can facilitate the establishment of native target tree species and may also improve biodiversity, productivity and soil fertility. However, there is little scientific- and practical experience with the method. This study, from southernmost Sweden, reports from an experiment on how fastgrowing nurse tree species (birch and hybrid larch) influence the ecological growing conditions, and survival and growth in native target tree species (ash, beech, linden, Norway spruce, oak and wild cherry). Following 15 years from planting in 2002, our results show that the nurse crop had reduced the amount of competing vegetation (herbaceous– and woody species) but the effect was rather weak. Survival and growth varied greatly among target tree species, but the nurse crop had little influence on survival. Only Norway spruce, beech and oak survived in acceptable numbers (> 60%) for successful establishment. Survival was particularly low for ash. The nurse crop did, however, improve stem form in the target trees. We also report results on wood production and productivity since transgressive over-yielding has been observed similar studies elsewhere. Even if productivity is increased, the more complex forests structures may be an obstacle for costeffective management. However, for restoration practitioners, using nurse trees for rapidly building a new forest structure and simultaneously increase productivity, might be a costeffective strategy.

Restoration of mixed pine and beech forests: Influence on establishment from adjacent forests, fencing and mechanical site preparation

Magnus Löf[1], Jörg Brunet[1]

[1] Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre, Alnarp, Sweden

Mixed forests of *Pinus sylvestris* and *Fagus sylvatica*, and other deciduous species, can be designed to meet economic-, environmental- and social objectives during adaptation of forest management to climate change. Mixed forests of conifers and broadleaved tree species can, for example, increase productivity, biodiversity, and temporal stability of productivity and improve recreation values. There is, however, a lack of knowledge on how to establish such stands in a cost-effective way. The purpose of this study was to assess the effects of proximity to mixed forest, protection from browsing and of inverting site preparation on the establishment of planted beech and naturally regenerated tree species. The field experiment was established in 2011 and measurements of survival and growth of planted and naturally regenerated seedlings along with browsing damage was conducted regularly until 2017. The distance to mixed forest did not have a significant effect on survival and growth, not on amount of seedlings and nor on browsing damage. For natural regeneration, *Betula* spp., *Salix caprea* and *Pinus sylvestris* were the most common, and the amounts were positively influenced by site preparation. Both fencing and site preparation resulted in slightly better growth for most tree species. The effects on survival from these two treatments was, however, relatively minor. High deer populations is perhaps the greatest challenge for mixed forest regenerations. In this study, the amount of browsing damage to seedlings varied much between tree species. Especially pine seedlings were much damaged, and the pattern of browsing seem to be much site dependent.

Light regulation in the maintenance of a continuous natural rejuvenation of uneven aged mixed stands of fir, spruce and beech

Ahmet Lojo[1], Admir Avdagić[1], Ismet Fazlić[1]

[1] University of Sarajevo, Faculty of Forestry, Chair of Forest Management Planning and Urban Greenery, Zagrebačka 20, 71000 Sarajevo, Bosnia and Herzegovina

Successful management of uneven-aged mixed stands as a permanent growing form requires careful planning of continuous natural rejuvenation of forest stands. The amount of light on the ground is crucial for successful rejuvenation. To analyse the available amount of light we use canopy as indicator. To define maximal canopy in uneven-aged mixed stands (just before cutting) is very important. Maximum crown coverage has huge effect on volume increment and on stand rejuvenation dynamics. With higher crown coverage the volume increment is higher, but with total crown coverage rejuvenation could be terminated. If logging in uneven aged stands has not been carried out for some decades, stands will lose they structure (L-shape distribution), thin trees lag behind in normal development or dry. Also level of crown coverage is related to basal area and stand volume. In order to define a “normal” basal area in volume for uneven-aged stands is necessary to define “optimal crown coverage”. For successful control of quality forest management in B&H, during developing medium-term management plans, percentage of the crown coverage, abundance and quality of rejuvenation are recorded within different stands. This paper will present the results of research on the abundance and quality of young plants depending on the crown coverage. We will present how is problem of maximum crown coverage in uneven-aged mixed stands is solved using it as a basis for defining the optimal - "normal" composition of uneven-aged mixed stands of fir, spruce and beech.

A new generation plantation with masson pine – precious broadleaved mixed tree species in southern China: its silvicultural regime and preliminary results

Yuanchang Lu[1,2], Yangsheng Xie[1,2], Xianzhao Liu[1], **Hong Guo**[1]

[1] Chinese Academy of Forestry
[2] Research Center of Forest Management Engineering, SFA of China

China has the largest artificial plantation area in the world, and masson pine (*Pinus massoniana*) is the largest used plantation species in southern China. How to maintain the advantage of masson pine as a dominant species and overcome its inadequacy is a major scientific problem of forest management, and it is also a new direction of Chinese forestry study in recent 2 decades. This paper introduces the research of transformation the single structured masson pine plantation into a mixed form with precious hardwood trees as a new generation of plantation, includes the analysis of ecological, silvicultural and economic characteristics of tree species, the design of silvicultural regime under the multi-functional, whole life-cycle and close-to-natural management objectives, stand dynamics and management effects based on the 10-year monitoring data from a typical demonstration forests. These preliminary results show that the design of cultivation time process from single pine stand to mixed forest is very helpful, the process management requires more investment and technology, but the benefits are also more, understanding and utilization the tree species relationship is the key scientific basis to realize transforming process, and horizontal structure is the sensitive, reliable and comprehensive technical index of effects obtained.

Tree responses to climate variation in European forests across diversity gradients: results from the network of automated measurement devices

Radim Matula[1,2], Roman Plichta[1], Martin Šrámek[1], Roman Gebauer[1], Hana Vyčítalová[1], Fernando Valladares[3], Olivier Bouriaud[4], Leena Finér[5], Kris Verheyen[6], Michael Scherer-Lorenzen[7]

[1] Department of Forest Botany, Dendrology and Geobiocoenology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00 Brno, Czech Republic
[2] Department of Forest Ecology, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 00 Prague, Czech Republic
[3] MNCN-CSIC, Serrano,115 bis 28006 Madrid, Spain
[4] Faculty of Forestry, Stefan cel Mare University of Suceava, Universitatii, Street 13, Suceava 720229, Romania
[5] Natural Resources Institute Finland (Luke), Yliopistokatu 6, FI-80100 Joensuu, Finland
[6] Forest & Nature Lab, Ghent University, Geraardsbergsesteenweg 267, B-9090 Melle- Gontrode, Belgium
[7] Faculty of Biology, Geobotany, University of Freiburg, Schänzlestr. 1, 79104 Freiburg, Germany

Climate change has put many common European tree species under stress, reducing their productivity and increasing mortality. Besides changes in species composition, replacing monocultures with mixed-species stands is considered as a key step to make forests more resistant to the adverse climatic conditions. However, there are still significant gaps in understanding whether, how and where tree diversity may help modulate the impacts of climate change on forest resilience and productivity. To explore the issue, we installed automated high-resolution point dendrometers on approx. 620 trees together with microclimatic dataloggers (TMS4) in exploratory plots of the FunDivEUROPE network in Finland, Romania and Spain along tree diversity gradients ranging from 1–4 tree species (3 in Finland). The dendrometers have been measuring stem diameter changes (± 1μm) every 15 minutes, thus capturing not only growth but also water stress and its intensity. At the same frequency, TMS4s measure soil moisture and temperature in the understory. The results (from 1–2 growing seasons) indicate that some species benefit from higher tree diversity, but that some have reduced growth in mixtures, especially during drought. The data also revealed significant differences in within-year growth dynamics among species and species mixtures. Although these are only preliminary results, it is evident that the precise automated dendrometers in combination with soil probes are convenient tools for detecting mechanisms by which tree diversity and identity and their interactions with climate affect tree growth and resilience at different spatial and temporal scales.

Beech and silver-fir trees allometry and partitioning, in a primeval forest in the central Carpathian Mountains

Victor Mihaila[1,2], Gheorghe Stefan[1], Jorge Curiel-Yuste[2,3], Ion Catalin Petritan[2], Cosmin Braga[1], Vlad Crisan[1], Constantin Dumitru-Dobre[1], Any Mary Petritan[1]

[1] National Institute for Research and Development in Forestry "Marin Dracea"
[2] "TRANSILVANIA" University of Brasov, Faculty of Silviculture and Forest Engineering
[3] BC3-Basque Centre for Climate Change

Biomass is one of the key elements of monitoring carbon storage in forest ecosystems. Allometric equations are the most commonly used to estimate it, but because of the large variability across Europe, the need for specific local equations rises. To estimate the biomass of the Sinca beech-silver fir mixed virgin forest we developed allometric equations for the two main tree species, for all major tree components (stem, branches, leaves and roots) and compared them with European generic functions. Nineteen beech (0.3-88 cm) and twenty-three silver fir trees over a long gradient (0.3-93 cm) of diameters at breast height (DBH) have been harvested and we quantified each components biomass. Knowing that biomass varied over the DBH gradient, we found that stem biomass allocation increased from 40% to 70% for beech and 57% to 73% for silver fir, branches biomass allocation fluctuated freely, whereas foliage, needles and roots biomass allocation decreased with DBH.We developed models using a wide variety of biometrical parameters for all components. The generic equations estimated biomass very well for branches and leaves (8 kg difference at a DBH of 74 cm), they underestimate stem, while they overestimate root biomass starting from a 30 cm DBH. Using our equations, we established a precise methodology that we can use to expand biomass to the entire virgin forest. The comparison with the generic models gave us an insight on how carbon is sequestered at larger scales, but also showed the need for local biomass equations when accounting for bigger DBHs.

Impact of biodiversity and competition on foliar nitrogen resorption in plantation forests

Taylor Nelson[1], Lorenzo Cortrozzi[1, 2, 3], Gordon McNickle[3, 4], Brady Hardiman[2], Douglass Jacobs[2], John Couture[1, 2, 3]

1 Department of Entomology, Purdue University, West Lafayette, IN, USA
2 Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN, USA
3 Center for Plant Biology, Purdue University, West Lafayette, IN, USA
4 Department of Botany and Plant Pathology, Purdue University, West Lafayette, IN, USA

Generally, increased biodiversity enhances ecosystem productivity in forest systems. While niche-use efficiency is thought to drive this positive relationship, the specific mechanisms influencing the pattern are largely unknown. One suggested mechanism is nutrient use efficiency. A process affecting nutrient use efficiency is the mobilization of nutrients from foliar tissue to storage areas prior to senescence. Nitrogen is an important growth limiting nutrient for forest productivity and it is unclear how nutrient dynamics are influenced by different levels of tree diversity and competition. To test how biodiversity and competition affect nitrogen resorption, we calculated nitrogen resorption efficiencies (NRE) across a full factorial design that includes two levels of competition, implemented as different planting densities, and diversity levels. We collected samples from a twelve-year-old mixed planting that includes three tree species (red oak, black cherry, and American chestnut) planted at two planting densities (1 and 2 meter spacing). We collected mid-season foliar (August) and senescent litter samples (Sept-Nov) in 2017, and we determined nitrogen concentrations and calculated NRE. We found that as diversity and planting density decreased NRE increased, but the response varied among species. This outcome suggests that the influence of diversity on ecosystem functioning depends on competitive interactions, but that different combinations of species likely affect biodiversity-productivity relationships.

Mixed forest stands in Europe: can we spot them from highresolution remote sensing?

Loredana Oreti[1], Francesca Giannetti[2], Antonio Tomao[1], Anna Barbati[1]

[1] Department for Innovation in Biological, Agro-Food and Forest System, Università degli Studi della Tuscia, S. Camillo de Lellis snc, 01100 Viterbo, Italy
[2] Department of Agricultural, Food and Forestry System, Università degli Studi di Firenze, Via San Bonaventura 13, 50145 Florence, Italy

In forest inventories stands dominated by one tree species are classified as monospecific stands even if containing several forest species, if these contribute less than 10-20% to canopy cover or stand density. Official statistics provided by the State of Europe forests report that about two-thirds of the European forests contain from two up to six (or more) tree species. But mixed forest stands, where two or more tree species contribute each to more than 10-20% to canopy cover/stand density, might indeed not be sampled with sufficient intensity by traditional forest inventories, compared to monocultures, especially in forest landscapes where the average stand condition is relatively species poor. This limits the set-up of replicated experiments, at single or several sites, to analyse in realworld conditions e.g. the effect of mixing of two (or more) tree species on forest ecosystem properties and services. Designing such experiments would benefit from high resolution maps of monospecific vs mixed stands. Today, Sentinel 2 (S2) multispectral satellite imagery allows to cover large areas over a short period of time, with a relatively high spatial resolution (10-20 m). Furthermore, very high resolution images (10-20 cm) are increasingly available. The aim of this contribution is to offer an exploratory analysis of the capabilities offered by a combination of very high resolution imagery and S2, semiautomatic segmentation and Random Forest classifier, for the detection and mapping of widespread mixed forest stand types in Europe, based on a case study characterized by different admixtures of coniferous and broadleaved tree species.

Facets and Prospects of rooted cuttings to promote mix-planting of Indigenous Forest Tree Species (IFTS) in the greening program of the Philippines

Albert Pinon[1]

[1] Assistant Professor, Institute of Renewable Resources, College of Forestry and Natural

Resources, University of the Philippines at Los Banos, Laguna Increasing forest degradation as driven primarily by worsening climatic condition and continuous rise in the global population prompted the use of IFTS in massive reforestations, particularly in the greening program of the Philippines. Science has proved the many advantages of IFTS against the exotics, particularly when planted as a mixture of species. However, aside from inadequate supply of quality seeds for better growth and survival due to various causes (i.e. erratic flowering, few quality seed sources, etc.), the country have limited established cloning protocol for IFTS to augment its seedling needs. This limitation affects the provision of planting materials relevant to successional stages from pioneer to shade-tolerant and climax species, which in turn encourages monoculture and limits the practice of mixed-plantations even for non-commercial purposes (i.e. mine-out and watershed rehabilitation). As such, to expedite the seedling production, the Department of Environment and Natural Resources (DENR) used the rooting of cuttings technique. It is done simply by collecting the seeds from identified mother trees, raised the seedlings to the nursery, harvested and treated the orthotropic shoots with rooting hormone to induce rooting. With this technique, the DENR have used a number of IFTS in its nationwide seedling production that gave rise to various discoveries and difficulties. This study reveals the great opportunities in the use of rooted cuttings not only as an effective alternative in mass-producing native trees, but a potential tool to promote mix planting, particularly for rehabilitating watersheds and various degraded areas.

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Scots pine (Pinus sylvestris L.) struggles in mixtures in boreal forests

Roman Plichta[1], Hana Vyčítalová[1], Martin Svátek[1], Martin Šrámek[1], Roman Gebauer[1], Leena Finér[2], Radim Matula[1,3]

[1] Department of Forest Botany, Dendrology and Geobiocoenology, Mendel University in Brno, Brno, Czech Republic
[2] Natural Resources Institute Finland, Helsinky, Finland
[3] Department of Forest Ecology, Czech University of Life Sciences Prague, Prague, Czech Republic

Mixed forests have usually higher productivity and stability than the monocultures. However, the effect of mixing could result in different performance of individual tree species. Scots pine (*Pinus sylvestris* L.) is one of the most common species in Europe but has suffered several large-scale declines in the last decades likely due to unfavourable climatic events. To increase its resilience, growing Scots pine in species-rich mixed stands instead of monocultures is hypothesized. To study this hypothesis, stem diameter changes together with microclimate were monitored in pure stands of Scots pine and mixtures with *Picea abies* and *Betula pendula* in exploratory plots of FunDivEUROPE in boreal forests in Finland during growing season 2018, using automated devices (with 15-min resolution). Contrary to our expectations, the high temperatures and drought led to higher water stress and reduced growth of Scots pine in mixed stands contrary to monocultures. Soil moisture data indicate that greater soil water depletion during drought in mixed stands participated to these effects, presumably due to higher belowground competition. Surprisingly, our results suggest that in boreal forests, Scots pine may have reduced growth in mixed stands under climate change.

Silvilcultural options for rehabilitating high graded mixedwood stands in North America

Patricia Raymond[1], Marcel Prévost[1], Vincent Roy[2]

[1] Direction de la recherche forestière, Ministère des Forêts, de la Faune et des Parcs, 2700 rue Einstein, Québec, Québec, G1P 3W8
[2] Centre canadien sur la fibre de bois, Service canadien des forêts, Ressources naturelles du Canada, 1055 Rue du Peps, Québec, QC G1V 4C7

In Northeastern North America, over 10 million hectares of mixed hardwood-conifer forest mark the transition between the temperate and boreal forests. Many times, these stands have been harvested with selective practices such as diameter-limit cutting. By focusing on timber trees of economically valuable species, these cuts often left stands with highly variable density and impoverished in terms of composition and wood quality. In many cases, the lack of care to the regenerating layer, combined to damages by spruce budworm (*Choristoneura fumiferana*) epidemic, caused regeneration deficiencies, especially on productive sites such as the ones supporting yellow birch (*Betula alleghaniensis*)-conifer stands. Yet, a high proportion of stands were invaded by noncommercial species and required rehabilitation treatments to sustain wood production and other ecosystem services (Power et al. 2019). Here, we assesses the 15-yr effects of rehabilitation scenarios on stand growth, quality, vigor and regeneration in an experiment established in 2001 near LaTuque (Québec, Canada). The trial comprised 4 blocks comparing 4 regeneration methods applied on 1-ha experimental units: untreated (let grow, 11.5 m²/ha), uniform shelterwood (50 seed trees/ha, 3.5 m²/ha), strip clearcutting (20-m strips) and seed-treed clearcutting (10 seed trees/ha). Natural regeneration monitoring units (0.5 ha) were divided in 3 subplots to test site preparation: no site preparation, mechanical raking and spot scarification (400 spots/ha). After 15 years, untreated and shelterwood treatments improved stand volume, vigor and regeneration, but only shelterwood improved quality. Our results show the resilient nature of these mixedwoods stands. However, silvicultural effort is needed to restore stand quality.

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Underplanting of Norway spruce: Effect of shelter density and soil preparation on height growth and survival

Ditlev Reventlow[1], Thomas Nord-Larsen[1]

[1] Department of Geosciences and Natural Resource Management

Converting large areas of unstable non-native monoculture Norway spruce (*Picea abies* Karst) forest to stable mixed forest is desired, but difficult, especially on poor sandy sites prone to late frost and wind throw. Based on a 29 ha field experiment in western Denmark, we examined the growth and survival of beech (*Fagus sylvatica*), Douglas fir (*Pseudotsuga menziesii*) and silver fir (*Abies alba*) at 1 year, 3-6 years and 15-19 years after being underplanted below a Norway spruce shelter in different mixing proportions and fenced. The effect of different shelter densities (both during the initial and later stage), different soil preparation techniques (shallow patch-wise or slightly deeper stripe-wise) and how these variables interacted were examined. Wind throw in 2005 allowed for comparison with areas that had the shelter removed after 6 years. Stripe-wise soil preparation generally initially increased both survival as well as growth rate, but had less effect in the later stage. A denser shelter reduced the growth of all species, but least for silver fir, and especially for Douglas fir. Survival of silver fir was not much affected by shelter density when shelter density was above a certain limit, but strongly declined at shelter densities below this limit. Douglas fir had markedly reduced survival and height growth at higher shelter densities.

Role of root associated fungal communities in ecosystem functioning in European beech stands mixed with Norway spruce and Douglas fir

Alicia Rivera[1], Dominik Schneider[2], Rolf Daniel[2], Andrea Polle[1]

[1] Forstbotanik und Baumphysiologie, Büsgen-Institut, Georg-August Universität Göttingen, Büsgenweg 2, 37077, Göttingen, Germany.
[2] Genomische und Angewandte Mikrobiologie und Göttingen Genomik Labor, Institut für Mikrobiologie und Genetik, Georg-August Universität Göttingen, Grisebachstraße 8, 37077, Göttingen, Germany.

German forests are facing environmental challenges like rising temperatures, prolonged summer droughts, pest attacks and high loads of nutrient deposition. Mixed forests are anticipated to be more resilient to such (a)biotic stressors than monocultures. However, the impacts of admixing introduced species on ecosystem functioning are not completely understood. Below-ground, microbes play a central role in nutrient cycling. Ectomycorrhizal fungi support tree nutrient and water uptake, improving plant fitness. These fungi have been well studied in beech forests, but less is known about host preference, functional diversity and overall impacts on ecosystem processes in mixed stands of European beech with conifers. Douglas fir, a western north American species that was introduced to Germany in 1831, recently became more attractive as a potential replacement for Norway spruce which is susceptible to drought and bark beetle outbreaks at lower altitudes. Yet, symbiotic dynamics and fungal diversity hosted by Douglas fir in German mixed forests are scarcely quantified. Therefore, examining root fungal community assemblages, host affinity and functional trait diversity of European beech forests mixed with Norway spruce or Douglas fir in comparison to monocultures is a current priority. For this purpose, root samples were collected in 40 plots across a nutrient and water availability gradient in Lower Saxony, Germany. Root fungal communities were studied by Illumina sequencing of the ITS2 region. This study expands our understanding of the role of root associated fungi in ecosystem processes in mixed and pure forests and thus enables further development of adaptive forest management strategies.

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Tree diversity and fertilization effects on the above- and belowground nutrition of young tree communities

Dai Saito[1], Friderike Beyer[1], Grégoire T. Freschet[2], Sho Kawano[1], Dóra Lajos[1], Charles Nock[3], Michael Scherer-Lorenzen[4], **Eiji Yamazaki[1]**, Jürgen Bauhus[1]

1 Chair of Silviculture, Faculty of Environment and Natural Resources, University of Freiburg, Freiburg, Germany
2 Theoretical and Experimental Ecology Station- CNRS, Moulis, France
3 Department of Renewable Resources, Faculty of Agricultural, Life and Environmental Sciences, University of Alberta, Edmonton, Canada
4 Geobotany, Faculty of Biology, University of Freiburg, Freiburg, Germany

Mixed species forests can be more productive than monocultures. Although overyielding has been explained by the concept of competitive reduction and facilitation, it can also be described by the Production Ecology Equation as a function of resource supply and recycling, the proportion of resource captured and resource-use efficiency. These three variables of the equation can be influenced at the species and community level by species' interactions in mixtures. However, in contrast to previous attempts, fully capturing these aspects of tree nutritional responses to species diversity requires accounting for both aboveground and belowground components of tree nutrition. Additionally, little is known about how the nutritional response to tree diversity changes along abiotic gradients. Here we investigate tree diversity and fertilization effects on the nutrient content of leaves, branches and fine roots, and leaf resorption efficiency and proficiency in a young tree diversity experiment in Freiburg, Germany. Six European tree species were planted at high density in monocultures, six combinations of two-species mixtures and six combinations of four-species mixtures and maintained at two levels of fertilization, nonfertilized versus N and P addition. For each community, the three components of the Production Ecology Equation were partly captured by the leaf nutrient input via litter, the net nutrient uptake and nutrient resorption efficiency. This study explores our hypotheses: 1) tree diversity increases, but fertilization decreases foliar nutrient resorption efficiency; 2) tree diversity and fertilization enhance community-level net nutrient uptake; 3) tree diversity and fertilization shift biomass and nutrient allocation from belowground to aboveground organs.

Thinning scenarios focusing on biodiversity conservation in protected forest of Northern Vietnam. Effects on habitat value and economic yield

Gianluca Segalina[1], Cuong Nguyen Dang[2], Rosario Sierra de Grado[1]

[1] Institute for Research in Sustainable Forest Management (iuFOR), University of Valladolid, Palencia, Spain
[2] Forestry faculty, Thai Nguyen University of Agriculture and Forestry, Thai Nguyen, Vietnam

Forest protection policy in Vietnam since the 1990s has led to an overall increase in forest surface, but at the same time it subtracted livelihoods from local populations, and it displaced the deforestation to the neighboring countries. Our aim is to contribute to the sustainable use of tropical forests in northern Vietnam compatible with the preservation of biodiversity. To do that, we simulated four thinning scenarios and their effects on both biodiversity and economic values were assessed. The scenarios were defined through two criteria: tree dominance and tree habitat value. The study took place in a marteloscope located in a naturally regenerated mixed forest enriched with native tree species. The habitat value, evaluated by tree-related microhabitats, was used as a proxy for biodiversity. 58 different tree species were found within the one-hectare plot. Co-dominant trees with a higher diameter at breast height resulted in the highest average habitat value that coincided with the findings in temperate forests, although with a weak relationship. In our area of study, the criterion of biodiversity conservation had a marginal effect on economic benefit. Both results together show that a meeting point between profitability and biodiversity conservation is possible.

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Productivity of Scots pine (*Pinus sylvestris*) stands in Central Europe: biodiversity more important than soil fertility?

Piotr Sewerniak[1]

[1] Department of Soil Science and Landscape Management, Nicolaus Copernicus University in Toruń, Poland

The study was conducted in 349 plots located in pure and mixed Scots pine stands in south-western Poland. In each plot the top height of a pine stand was measured, phytosociological relevé was taken and soil properties related to fertility (texture, pH, nutrients) were investigated to the depth of 150 cm. Based on the field measurements, site index (H100) was calculated for each pine stand, which was considered in the study as an indicator of the stand productivity. The biodiversity indices which were determined for each plot were: i) total species richness of vascular plants, ii) species richness of vascular plants occurring in ground vegetation (this indicator enabled to reduce forest management effects on plant biodiversity), and iii) the elaborated indicator including the cover of all broadleaved species of trees and shrubs occurring in a plot. It was found that the site index was significantly, positively related both to all the studied biodiversity indices as well as to some investigated edaphic soil attributes; however, the former relations were stronger. This especially concerned plots with rusty soils (WRB: Brunic Arenosols), which are the most common soil type in lowland forests of Central Europe. The results suggest that favour ecological state of pine ecosystem can be more important for its productivity than edaphic conditions of a soil. Thus, pine monocultures which have been commonly artificially introduced in Central Europe on soils of medium and even high fertility should be converted into mixed forests which would positively affect productivity of such forest sites.

Do mixed conditions impact the stem form? The case of two pine species

Rosario Sierra-de-Grado[1], **Cristóbal Ordoñez**[1], Valentín Pando[1]

[1] Institute for Research in Sustainable Forest Management (iuFOR). University of Valladolid.

Several studies indicate higher productivity in mixed forests compared to monospecific. However, less consensus has been reached on an important aspect of economic performance such as the quality of the wood produced in mixed versus monospecific forests. The higher productivity is attributed in part to a greater heterogeneity in the structure of the stand that allows better use of resources. However, we do not fully understand the relationships between greater heterogeneity in sizes, ages, shapes, spacing, etc. of the trees of the stand and the log and wood quality. Our aim is to compare variables related to the stem form in adult trees of two conifer species growing in pure and mixed conditions. We studied 11 'triplets' of *Pinus sylvestris* and *Pinus pinaster*. Each triplet consists in three plots, one in a mixed-species stand and two in the respective monospecific conditions, even-aged and located in similar environmental conditions. We recorded slenderness (H/D), basal and general leaning of the trunks, stem straightness and number of times the main apex has been lost producing a curvature in the stem. We have found that *P. sylvestris* is more sensitive to mixed compared to pure conditions than *P. pinaster*. There was a significant effect of the triplet, maybe related to the habitat conditions that favours to each of the studied species.

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Thinning effects on growth in Pinus pinaster and Quercus pyrenaica mixed stands

Nuria Simón[1], Ricardo Ruiz-Peinado[1, 2], Andrés Bravo-Oviedo[2, 3], Felipe Bravo[2, 4], Jorge Aldea[5], **Miren del Río** [1, 2]

[1] Spanish Institute for Agriculture and Food Research and Technology (INIA)-CIFOR, Spain
[2] Sustainable Forestry Management Research Institute (iuFOR) UVa-INIA, Spain
[3] National Museum of Natural Sciences, Spanish National Research Council (MNCN, CSIC), Spain
[4] E.T.S. Ingenierías Agrarias, Universidad de Valladollid (Uva), Palencia, Spain
[5] Swedish University of Agricultural Sciences (SLU), Sweden

Studies on growth and yield in mixed stands have significantly increase during last years due to the potential benefits of mixed forest There are some evidences that mixed stands might show more plasticity in growth response to thinning, however there is still scarce information on thinning effects on mixed-species stands. The aim of this study is to analyse the effect of thinning intensity on growth and productivity in two Mediterranean pine-oak mixed stands. We used two thinning experiments located at two sites with contrasting drought conditions (hereafter named mesic and xeric), measured three times after the thinning in 2010. The experiments follow a latin square design with three treatments, control (un-thinned), moderate, and heavy thinning (25% and 40% of pine basal area removed respectively). Our results show that thinning promoted the diameter growth of both pine and oak, with a stronger reaction after heavier thinning except for oak at mesic site, which reacted better after moderate thinning. The pattern of basal area increment with stand density depended on site and climatic conditions during the period. At the most mesic site the basal area increment increased with stand density, pattern mainly determined by pine reaction since oak showed no trend. In contrast, at the more xeric site the grater stand basal area increment was found at middle densities after moderate thinning. Our findings suggest that moderate thinning might be a good strategy to face with climate change, as they can reduce the impact of extreme droughts without reducing carbon sequestration.

Integrating knowledge of the ecological and genetic effects of logging on a subantarctic mixed forest of Nothofagus

Georgina Sola[1], Verónica El Mujtar[1], Luis Chauchard[2], Paula Marchelli[1], Hernán Attis Beltrán[1], **Alejandro Dezzotti**[3], Leonardo Gallo[4]

[1] Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina
[2] Departamento Forestal, Universidad Nacional del Comahue, San Martín de los Andes, Argentina
[3] Departamento de Ecología, Universidad Nacional del Comahue, San Martín de los Andes, Argentina
[4] Unidad de Genética Forestal, Instituto Nacional de Tecnología Agropecuaria, San Carlos de Bariloche, Argentina

The understanding of the biological consequences of silviculture is crucial for obtaining resources while ensuring ecological sustainability of forests, particularly in the context of global climate change scenarios (Ratnam et al. 2014). We studied the effects of a shelterwood system at different spatial scales after 20 yr of the implementation, on the population and genetic structure of a forest composed of the evergreen *Nothofagus dombeyi*, and the deciduous *N. alpina* and *N. obliqua* (Nothofagaceae) located in the Lanín Natural Reserve, Argentina. This exceptionally valuable ecosystem produces high-quality timber in the humid temperate region of southern South America (Donoso 1993). We studied the genetic diversity, gene flow, introgressive hybridization and spatial structure and dynamics of tree regeneration. At micro-site scale, an intensive sampling of pre- (mature trees) and post- (regeneration) harvested individuals was combined with microsatellite genotyping (> 2000 individuals and 15 markers) and micro-environmental characterization. At stand scale, we focused on the influence of site condition, altitude and post-harvest stand structure on regeneration composition and establishment. After a long study period, we were capable of providing recommendations to improve the management strategies in general, and the silvicultural regime in particular, for the conservation of ecological and genetic features. At present, we are starting to integrate studies on the compositional and functional diversity of understory plants. Through this interdisciplinary approach, we will enhance our knowledge so as not to alter the stability and resilience of this mixed Nothofagus forest under schemes of multi-species timber production.

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Longevity of habitat trees and tree-related microhabitats in the Black Forest, Germany

Andreea Petronela Spinu[1,2], Jürgen Bauhus[1,2]

[1] Chair of Silviculture, University of Freiburg, Tennenbacherstr. 4, 79106 Freiburg, Germany
[2] ConFoBi (Conservation of Forest Biodiversity in Multiple-Use Landscapes of Central Europe) Research Training Group, Albert-Ludwigs University of Freiburg, Germany

Tree-related microhabitats (TreMs) are specific morphological structures on standing trees that act as ecological niches for many forest-specialist species. Retention of large trees, dead or alive, bearing TreMs (habitat trees) has been suggested as a successful practice to improve biodiversity in Central European forests. The longevity of both the habitat trees and their TreMs has not yet been studied in continuous-cover forestry, despite the critical importance of such information for assessing the long-term effects of this practice. To address this knowledge gap, this study utilizes repeated inventories of TreMs on the 15 potential habitat trees (living), in 80 one-hectare plots in the Black Forest, Germany. The first inventory was carried out in 2016. Occurence of TreMs on dead trees will also be recorded in future inventories. Mortality rates will be calculated using aerial image interpretation and TreMs longevity will be predicted using survival analysis. We hypothesise that habitat trees experience higher mortality rates because larger trees are more susceptible to environmental stressors and their vitality is decreased by occurrence of TreMs. Dispersed trees are expected to die faster than those in clumped distribution because their crowns are more exposed. The abundance and diversity are higher on dead trees. This is the first attempt to investigate mortality of habitat trees and the first time-series of development of TreMs in Central European forests. Knowledge on TreMs longevity and their supporting structures is essential for future management decisions, since trees with different longevity might be selected to provide continuity of TreMs over time.

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Effect of harvesting intensity on growth and natural regeneration in exotic tree plantation on highland

Wathinee Suanpaga[1], Nopparat Kaakkurivaara[2], Khanchai Prasanai[2], Venus Tuankrua[3], Supattra Thueksathit[3]

[1] Department of Silviculture, Faculty of Forestry, Kasetsart University, Bangkok, 10900, Thailand
[2] Department of Forest Engineering, Faculty of Forestry, Kasetsart University, Bangkok 10900, Thailand
[3] Department of Conservation, Faculty of Forestry, Kasetsart University, Bangkok 10900,Thailand

Exotic species are encouraged to be planted in highland areas of Thailand as a source of woods and soil and water conservation, including ecosystem services. The growth and natural regeneration in mixed exotic tree plantations under three harvesting intensities was studied in 30-year-old plantations of exotic tree species such as *Acacia confusa* Merr., *Cinnamomum camphora* (L.) J. Presl., *Fraxinus griffithii* C.B. Clarke., *Liquidambar formosana* Hance., and *Eucalyptus camaldulensis* Dehnh., with a spacing of 2 m x 2.5 m at Ang Khang Royal Agricultural Station, Chiang Mai province, Thailand. These aimed to provide a management guideline in a sustainable forest plantation. Trees, saplings, and seedlings were evaluated at pre-harvesting, post-harvesting, 6 and 12 months after harvesting with different intensities of 0%, 20%, and 40% of basal area. The result showed that three harvestings did not affect species richness, species diversity index, total volume, and relative growth rate of diameter at 1.30 m, while those have a clear effect on tree density, leaf area, percentage of cover area, and relative growth rate of the height of trees. After harvesting, species diversity index and individual density of saplings and seedlings among harvesting intensities were a significant difference. Besides, the removal of 40% basal area had an impact on the remaining stand. Thus, the harvesting of 20% basal area is recommended to practice for sustainable management on highland forest plantation.

Biomass monitoring in mangrove forest restoration after shrimp farming using remote sensing image case study in Suratthani Province, Thailand

Weerakaset Suanpaga[1], Wathinee Suanpaga[2]

[1] Faculty of Engineering, Kasetsart University,Thailand.
[2] Faculty of Forestry, Kasetsart University,Thailand.

Exploring mangrove forests is difficult and takes a long time. If there are some tools to help assess and monitor the growth of forest restoration, it will help to manage the area well. Therefore, the application of satellite images is one option that will help data collection easier. Don Sak national reserved mangrove forest, Don Sak district, Surat Thani province was degraded by shrimp farming. Since 1997, various indigenous mangrove tree species were planted by using 1.5 m x 1.5 m in spacing. This article aims to find the relationship between the value of biomass and Landsat images and to monitor mangrove forest restoration on abandoned shrimp farms in during July 2014 – May 2017. The result of this study shows the strong relationship between biomass value and reflectance from the green wave range. *Rhizophora mucronate* produces the highest biomass followed by *Ceriops tagal*. And also, the biomass of this study area has the mean annual increment of biomass with an increasing rate of 16.94 tons per hectare.

Natural regeneration dynamic of mixed Nothofagus forests in southern Patagonia: influence of canopy composition and landscape

Mónica Toro-Manríquez[1], Rosina Soler[1], María Vanessa Lencinas[1], Álvaro Promis[2], Alejandro Huertas-Herrera[1], A. Paula Blazina[1], Juan Andrés Miller[1], Guillermo Martínez Pastur[1]

[1] Austral Centre for Scientific Research (CADIC-CONICET). Houssay 200 (9410), Ushuaia, Tierra del Fuego, Argentina
[2] Department of Silviculture and Nature Conservation, University of Chile. Av. Santa Rosa 11315 (9206), La Pintana, Santiago, Chile

Species composition of tree recruitment in mixed forests is a determining factor related to the canopy structure. This work determines if the mixed forests of *Nothofagus pumilio* and *N. betuloides* present transitions towards forest types with the dominance of one of these species or are a stable system, by the analyses of its natural regeneration dynamics. Three forest types were selected (pure *N. pumilio*, pure *N. betuloides* and mixed stands) in two contrasting landscapes (coast and mountain) in Tierra del Fuego, Argentina. Forest structure and microclimate (air temperature, soil moisture) were evaluated for each stand (n=12), while seed production and natural tree regeneration were monitored annually (2014-2019). Data were analysed with ANOVAs, general linear models and multivariate techniques. Seedling recruitment of *N. pumilio* and *N. betuloides* was proportional to seed production with significant inter-annual variability. *Nothofagus pumilio* was more successful than *N. betuloides* in seedlings recruitment in every forest type and landscape. Forest structure and microclimate also played important roles in the dynamics of mixed *Nothofagus* forests. Multivariate analyses revealed a stronger effect of the landscape rather than canopy composition. Our results show a tendency in mixed *Nothofagus* forests towards a transition to pure *N. pumilio* forests, mainly due to greater success in its regeneration strategy.

Obvious shift in growth dynamics of common beech in European Mountain regions

Enno Uhl[1], Miren del Rio[2,3], Hans Pretzsch[1], Michael Heym[1], Michal Bosela[4,5], Francesco Giammarchi[6], Mirolav Svoboda[7], Tzvetan Zlatanov[8], Maria Hoehn[9], Kamil Bielak[10], Maciej Pach[11], Soraya Versace[12], Fabio Lombardi[13], Michal Bellan[14,15], Alvaro Rubio-Cuadrado[16], Javier de-Dios-García[17], Matija Klopčič[18], Lucian Dinca[19], Dejan Stojanovic[20], Branko Stajic[21], Admir Avdagić[22], Aida Ibrahimspahic[22], Viktor Kurylyak[23], Roberto Tognetti[24]

[1] Department of Ecology and Ecosystem Managment, Technicla University of Munich
[2] Department of Forest Dynamics and Management, INIA, Forest Research Centre, Madrid, Spain
[3] Sustainable Forest Management Research Institute, University of Valladolid - INIA, Palencia, Spain
[4] Department of Forest Management and Geodesy, Technical University in Zvolen, Zvolen, Slovakia
[5] National Forest Centre, Department of Forest Landscape and Ecology, Zvolen, Slovakia
[6] Faculty of Science and Technology, Free University of Bolzano-Bozen, Bolzano, Italy
[7] Department of Botany, Faculty of Horticultural Science, SZIU, Budapest, Hungary
[8] Institute of Biodiversity and Ecosystem Research, Bulgarian Academy of Sciences, Sofia, Bulgaria
[9] Department of Forest Ecology, Czech University of Life Sciences Prague, Prague, Czech Republic
[10] Department of Silviculture, Warsaw University of Life Sciences, Warsaw, Poland
[11] Department of Forest Ecology and Silviculture, Faculty of Forestry, University of Agriculture in Krakow, Krakow, Poland
[12] Dipartimento di Bioscienze e Territorio, Università degli studi del Molise, 86090 Pesche (IS), Italy
[13] Dipartimento di Agraria, Università Mediterranea di Reggio Calabria, Loc. Feo di Vito, 89122 Reggio Calabria, Italy
[14] Mendel University in Brno, Faculty of Forestry and Wood Technology, Department of Forest Ecology, Brno, Czech Republic
[15] Global Change Research Institute of the Czech Academy of Sciences, Bělidla 4a, 603 00 Brno, Czech Republic
[16] Departamento de Sistemas y Recursos Naturales, Escuela Técnica Superior de Ingeniería de Montes, Forestal y del Medio Natural, Universidad Politécnica de Madrid, Madrid, Spain
[17] AGROTECNIOForest Science and Technology Centre of Catalonia (CTFC), Solsona, Spain
[18] University of Ljubljana, Biotechnical Faculty, Department of Forestry and Renewable Forest Resources
[19] National Institute for Research and Development in Forestry (INCDS) "Marin Drăcea", Voluntari, Romania
[20] Institute of Lowland Forestry and Environment, University of Novi Sad, Antona Čehova 13, 21000 Novi Sad, Serbia
[21] Faculty of Forestry, University of Belgrade, 11000, Belgrade, Serbia
[22] Department of Forest Management and Urban Greenery, Faculty of Forestry, University of Sarajevo, Bosnia and Herzegovina
[23] Institute of forestry and horticulture, Ukrainian National Forestry University, Lviv, Ukraine
[24] Department of Agricultural, Environmental and Food Sciences, University of Molise, Campobasso, Italy

European beech (*Fagus sylvatica* (L.) plays a major role in the composition of forests throughout the continent. Although more adapted to Atlantic climates, this tree species is quite competitive in many biogeographic regions all over Europe. Several studies revealed that growth of beech in low elevations has benefited from changes in climatic conditions during the last decades, most probably due to extended vegetation period and atmospheric nitrogen deposition. Depending on altitude and geographical location, European beech is also well represented in most European mountainous forest ecosystems. We can assume that altitudinal-specific growth conditions and interaction with increasing air temperature have improved tree growth performance. But up to the present evidence is still uncertain. Based on tree growth modeling and tree ring data derived from a newly established trial series in mono specific and mixed conifer-beech stands across various mountain regions of Europe we analysed the present and recent growth performance of European beech on tree and stand level productivity. Here, we investigate how growth patterns have changed over time and how possible changes vary with site conditions. First results indicate that changes in growth dynamics as observed in lower elevations cannot be simply transferred to mountain regions.

Effect of species mixing and competition on stem shapes in pure and mixed stands of pine and oak

Sara Uzquiano[1], Martin Jacobs[2], Martin Ehbrecht[3], Domink Seidel[3], Felipe Bravo[1]

[1] Sustainable Forest Management Research Institute, Spain
[2] Technical University of Munich, Germany
[3] Goerg August University of Goettingen, Germany

Understanding forest dynamics is crucial to assuring sustainable forest management. In the face of climate change, mixed forests potentially serve as more stable carbon sinks than pure stands. However, while the forest dynamics of pure stands are generally well understood, the dynamics of mixed forests have yet to be quantified. This work aims to quantify the effect of interspecies tree competition on stem shape in mixed stands relative to the lack thereof in pure stands. We focus on mixed forests of pine (*Pinus sylvestris*) and oak (*Quercus petraea*), as they are two species that occur widely across most of Europe. Our study area is composed of two triplets of 30 m^2 stands (two pine, two oak, and two mixed stands) located in northern Spain. We have used Terrestrial Laser Scanning (TLS) to create 3-D images of the forest interiors. We used an average of 20 scans per plot (depending on stand density) with 28 million points per capture and a spatial resolution of 7mm in 10 m. Stems were isolated and selected by a self-developed algorithm, designed to discover clusters of arbitrary shapes. We expect to isolate 60 trees per plot and analyse their lean, sweep, diameter at breast height and bark anomalies to compare stem characteristics between pure and mixed conditions via linear models. By quantifying the effect of intra and interspecies competition, we intend to improve future management of mixed forests.

Pioneering Linked Open Data in the forestry domain

Guillermo Vega-Gorgojo[1], José M. Giménez-García[1], Cristóbal Ordóñez[2], Felipe Bravo[2]

[1] Department of Signal Theory, Telecommunications, and Telematics Engineering, University of Valladolid
[2] Sustainable Forest Management Research Institute, University of Valladolid

Forest inventories and land cover maps are fundamental resources for forestry management and research.[1,2] Moreover, these resources can be used for other purposes, including data journalism, territorial planning (including environmental, landscape and rural planning), or leisure activities. Unfortunately, exploiting forest inventories and land cover maps is a non trivial task that requires domain expertise and technical skills. The key problems are data accessibility and interoperability that can be addressed through Linked Open Data (LOD).[3,4] As part of the Cross-Forest project,[5] we have created a LOD version of the Spanish Forest Inventory and Forestry Map. First, we have developed a suite of ontologies[6,7] to model forest inventories (with concepts such as Plot, Tree, PlantSpecies, and TreeMeasure), forestry maps (Patch , Use , CanopyCover...), and geographical positions (SpatialEntity , Position , Polygon, CRS, Datum…). Second, we have transformed the Spanish sources into LOD using the aforementioned ontology suite. The resulting dataset includes 92K plots, 1.4M trees, and 680K land cover patches. In addition to the original data, we provided WGS84 coordinates for all positions, a simplified low-resolution layer of land cover patches, and mappings to well-known resources.[8] Finally, we developed a web-based tool[9] for exploring the resulting dataset—this can be easily done through an interactive map that displays patches, plots, and trees in the area of interest.[10] Mixed forests management and research can thus benefit from using LOD to simplify data access and integration. Our solution improves previous efforts[11,12] by integrating forest inventory and forestry map data in a LOD dataset, and by providing an exploration tool.

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Is the effect of inter and intraspecific competition on radial growth mediated by climate events?

Marta Vergarechea[1,2], Nicolas Cattaneo[3], Miren del Río[1,2], Rafael Calama[1,2]

[1] Department of Forest Dynamics and Management. Forest Research Center. INIA-CIFOR. Crta. de la Coruña, km 7,5 - 28040 Madrid
[2] Sustainable Forest Management Research Institute UVa-INIA. Av de Madrid, 503, 34004 Palencia
[3] Département de Biologie, Chimie et Géographie. Université du Québec à Rimouski UQAR

Different studies undertaken in the Mediterranean basin have shown that the projected climate scenarios will modify forest dynamics. In this context, tree species interactions could be one of the factors susceptible to change, mainly due to the availability of the resources, with complementary effects during low-growth years and competition in highgrowth years. Consequently, the study of inter-tree relationship is essential to provide insights about the relative contributions of competition and climate on individual tree growth. Here, we used individual tree models and competition indices over a period of 15 years. Using data from 500 trees (250 *P. pinea* and 250 *P. pinaster*) in both mixed and monospecific plots, we analyzed species interactions by using competition indices. Different competition indices formulations were used in order to consider size-symmetric and size-asymmetric competition, and intra and interspecific interactions. We also evaluated how the size of the tree influences competition of both species. Finally, by considering the interaction between competition and year, we were able to evaluate temporal dependencies on tree interactions within species as well as between species. These approaches allow us to identify the main mode of competition in these Mediterranean forests, as well as to observe whether these trends are aggravated during water-stressed years.

Rooting space occupation in a mediterranean mixed Scots pine–European beech forest

Antonio Yeste[1], Juan A. Blanco[1], J. Bosco Imbert[1], Helena Zozaya-Vela[1], Martín Elizalde-Arbilla[1], David Candel-Pérez[1], Yueh-Hsin Lo[1], Federico J. Castillo[1]

[1] Universidad Pública de Navarra, Departamento de Ciencias, Pamplona, Spain

Soil occupation and rooting space sharing capacity of Scots pine (*Pinus sylvestris*) and european beech (*Fagus sylvatica*) were evaluated in a mixed forest in the Western Pyrenees (Spain). The stand was originally a monospecific pine forest where natural regeneration of beech took place, leading to the present co-occurrence of patches dominated by pines and mixed patches codominated by both species. Three tree types were selected: pines in the pine monospecific patches (P), and pines and beeches in the mixed patches (PM and BM). Soil cores were extracted in May 2018 at 50 cm of the trunk, taking 5 consecutive samples of 13 cm depth, down to a total depth of 65 cm. Fine root (diameter < 2 mm) functional traits and biomass were measured and soil chemical analyses were performed. No clear signs of species complementarity in the rooting space were found, as beech fine roots tended to dominate the soil with higher specific root length and vastly greater biomass: beech fine root biomass under beech trunks was four times bigger (on average) than pine root biomass under pine trunks. Pine root biomass was reduced when in proximity of beech (especially in the upper layer of the soil), being the biomass under PM a third of that under P. Lower pH and ammonium concentration were found under beech trees, which could be linked to a higher uptake activity. Our results point towards species competence at the soil level, emphasizing the contrasting ecological strategies of a pioneer and a mid-late successional species.

Session 4: Mixed forests and policy aspects

Key-note talk: Tamas SZEDLAK. European Commission, DG Agriculture, Belgium.

Mixed forests in the EU Forest Strategy and under the Common Agricultural Policy

The year of 2020 is an important year for the EU in many reasons; the European Commission presented on 11 December 2019 The European Green Deal – a roadmap for making the EU's economy sustainable by turning climate and environmental challenges into opportunities across all policy areas and making the transition just and inclusive for all. The European Green Deal sets out how to make Europe the first climate-neutral continent by 2050, boosting the economy, improving people's health and quality of life, caring for nature, and leaving no one behind. The Communication presents an initial roadmap of the key policies and measures needed to achieve the European Green Deal, all EU actions and policies will have to contribute to its objectives. The challenges are complex and interlinked. The policy response must be bold and comprehensive and seek to maximise benefits for health, quality of life, resilience and competitiveness. It will require intense coordination to exploit the available synergies across all policy areas. As part of this roadmap, among others, both the EU Biodiversity Strategy and the EU Forest Strategy will be renewed in 2020. The new EU Forest Strategy will be adopted by the end of 2020 addressing the needs for climate action, rural areas and developing the bioeconomy, respecting biodiversity conservation objectives, the EU Bioeconomy strategy, Circular Economy Action Plan, EU Biodiversity Strategy as well as SDG and Paris Climate Agreement commitments.
The new Common Agricultural Policy (CAP) for the post 2020 period, which provides the main financial support for the Forest Strategy implementation through rural development policy, is also under legislative process. This presentation intends to provide an overview about the potential linkages between mixed forests and the above mentioned policy frameworks.

	Tamas SZEDLAK graduated as a forester in 1978, followed by an MSc in Forestry in 1987. Shortly after graduating, he partnered with climatologists to publish a paper on the relationship between climate change and forestry. In 1992, Tamas wrote his thesis on agroforestry and obtained his second degree on tropical agriculture and forestry. After working over 10 years in forests at the Hungarian State Forest Service, he became an official of the Ministry of Agriculture in Budapest, where he contributed to Hungary's preparation for the accession to the EU. Since 2004, he worked for the European Commission in the Directorate-General for Agriculture and Rural Development. He deals with various forestry-related issues, primarily around its role in rural development, biodiversity and practical aspects under the changing climate. He follows the forestry and agroforestry-related policy development, including the preparation of the legislative background for the CAP post 2020 period. As a former practicing forester, one of his main motivations is to enhance the science-policy-practice connections.

Landscape restoration for mixed forests: key strategies for navigating the constraints and opportunities of multi-scale forest governance and management dynamics in Sweden

Lucas Dawson[1], Marine Elbakidze[2]

[1] Environmental and Resource Dynamics Group, Department of Physical Geography, Stockholm University
[2] School for Forest Management, Faculty of Forest Sciences, Swedish University of Agricultural Sciences

Conventional intensification of forestry, focusing on the cultivation of relatively few species, has dramatically reduced forest biodiversity, increased risks relating to climate change and biotic/abiotic damage, and threatens the sustainable provision of ecosystem services important for human wellbeing. Landscape restoration is an important strategy for improving the functionality, resilience, and long-term productivity of forests. Several national and trans national institutions – e.g. the Bonn Challenge and the New York declaration – have evolved as important drivers of restoration. However, complex multiscale system dynamics make evaluation of emergent policy and management interventions difficult, and little is known about how landscape restoration initiatives are influenced by the governance contexts in which they are situated. We used a qualitative complex systems approach to explore the causal dynamics underlying the planning and implementation of Sveaskog's Ekoparks, which aim at the restoration of a national scale network of mixed forests in Sweden. We found five processes that were key to restoration outcomes, *viz.* planning, garnering stakeholder support, adequacy of inputs, implementation, and knowledge management. Major constraints related to formal and informal institutional contexts, regulatory flexibility, socio-cultural factors, and financing. Key strategies identified relate to management of positive feedback loops concerning stakeholder perceptions, adaptive learning cycles, and knowledge sharing practices. These findings resonate strongly with those of other recent studies we have conducted concerning causal dynamics of landscape restoration projects across a variety of scales and governance contexts in Europe, suggesting a wider relevance for these results.

Foresight studies as a tool to estimate future impacts of forest pests and diseases

Johanna Witzell[1], Carmen Romeralo[1]

1 Swedish University of Agricultural Sciences, Southern Swedish Forest Research Centre, Alnarp, Sweden

Policy and decision making around pest and disease outbreaks tends to occur reactively, relying on information that is extrapolated from the past. However, in the rapidly changing environment, past experiences may not provide appropriate guidance for the decisions. When facing completely new pests and pathogens, there may not even be a past to lean on. In all situations, the reactive, backward looking approach limits the consideration of a full suite of future-oriented control, containment and management solutions. Originally developed for business and military purposes, foresight approach can support proactive, forward-looking decision-making and increase the preparedness of a system to meet possible, probable and desired futures. Several methods can be utilized in foresight studies.
We applied two foresight tools, i.e., “7 questions” and “Mapping of drivers” and used questionnaires to gather intelligence among a group of over 30 experts possessing knowledge and experience that is of high relevance for control and management of Pine pitch canker disease (PPC), caused by an invasive pathogen *Fusarium circinatum*. Drivers were categorised as political, economic, societal, technological, environmental, legislative and scientific. The results of the questionnaire are used to discover future options to restrict the spread of PPC and reduce its negative impacts on ecosystems and forestry, to explore the dynamics of the change, and to define crucial research questions for future studies on PPC. To our knowledge, foresight studies have rarely been explored as a tool to assess opportunities to proactively respond to forest pest and pathogen outbreaks.

Are mixtures a good option to reduce drought-induced risk of forest decline? Carbon accounting and economic approach

Sandrine Brèteau-Amores[1], Mathieu Fortin[2], Pablo Andrés-Domenech[3], Nathalie Bréda[4]

[1] BETA, INRA Nancy, France
[2] Canadian Forest Service, Ottawa, Canada
[3] BETA, AgroParisTech, Nancy, France
[4] Silva, INRA, Champenoux, France

Drought is the principal source of stress limiting forest health and it causes financial losses for forest owners and amenity losses for society. The major part of the forested area in the Grand Est region (France) is dominated by beech, which is predicted to decline in the future due to repeated drought events driven by climate change. Beech forests need to adapt and mixture is known to decrease drought risk. In this context, the objective of the paper was to compare, from an economical perspective, different forest adaptation strategies aiming at reducing drought-induced risk of decline. For this purpose, we studied two types of mixture that we analysed separately and jointly: mixture of beech species with oak species and age mixture (i.e. from an even-aged to an uneven-aged forest), which is rarely considered as an adaptation strategy. We also considered two types of loss (financial, and in terms of carbon sequestration) under different recurrences of drought, that are a consequence of climate change. We combined a forest growth simulator (MATHILDE) with a traditional forest economic approach (Fautsmann's LEV and Hartman's LEV). The maximisation of the two LEV criteria made it possible to identify the best adaptation strategies in economic terms. We also developed the carbon approach considering different accounting methods (from the market value to the social cost of carbon). The results are discussed taking into account the trade-offs between the financial balance and the carbon balance, and the underlying question of the additivity (or not) of the two adaptation strategies.

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Forest Development Types: defining a useful concept for the design and management of site adapted mixed species stands in Britain

Jens Haufe[1], Gary Kerr[1], Victoria Stokes[1]

[1] Forest Research, United Kingdom

The concept of Forest Development Types (FDTs) is widely used in forestry practice in Germany and other European countries to design and manage site adapted mixed stands. There is no equivalent tool in Britain but at a time when we are trying to increase the resilience of the forest estate the idea of FDTs has caught the imagination of forest managers and policy makers. This paper will outline the process of defining the concept of Forest Development Types for forestry in Britain. The main challenge has been to design a system that can accommodate: (1) a predominantly plantation forest estate of non-native species; (2) a wide range of climate and edaphic factors, and (3) the existing National Vegetation Classification for native woodlands.

Long-term development of spruce-birch mixed stand on drained peat soil and its carbon pools

Janis Vuguls[1], Zane Libiete[1], Peteris Zalitis[1], Ainars Lupikis[1], Andis Lazdins[1], Aris Jansons[1]

[1] Latvian State Forest Research Institute Silava, Salaspils, Latvia

Spruce-birch mixture is commonly found in hemiboreal and boreal forests and different management strategies of it suggested. Aim of our study was to characterize the long-term development of spruce-birch mixed stand on drained deep peat soils. Growth of the pure spruce stand and spruce-birch mixed stand in site in eastern part of Latvia (57ºN), drained in 1960, was followed by repeated measurements from 1978 to 2018. No management was carried out during that time. The carbon pools were assessed at the end of the measurement period. Over the time birch has gradually declined. Higher standing volume (thus, also larger carbon pool) was in pure spruce stand, higher deadwood volume – in spruce-birch mixture. Density of the peat layer after the drainage has increased without much loss of the carbon to the atmosphere. Higher stand productivity has also ensured higher total carbon pool. Long term policies aimed at maximizing the carbon storage in forests on deep fertile peat soils have to aim for the measures increasing the productivity and creation of the mixed forests at a landscape scale or at stand-scale for limited time *via* suitable silvicultural treatment.

Session 4: Mixed forests and policy aspects. Poster presentations

The role of mixed forests as solution to reduce negative growth anomalies caused by extreme droughts in Boreal conifers of Sweden

Jorge Aldea[1], Jonas Dahlgren[2], Jonas Fridman[2], Magnus Löf[1]

[1] Southern Swedish Forest Research Centre, Swedish University of Agricultural Sciences, Alnarp, Sweden.
[2] The Swedish National Forest Inventory, Department of Forest Resource Management, Swedish University of Agricultural Sciences, Umeå, Sweden.

Anthropogenic climate change is projected to lead to more frequent and intense climate extremes such as heat waves and severe droughts even at northern latitudes. Extreme droughts have already been shown to be one of the main causes of dieback and a predisposition factor for bark beetle attacks on Norway spruce and Scots pine, causing losses of environmental and economic value in Sweden. Much knowledge regarding climate–growth relationships has been gained by studying tree rings, although representative tree-ring data is rarely available for large spatial scales (usually concerning to spatially limited conditions). Here, we used tree ring data from Swedish National Forest Inventory to identify the spatial and temporal changes of negative growth anomalies induced by drought for Norway spruce and Scots pine at large scale (the whole country). The probability of negative growth anomaly occurrence increases inversely to water balance during growth season, being especially acuted in the south-east of Sweden for Norway spruce. In addition, stand basal area increases the probability to present a negative growth anomaly, although site conditions may modulate it. In general terms, resilience decreased from 1985 for Norway spruce but not for Scots pine. Results obtained here may serve to support decision making in policy and forest management to counteract the ongoing adverse effects of climate change in boreal forests.

Species mixture vs. age mixture: how to conciliate wood production and carbon sequestration objectives under drought and windstorm risks in forest

Sandrine Brèteau-Amores[1], Rasoul Yousefpour[2], Marc Hanewinkel[2], Mathieu Fortin[3]

[1] BETA, INRA, Nancy, France
[2] Chair of Forest Economics and Forest Planning, University of Freiburg, Freiburg-in-Breisgau, Germany
[3] Canadian Forest Service, Ottawa, Canada

Forests provide ecosystem services such as wood production and carbon sequestration. However, forests are sensitive to climate change, and financial and amenity losses are expected for forest owners and society, respectively. The forests in the Grand-Est region (France) are dominated by beech, which is predicted to decline in the future due to repeated drought events driven by climate change. Forests in this region are also threatened by windstorm event. Beech forests need to adapt and mixture is known to decrease drought and storm risks. In this context, the objective of the paper was to compare, from an economical perspective, different forest adaptation strategies with the objective of reducing drought-induced and storm-induced risks of decline. For this purpose, we studied two types of mixture that we analysed separately and jointly: species mixture with oak and age mixture (i.e. from an even-aged to an uneven-aged forest). We also considered two types of loss (financial, and in terms of carbon sequestration) under different frequencies of drought and storm risks. We combined a forest growth simulator (MATHILDE) with a classical forest economic approach (Hartman's LEV). Maximizing the LEV criterion allowed the identification of the best adaptation strategies in economic terms. An optimisation of forest management was performed according to wood production and carbon sequestration objectives. The results are discussed taking into account the tradeoffs between the financial balance and the carbon balance, and the underlying question of the additivity (or not) of the two risks as well as of the two adaptation strategies.

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The potential of plantations mixed with local species to reforest the Sudanese area in West Africa

Brahima Coulibaly[1], Dominique Louppe[2], Anatole Kanga N'Guessan[1], N'klo Ouattara[3], Bruno Herault[2,4]

[1] CNRA, Forest and Environment Research Programme, Ivory Coast
[2] CIRAD, Forest and Socities Research Unit, France
[3] Université Peleforo Gbon-Coulibaly, Ivory Coast
[4] INP-HB, Department of water, Forest and environment, Ivory coast

In west Africa, the Sudanese sector is characterized by an alternation of open forest, wooded, wooded and grassy savannas and lateritics plateaus. After the partial failure of large industrial plantations of exotic species in the late 1970s in Sahelo-Soudanien countries, tentative research has been initiated on the forestry potential of local species in plantations. In northern Côte d'Ivoire, the Kamonon Diabate station was created in 1988 in Lataha (Korhogo) to experimente locals and exotics forest species. This station, protected until now, has allowed the long term study of the behavior of nearly 90 local species in plantations over 100 ha of trials, a unique experiment in the Sudanese sector of West Africa. The purpose of tis paper is to present and update assesment of this historical tests by analyzing the productivity and 25-30 year survival of trees planted in the 1990s. We propose a classification of species according to their potentiel to produce (i) timber, (ii) fuelwood and (iii) non-timber forest products. Finally, we will highlight the most promising species mixtures for reforesting the Sudanese sector of West Africa.

Tree Biomass Allocation in Temperate Mixed Forests

Eric Cudjoe[1,2], Felipe Bravo Oviedo[1,2], Ricardo Ruiz-Peinado[2,3]

[1] ETS Ingenierías Agrarias, University of Valladolid (Campus at Palencia), Spain
[2] Forest Management Research Institute (iuFOR, UVa-INIA), Spain
[3] National Institute of Agricultural and Food Research and Technology (INIA), Spain

One of the key landmarks in sustainable resource management is the estimations of forest carbon stocks. This presents a hefty challenge to do in mixed forests as it has been showed that stand productivity can be benefited by mixtures. The work was focused on identifying how the stand mixture affects allometric relationships and tree biomass allocation. Triplet approach of monospecific and mixed stands of *Pinus sylvestris* L. and *Quercus petraea* (Matts.) Lieb. in Northern Spain was adapted. We fitted 4 different height-diameter models for monospecific and mixed forests for Scots pine and Sessile oak species. The Korf curve for height-diameter models performed better than Power equation, Meyer equation and Naslund's equation, as the lowest AIC and highest R^2 obtained suggested. There was no variation of height-diameter relationships for oak trees in monospecific or mixed stands but an extensive difference in the monospecific and mixed stands for Scots pine. Dirichlet regression was used to fit biomass models using diameter at breast height and total height as independent predictors for both species. The total aboveground biomass of trees growing in mixtures was not significantly different from trees growing in monospecific stands. The biomass proportion of different tree components in mixed stands was similar to that of monospecific stands. The results elucidate that there was no difference in both monospecific and mixed stands for both species studied. The biomass allometric models developed from monospecific stands can be used to predict tree biomass in mixed stands of the study mixture without any significant bias.

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Continuous Cover Forestry (CCF): a means of delivering mixed forests in Europe

Bill Mason[1], Joao Carvalho[2], Jurij Diaci[3], Sauli Valkonen[4]

[1] Forest Research, Northern Research Station, Roslin, Midlothian, EH25 9SY
[2] UTAD, ProSilva Portugal
[3] ProSilva Slovenia
[4] Luke, Finland

Forest policies in many European countries aim to create diverse irregular forests to provide a range of ecosystem services. One way of fostering these mixed forests could be through greater use of Continuous Cover Forestry (CCF). However, we lack quantitative data on CCF management in Europe or information about factors that influence uptake of this silvicultural approach. We circulated a questionnaire in summer 2019 to improve understanding of these points. Aspects covered included: the silvicultural systems accepted as CCF in different countries; the proportion of forests managed through CCF and recent changes; the knowledge gaps and challenges limiting greater use of CCF. We received replies from over 20 countries from all European regions. Major findings included: single stem and group selection systems were always accepted as CCF and most included irregular shelterwood systems, while other shelterwood systems were allowed during the transformation process. We estimate that between 27 and 35 per cent of European forests are managed through CCF and this percentage has increased in recent decades, although we found that detailed information on the proportion of forests managed by different silvicultural systems was often lacking. Main knowledge gaps were Ecological (categories after Puettmann et al., 2015) primarily involving resilience to climate change. Most challenges were Logistical/Administrative such as: control of browsing pressures; lack of skilled forest workers; unsympathetic financial subsidies. Better integration of CCF silviculture with improved knowledge of mixed forest dynamics is desirable and should be an effective means of adapting forests to climate change.

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Study on Plant diversity of Col. Sher Jung National Park in Himachal Pradesh

S. Balaji Naik[1], Dr. Vimal Kumar Chauhan[1]

[1] Department of Silviculture and Agroforestry, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, India

The present investigation was carried out in Himachal Pradesh, India, with the aim to assess plant diversity of major forest communities. The Eight major forest communities selected were as following: *Shorea robusta, Eucalyptus tereticornis, Syzygium cumini, Shorea robust + Terminalia tomentosa, Shorea robusta+ Eucalyptus tereticornis, Shorea robusta+ Syzygium cumini, Shorea robusta+ Diospyros melanoxylon* and Mixed forest. In every forest community type, 3 quadrats of 31.62 m X 31.62 m size were randomly laid to study tree species. The shrub and herbaceous species were studied by laying 3 quadrats randomly in each forest community type. In each quadrat, a sub-quadrat of 5m X 5m size for shrubs and a sub-quadrat of 1m X 1m for herbaceous vegetation were selected. 90 plant species were recorded in these forests of which 6 were trees, 37 shrubs and 47 herbs. Shannon Weiner index for trees, shrubs and herbs in different forests varied from 0.00-1.60, 2.27-2.83 and 2.74-3.38. Simpson index for trees, shrubs and herbs in different forests ranged from 0.24-1.00, 0.06-0.10 and 0.37-0.70, and Margelef's species richness for trees, shrubs and herbs in different forests varied from 0-0.78, 1.10-2.03 and 1.41-2.71. Phytosociological attributes density and basal area of trees in different forests varied from 590 (Mixed forest) to 507 (*Eucalyptus tereticornis*) trees/ha and 52.61 (Sal forest) to 43.59 (Jamun forest) m^2/ha, in shrubs from 4633 (Sal forest) to 3333 (*Eucalyptus tereticornis*) plants/ha and 9.30 to 6.63 m^2/ha, and in herbs from 2,86,000 (Sal+Tendu forest) to 1,58,000 (*Eucalyptus tereticornis*) plants/ha and 120.33 to 57.6 cm^2/m^2.

Field trip - Snogeholm landscape laboratory

Thursday 26th March

Sign up for the field trip during the first day of the conference!

The field trip will go to a demonstration site with mono and multi-species plantations of all Swedish native tree species; Snogeholm landscape laboratory. It was established during spring 1994 on former agricultural land. The laboratory consists of in total 69 plots of which only 19 are planted monocultures. In the mixed plots, the tree compositions vary in planting structure, to create e.g. row or group mixing of the tree species. Also the function of the tree species varies in and between plots, where some species are primary or secondary crop trees, while others were planted to serve as nursery trees or understory vegetation. Many of the plots demonstrate the potential in establishing and growing noble broadleaves, especially oak (*Quercus robur*) and beech (*Fagus sylvatica*) in mixtures with other broadleaves. After 25 years the landscape laboratory have become a valuable recreation area for people in the region and a well-known excursion site for forest owners and students. During the years the plots have been repeatedly measured and tending and thinning have been made in order to maintain the original plan for each of the plots. Although some of the nursery trees are now harvested, some trees have been retained to show the history of the establishment era.

Practical guide

You will be guided in groups with two guides for each group. If possible, wear warm clothes and waterproof boots. There are no indoor facilities on site but toilets is available on the busses.

Time schedule

13.00 Departure from AF Borgen Lund in busses.

14.00 Round tour

15.30 Coffee

16.00 Departure from Snogeholm back to Lund

Tour guides

Per Gemmel, Eric Agestam, Per-Magnus Ekö, Johanna Witzell, Urban Nilsson, Björn Wiström, Lisa Petersson & Emma Holmström, Swedish University of Agricultural Sciences (SLU)

Matts Karlsson, Södra

Lars Drössler, Ilia State University

Anders Rosell & Charlotta Kabo Stenberg, the Scanian Landscape Foundation.

List of participants

Surname	Name	Organisation	E-mail
Ahmed	Iftekhar Uddin	BOKU University	iftekhar.ahmed@boku.ac.at
Aldea	Jorge	Swedish University of Agricultural Sciences	jorge.aldea@slu.se
Andivia	Enrique	Complutense University of Madrid	e.andivia@gmail.com
Ara	Mostarin	Swedish University of Agricultural Sciences	mostarin.ara@slu.se
Askarieh	Ali	University of Valladolid	ali.askarieh88@gmail.com
Avdagić	Admir	Faculty of Forestry	a.avdagic@sfsa.unsa.ba
Bakx	Tristan	INES, Lund University	tristan.bakx@nateko.lu.se
Barbati	Anna	University of Tuscia	barbati.sisfor@unitus.it
Barbeito	Ignacio	Swedish University of Agricultural Sciences	ignacio.barbeito@slu.se
Barrere	Julien	INRAE	julien.barrere@inrae.fr
Barsoum	Nadia	Forest Research	nadia.barsoum@forestresearch.gov.uk
Battaglia	Mike	USDA Forest Service	michael.battaglia@usda.gov
Bengtsson	Jan	Swedish University of Agricultural Sciences	jan.bengtsson@slu.se
Berggren Nieto	Kristina	Swedish University of Agricultural Sciences	kristina.berggren@slu.se
Bianchi	Simone	LUKE	simone.bianchi@luke.fi
Bielak	Kamil	Warsaw University of Life Sciences	kamil.bielak@wl.sggw.pl
Binkley	Dan	Swedish University of Agricultural Sciences	dan.binkley@colostate.edu
Blasko	Robert	Swedish University of Agricultural Sciences	robert.blasko@slu.se
Bonal	Damien	INRAE	damien.bonal@inra.fr
Bouwman	Meike	Wageningen University and Research	meike.bouwman@wur.nl
Bravo	Felipe	Universidad de Valladolid	fbravo@pvs.uva.es
Bravo-Oviedo	Andrés	National Museum of Natural Sciences	bravo@mncn.csic.es
Brazaitis	Gediminas	Vytautas Magnus University	gediminas.brazaitis@vdu.lt
Brèteau-Amores	Sandrine	INRA	sandrine.breteau-amores@inrae.fr
Brunner	Andreas	Norwegian Univ. of Life Sciences	andreas.brunner@nmbu.no
Brzeziecki	Bogdan	Warsaw University of Life Sciences	bogdan.brzeziecki@wl.sggw.pl
Bylund	Helena	Swedish University of Agricultural Sciences	helena.bylund@slu.se
Caffaro	Felipe	Symbiosis Investments	caffarofelipe@gmail.com
Calama	Rafael	INIA-CIFOR	rcalama@inia.es
Candel-Pérez	David	Universidad Pública de Navarra	david.candel@unavarra.es
Cardoso	Jéssica	UNBC	cardoso@unbc.ca
Cattaneo	Nicolas	Université du Québec à Rimouski	nicolas_cattaneo@uqar.ca
Cavasicci	Luciano	studio tecnico	studiorosellicavasicci@gmail.com
Chen	Yayuan	Swedish University of Agricultural Sciences	yayuan.chen@slu.se
Coll	Lluís	University of Lleida	lluis.coll@ctfc.cat
Cosmin	Braga	I.N.C.D.S. "Marin Dracea	braga_cosmin@yahoo.com
Coulibaly	Brahima	CNRA	cybrahim@gmail.com
Cudjoe	Eric	University of Valladolid	cudjoe09@uw.edu
Dawson	Lucas	Swedish University of Agricultural Sciences	lucas.dawson@slu.se
de Cáceres	Miquel	Forest Sciences Center of Catalonia	miquelcaceres@gmail.com
de Koning	Johannes	University of Copenhagen	jhc@ign.ku.dk
de Streel	Géraud	UCLouvain	geraud.destreel@gmail.com
del Río	Miren	INIA	delrio@inia.es
Desaine	Iveta	Skogssallskapet SIA	iveta.desaine@skogssallskapet.com
Dey	Daniel	USDA Forest Service	daniel.c.dey@usda.gov
Dezzotti	Alejandro	Universidad Nacional del Comahue	adezzotti@gmail.com
Didion-Gency	Margaux	WSL	margaux.didion@wsl.ch
Digiovinazzo	Patrizia	ERSAF - Lombardy Region	digiovinazzo.lifegestire2020@gmail.com
Drössler	Lars	Herr	lars.drossler@iliauni.edu.ge
Ducey	Mark	University of New Hampshire	mark.ducey@unh.edu
Engel	Markus	BOKU Institute of Forest Growth	markus.engel@boku.ac.at
Evans	Iwan	University of Birmingham	ixe698@student.bham.ac.uk
Gajjar	Lalabhai G	Petlad Sojitra Taluka Co Op Uni Ltd	gajjar.ppsultd@gmail.com
Gamfeldt	Lars	University of Gothenburg	lars.gamfeldt@gu.se
Getino	Marina	University of Valladolid	marina.getino@uva.es
Granhus	Aksel	Norwegian Institute of Bioeconomy R	aksel.granhus@nibio.no
Grossiord	Charlotte	EPFL/WSL	charlotte.grossiord@wsl.ch
Hammond	Maame Esi	Mendel university in Brno	esihammond6@gmail.com
Harris	Thomas	University of Georgia, USA	tbharri2@ncsu.edu
Haufe	Jens	Forest Research	jens.haufe@forestresearch.gov.uk
Hawkins	Christopher	Association of Peace River Woodlots	cdbh@adlardenvironmental.ca
Herault	Bruno	Cirad	bruno.herault@cirad.fr
Heres	Ana-Maria	Universitatea Transilvania Brasov	ana_heres@yahoo.com
Hernández	José Antonio	Colegio de Postgraduados	tecnobiosfera27@gmail.com
Himes	Austin	Mississippi State University	austin.himes@msstate.edu
Högberg	Peter	Swedish University of Agricultural Sciences	peter.hogberg@slu.se
Holmström	Emma	Swedish University of Agricultural Sciences	emma.holmstrom@slu.se
Houtmeyers	Silke	NMBU	houtmeyers.silke@nmbu.no
Huth	Franka	TU Dresden	f.huth@freenet.de
Hylen	Gro	NIBIO	gro.hylen@nibio.no

Surname	Name	Organisation	E-mail
Ibrahimspahić	Aida	Faculty of Forestry Sarajevo	a.ibrahimspahic@sfsa.unsa.ba
Jactel	Hervé	INRAE	herve.jactel@inrae.fr
Jansons	Aris	LSFRI Silava	aris.jansons@silava.lv
Jensen	Anna Monrad	Linnaeus University	anna.jensen@lnu.se
Johansson	Ulf	Swedish University of Agricultural Sciences	ulf.johansson@slu.se
Jourdan	Marion	Université Paris-Saclay	marion.jourdan@u-psud.fr
Kaupe	Dārta	LVMI "Silava"	darta.kaupe@inbox.lv
Kerr	Gary	Forest Research	gary.kerr@forestresearch.gov.uk
Klapwijk	Maartje	Swedish University of Agricultural Sciences	maartje.klapwijk@slu.se
Klingenfuss	Sara	University of Freiburg	sara.klingenfuss@biologie.uni-freiburg.de
Korboulewsky	Nathalie	INRAE Val de Loire	nathalie.korboulewsky@inrae.fr
Krajnc	Luka	Slovenian Forestry Institute	luka.krajnc@gozdis.si
Lariviere	Delphine	Swedish University of Agricultural Sciences	delphine.lariviere@slu.se
Lidman	Felicia	Swedish University of Agricultural Sciences	felicia.lidman@slu.se
Lodin	Isak	Swedish University of Agricultural Sciences	isak.lodin@slu.se
Löf	Magnus	Swedish University of Agricultural Sciences	magnus.lof@slu.se
López-Marcos	Daphne	University of Valladolid	dalomar86@hotmail.com
Lula	Mikolaj	Swedish University of Agricultural Sciences	mikolaj.lula@slu.se
Luna-Dlez	Estrella	University of Birmingham	e.lunadiez@bham.ac.uk
Lutter	Reimo	Swedish University of Agricultural Sciences	reimo.lutter@slu.se
Magh	Ruth	Swedish University of Agricultural Sciences	ruth.magh@slu.se
Maguire	Douglas	Oregon State University	doug.maguire@oregonstate.edu
Maleki	Kobra	University of Quebec (UQAT)	kobra.maleki@uqat.ca
Marinkovic	Marko	Public Enterprise "Vojvodinasume"	marko.marinkovic@vojvodinasume.rs
Martín Ariza	Ana	IuFOR	ana.martin@forest.uva.es
Martin-Blangy	Soline	INRAE	soline.martin-blangy@inra.fr
Mason	Bill	Forest Research	bill.mason@forestresearch.gov.uk
Mathys	Amanda	WSL	amanda.mathys@wsl.ch
Matula	Radim	Mendel University in Brno	radimmatula@gmail.com
Maundrell	Christopher	Peace Carbon Trades	chris@peacecarbontrades.ca
Mayberry	Jill	University of Aberdeen	jillian.mayberry@abdn.ac.uk
Metslaid	Marek	Estonian University of Life Science	marek.metslaid@emu.ee
Mihaila	Victor	I.N.C.D.S. "Marin Dracea	mvictor14bv@gmail.com
Mohren	Frits	Wageningen University	frits.mohren@wur.nl
Montague	Madeline	Purdue University	montague@purdue.edu
Morin	Xavier	CNRS	xavier.morin@cefe.cnrs.fr
Moser	W. Keith	USDA Forest Service, Rocky Mtn Res	warren.k.moser@usda.gov
Muñoz-Delgado	Bethany	USDA Forest Service, NRS	bethany.l.munoz@usda.gov
Nelson	Taylor	Purdue University	tmnelson@purdue.edu
Nilsson	Urban	Swedish University of Agricultural Sciences	urban.nilsson@slu.se
Nord-Larsen	Thomas	Copenhagen University	tnl@ign.ku.dk
Nothdurft	Arne	BOKU University	arne.nothdurft@boku.ac.at
Oboite	Felix	University of Alberta	oboite@ualberta.ca
Ordoñez	Cristobal	University of Valladolid	a_cristo@pvs.uva.es
Oreti	Loredana	University of study of Tuscia	loredanaoreti@unitus.it
Orumaa	Argo	Estonian University of Life Science	argo.orumaa@student.emu.ee
Osei	Richard	UCLouvain	richard.osei@uclouvain.be
Pach	Maciej	University of Agriculture in Krakow	rlpach@cyf-kr.edu.pl
Pardos	Marta	INIA	pardos@inia.es
Peris Llopis	Marina	University of Eastern Finland	marinp@uef.fi
Petritan	Any Mary	INCDS "Marin Dracea"	apetritan@gmail.com
Pir	Alp	Functional Forests	alppir@gmail.com
Plichta	Roman	Mendel University in Brno	roman.plichta@mendelu.cz
Poeydebat	Charlotte	INRAE	charlotte.poeydebat@inrae.fr
Ponette	Quentin	UCLouvain	quentin.ponette@uclouvain.be
Pretzsch	Hans	Technical University of Munich	hans.pretzsch@lrz.tu-muenchen.de
Raymond	Patricia	Quebec Min Forest Wildlife & Parks	patricia.raymond@mffp.gouv.qc.ca
Rebane	Sille	Estonian University of Life Science	sille.rebane@emu.ee
Rehschuh	Stephanie	Karlsruhe Institute of Technology	stephanie.rehschuh@kit.edu
Reventlow	Ditlev	University of Copenhagen	dire@ign.ku.dk
Reyes-Hernandez	Valentin	Colegio de Postgraduados	vareyhdz@gmail.com
Rivera Perez	Carmen Alicia	Forstbotanik und Baumphysiologie	rivera@gwdg.de
Rodríguez	Juanita	UQAT	rodj06@uqat.ca
Romeralo	Carmen	Swedish University of Agricultural Sciences	carmen.romeralo.tapia@slu.se
Ruiz-Peinado	Ricardo	INIA	ruizpein@inia.es
Schnabel	Florian	iDiv / Leipzig University	florian.schnabel@idiv.de
Serra Maluquer	Xavier	Instituto Pirenaico de Ecología (CSIC)	serramaluquer@ipe.csic.es
Sewerniak	Piotr	Nicolaus Copernicus University	sewern@umk.pl
Spinu	Andreea	University of Freiburg	andreea.spinu@waldbau.uni-freiburg.de
Stastny	Michael	Canadian Forest Service	michael.stastny@canada.ca
Steckel	Mathias	TUM	mathias.steckel@tum.de
Stokes	Victoria	Forest Research	victoria.stokes@forestresearch.gov.uk
Szedlak	Tamas	European Commission, DG Agriculture	tamas.szedlak@ec.europa.eu
Thurm	Eric Andreas	LandesforstMV	eric.thurm@outlook.de

Surname	Name	Organisation	E-mail
Toigo	Maude	CNRS	maude.toigo@cefe.cnrs.fr
Tomao	Antonio	University of Tuscia	antonio.tomao@unitus.it
Tonon	Giustino	Free University of Bolzano	giustino.tonon@unibz.it
Toraño Caicoya	Astor	Technical University of Munich	astor.torano-caicoya@tum.de
Torres	Gustavo	Universidad de Los Lagos	gustavo.torres@ulagos.cl
Torres Carro	Andrés	Universidade de Vigo	atc-2316@hotmail.com
Tubic	Bojan	Public Enterprise "Vojvodinasume"	btubic@vojvodinasume.rs
Tudoran	Amelia	Swedish University of Agricultural Sciences	amelia.tudoran@slu.se
Uhl	Enno	Technical University of Munich	enno.uhl@tum.de
Uzquiano	Sara	iuFOR-UVa	sara.uzquiano@forest.uva.es
Vega-Gorgojo	Guillermo	University of Valladolid	guiveg@tel.uva.es
Velázquez	Alejandro	Colegio de Postgraduados	alejvela@colpos.mx
Vesterdal	Lars	University of Copenhagen	lv@ign.ku.dk
Vodde	Floortje	Estonian University of Life Science	floortje.vodde@emu.ee
Vuguls	Janis	LSFRI SILAVA	janis.vuguls@silava.lv
Vyčítalová	Hana	Mendel University in Brno	xvycita1@node.mendelu.cz
Wambsganss	Janna	University of Freiburg	janna.wambsganss@waldbau.uni-freiburg.de
Wehnert	Alexandra	TU Dresden	alexandra.wehnert@freenet.de
Witzell	Johanna	Swedish University of Agricultural Sciences	johanna.witzell@slu.se
Wrethling	Fredrika	Swedish University of Agricultural Sciences	fredrika.wrethling@slu.se
Yamazaki	Eiji	University of Freiburg	eiji.ym12@gmail.com
Yeste	Antonio	Public University of Navarre	antonioyesteyeste@gmail.com

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KUNGL. SKOGS- OCH LANTBRUKSAKADEMIEN

Institutionen för sydsvensk skogsvetenskap
SLU
Box 49
SE-230 53 Alnarp
Telefon: 040-41 50 00 Telefax: 040-46 23 25

Southern Swedish Forest Research Centre
Swedish University of Agricultural Sciences P.O. Box
49, SE-230 53 Alnarp
Sweden
Phone: +46 (0)40 41 50 00 Fax: +46 (0)40 46 23 25

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