International conference

# LOCAL SOLUTIONS FOR REGIONAL AND GLOBAL FOREST MANAGEMENT CHALLENGES

Organized by SNS Growth and Yield researchers Network

In Salaspils and Rīga, Latvia

June 7–9, 2022

ISBN 978-9934-603-09-9

Latvian State Forest Research Institute “Silava”

Editor: Zane Lībiete

## PROGRAMME

**June 7**

10:45 Coffee

11:00 Start of the conference in Silava. Welcome

11:20 Andres Kiviste, Toomas Tarmu, Allar Padari and Diana Laarmann. Dominant height growth modelling on the Estonian forest permanent plot data

11:35 Joonas Kollo, Steffen M. Noe, Allar Padari, Alisa Krasnova, Ahto Kangur. Linking the measurement data of the substance flows of the SMEAR Estonia measuring station with the place of growth

11:50 Oscar Nilsson, Line Djupström. Different regeneration methods of Scots pine in a nature consideration gradient

12:05 Pauls Zeltiņš, Kristaps Ozoliņš, Guntars Šņepsts, Jānis Donis, Arnis Gailis. Height growth models for improved forest reproductive material of main tree species in Latvia

12:20 Kobra Maleki, Rasmus Astrup, Christian Kuehne, J. Paul McLean, Clara Antón-Fernández. Growth and yield model for long-term projection of the main tree species in Norway

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12:35 Simone Bianchi, Sauli Valkonen, Annika Kangas. METSÄNVALO: Citizen scientists for a light-growth study in forest regeneration

12:40 Martynas Narmontas. Projection of Tree Taper Using Stochastic Differential Equations

12:45 Swastika Chakravorty, Narayanan Subramanian. Growth comparison of birch and spruce in selected experimental forests in Sweden

12:50 Pauls Zeltiņš, Arnis Gailis, Āris Jansons. Tree breeding mitigates the potential adverse effect of climate change

12:55 Juris Katrevičs, Baiba Jansone, Pauls Zeltiņš, Jānis Donis. Spacing and clone affecting the potential revenue of the owner of Norway spruce plantation

13:00 Iveta Desaine, Beate Bērziņa, Jānis Donis, Diāna Jansone, Āris Jansons. Effect of bark stripping on volume increment of Norway spruce

13:15 Lunch in Salaspils. Departure to a short field trip before transport to the hotel

**June 8**

*Field day*

9:00 Departure to field trip.

Stories in the forest:

- Āris Jansons, Pauls Zeltiņš, Guntars Šņepsts. Realize genetic gain for Scots pine in Latvia
- Dagnija Lazdiņa, Austra Zuševica, Toms Arturs Štāls, Kārlis Dūmiņš, Viktorija Vendiņa, Kristaps Makovskis. Municipal and green energy residues for tree growth improvement – use of waste water sludge, wood ash and digestate as N.P K and microelement source (Hybrid aspen, poplar and pine), different forest regeneration: tests of interaction between tree species x plant type x soil scarification
- Raitis Rieksts-Riekstiņš, Āris Jansons, Diāna Jansone. Productivity of lodgepole pine and Scots pine on poor soils in hemiboreal forests: tree species and breeding effects
- Roberts Čakšs, Tālis Gaitnieks, Jānis Donis. Rot affecting increment and carbon storage in Norway spruce stands on peat soils
- Valters Samariks, Laura Ķēniņa, Māra Kitenberga, Nauris Īstenais, Āris Jansons. Long term effect of melioration systems on greenhouse gas balance in old Scots pine forests on organic soils
- Kārlis Bičkovskis, Guntars Šņepsts, Aldis Butlers, Andis Lazdiņš, Jānis Donis, Āris Jansons. Changes in forest drainage have a marked short and long term effect on carbon storage
- Daiga Zute, Ieva Jaunslaviete, Dārta Kaupe. Carbon storage in old-growth coniferous stands on organic soils
- Oskars Krišāns, Andris Seipulis, Nauris Īstenais, Āris Jansons. Factors affecting wind damages of trees in hemiboreal forests
- Diāna Jansone, Roberts Matisons, Stefānija Dubra, Āris Jansons. Growth potential of introduced tree species in Latvia
- Daiga Zute. From increment of trees to effect on climate change mitigation: policy considerations

Lunch in the forest. Organized dinner. Transport to the hotel.

**June 9**

9:00 Martin Goude, Urban Nilsson, Euan Mason, Giulia Vico. Using hybrid modelling to predict basal area and evaluate effects of climate change on growth of Norway spruce and Scots pine stands

9:15 Toomas Tarmu, Andres Kiviste, Ain Näkk, Diana Laarmann. Application of sonic tomography (PICUS 3 sonic tomograph) to detect and quantify hidden wood decay in Estonian spruce stands

9:30 Axelina Jonsson, Narayanan Subramanian, Renats Trubins, Tomas Lundmark, Per-Erik Wikberg, Karin Hjelm, Urban Nilsson. The young forest stands in Northern Sweden, now and in the future – a HEUREKA analysis

9:45 Jorge Aldea, Simone Bianchi, Emma Holmström, Jari Hynynen, Urban Nilsson, Daesung Lee, Saija Huuskonen. Evaluation of growth models for mixed forests used in Swedish and Finnish decision support systems

10:00 Artis Becs. Biomass harvest in first thinning of biomass-dense stands as an alternative to late pre-comercial thinning?

10:15 Steffen Noe. Application of non-linear mixed models in growth estimations

10:30 Toms Kondratovičs, Ineta Samsone, Mārtiņš Zeps. Development of specially adapted LED luminaires for providing efficient and energy efficient tree propagation and rooting process

10:45 Coffee break

11:00 Daesung Lee, Jouni Siipilehto, Jari Hynynen. Growth and yield models for clonal hybrid aspen plantation in southern Finland and Sweden

11:15 Roberts Matisons, Diāna Jansone, Kristaps Ozoliņš, Pauls Zeltiņš, Āris Jansons. Nonlinear weather-growth relationships of Norway spruce and Scots pine in hemiboreal forests

11:30 Andis Lazdins. Climate change mitigation potential of afforestation in organic soils in farmlands

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*11:45 Roberts Čakšs, Guntars Šņepsts, Jānis Donis, Āris Jansons. Factors affecting the occurrence of stem rot in Latvia*

*11:50 Endijs Bāders, Oskars Krišāns. Remote sensing facilitates the selection of future proof genotypes*

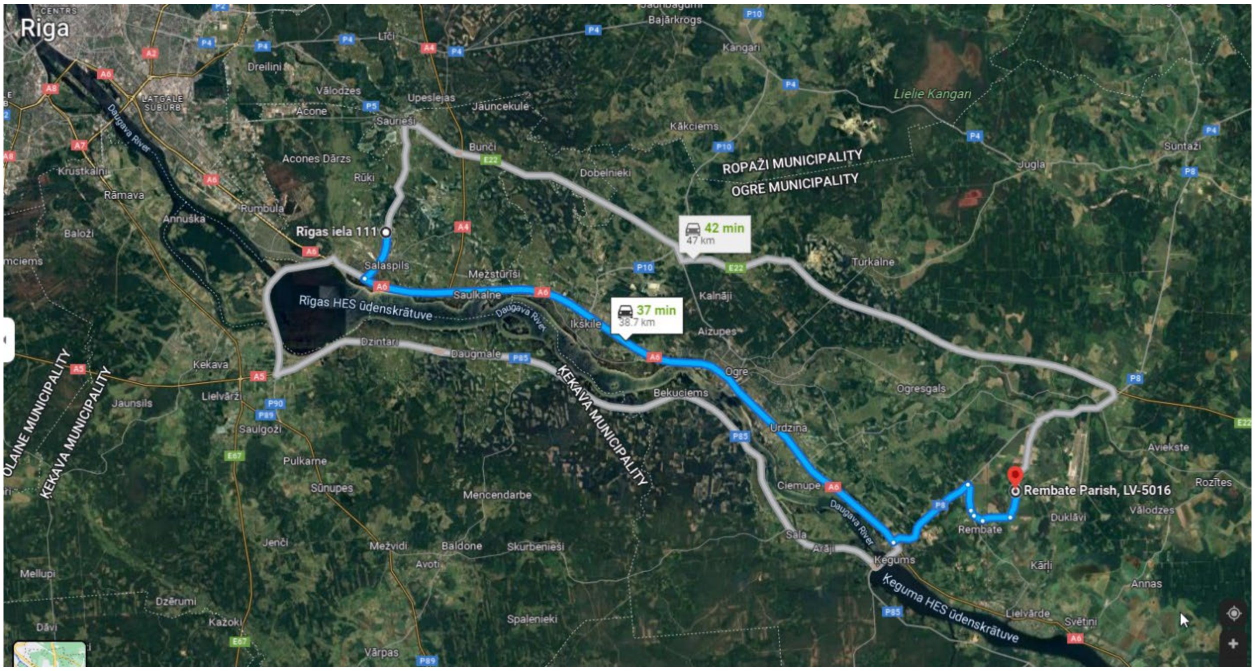
*11:55 Raitis Rieksts-Riekstiņš, Arnis Gailis, Una Neimane, Āris Jansons. Spike knots of young coniferous trees – something to be worried about?*

12:00 Concluding remarks

12:30 Lunch at the hotel

## FIELD TRIP DETAILS

7th of June, 2022




(credit: Google maps)

Progeny trials in Rembate (birch, hybrid aspen, spruce, alder etc.), including tests of interaction effects: clone x fertilization, genotype x plant material. Total area > 30 ha, initiated at 1998 *

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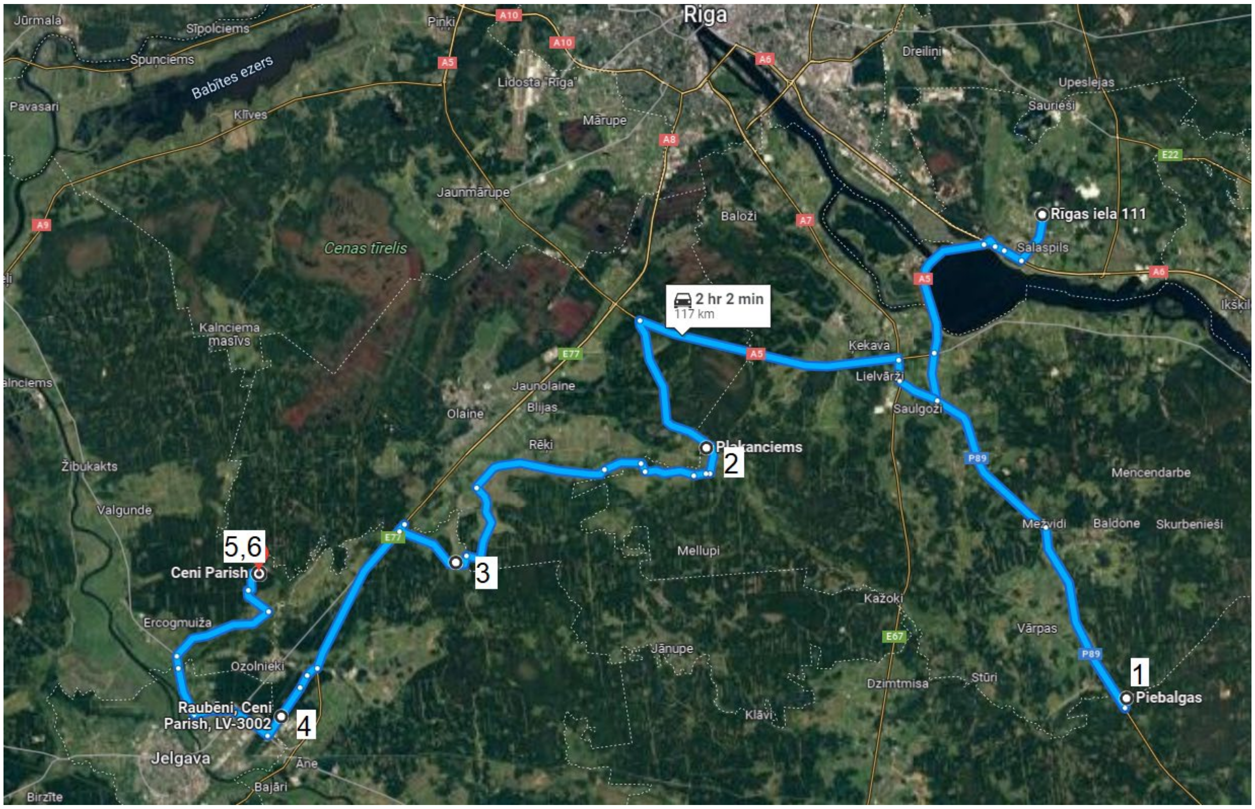
* Development of a new technology for the production of plant fertilizers from the residues of biogas plant digestion (digestate) and woodchip cogeneration (woodchip ash) (19-00-A01612-000008)

NACIONĀLAIS ATTĪSTĪBAS PLĀNS 2020

EIROPAS SAVIENĪBA
EIROPA INVESTĒ LAUKU APVIDOS
Eiropas Lauksaimniecības fonds lauku attīstībai

Atbalsta Zemkopības ministrija un Lauku atbalsta dienests

8th of June, 2022




(credit: Google maps)

1. Provenance, progeny, and realized genetic gain trials Zvirgzde (Scots pine, lodgepole pine), Total area > 20 ha, initiated at 1975
2. Effect of forest drainage on greenhouse gas emissions and storage, tree growth. One of the first targeted forest drainage systems in Latvia (established 1895). Pine genetic resources stand
3. Forest regeneration: tests of interaction between tree species x plant type x soil scarification *
4. Wind damages in forests – demonstration site
5. Progeny trials of Scots pine, lodgepole pine
6. Trials of introduced tree species

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* New work methods and technologies to improve the efficiency of forest stand regeneration, tending and protection of young stands (5-5.9.1_007o_101_21_77)

LATVIJAS VALSTS MEŽI

# MODELLING DOMINANT HEIGHT DEVELOPMENT ON ESTONIAN FOREST PERMANENT PLOT DATA

**Andres Kiviste, Toomas Tarmu, Allar Padari, Diana Laarmann**
*Estonian University of Life Sciences, Institute of Forestry and Engineering, Chair of Forest and Land Management and Wood Processing Technologies*
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Dominant height based site index models are common tools in forest research and practice in most European countries. In Estonian forestry the mean height based site index model is used which makes complicated to compare and/or apply forest models from Nordic and Western countries in Estonia. This study is the first attempt to develop a dominant height growth model for Estonian forest stands.

The Estonian Network of Forest Research Plots (ENFRP) measured from 1995 up to now comprises data from repeated measurements of more than thousand monitoring plots with radius of 15, 20, 25 or 30 m depending on stand density and other stand characteristics on site. Every sample plot is re-measured after a five-year interval. According to our survey protocol, the stem diameter at breast height is recorded for every tree in two perpendicular directions and tree height for sample trees. (Kiviste et al. 2015).

Dominant height for plot was calculated as follows: (1) A number of thickest trees (corresponding to hundred per hectare trees) as dominant trees on plot were selected; (2) The Näslund's height curve parameters were estimated on sample trees height/diameter measurements; (3) Mean square diameter of the dominant trees was calculated as dominant diameter; (4) Dominant height was predicted at dominant diameter using the height curve with calibration.

For modelling dominant height/age series the polymorphic algebraic difference transformation of Hossfeld IV growth function (Elfving & Kiviste, 1997) gave the best fit.

$$d = \frac{a_2}{25^{a_3}} \qquad r = \sqrt{(H_1 - d)^2 + 4 \cdot a_2 \cdot \frac{H_1}{{A_1}^{a_3}}} \qquad H_2 = \frac{H_1 + d + r}{2 + \dfrac{\dfrac{4 \cdot a_2}{{A_2}^{a_3}}}{H_1 - d + r}}$$

where height $H_2$ at any age $A_2$ can be predicted when height $H_1$ at age $A_1$ is known, $a_2$ and $a_3$ are model parameters estimated separately for Scots pine ($a_2 = 6790$, $a_3 = 1.5934$), Norway spruce ($a_2 = 5965$, $a_3 = 1.607$) and Silver birch ($a_2 = 2707$, $a_3 = 1.3673$) dominating stands on the ENFRP data set.

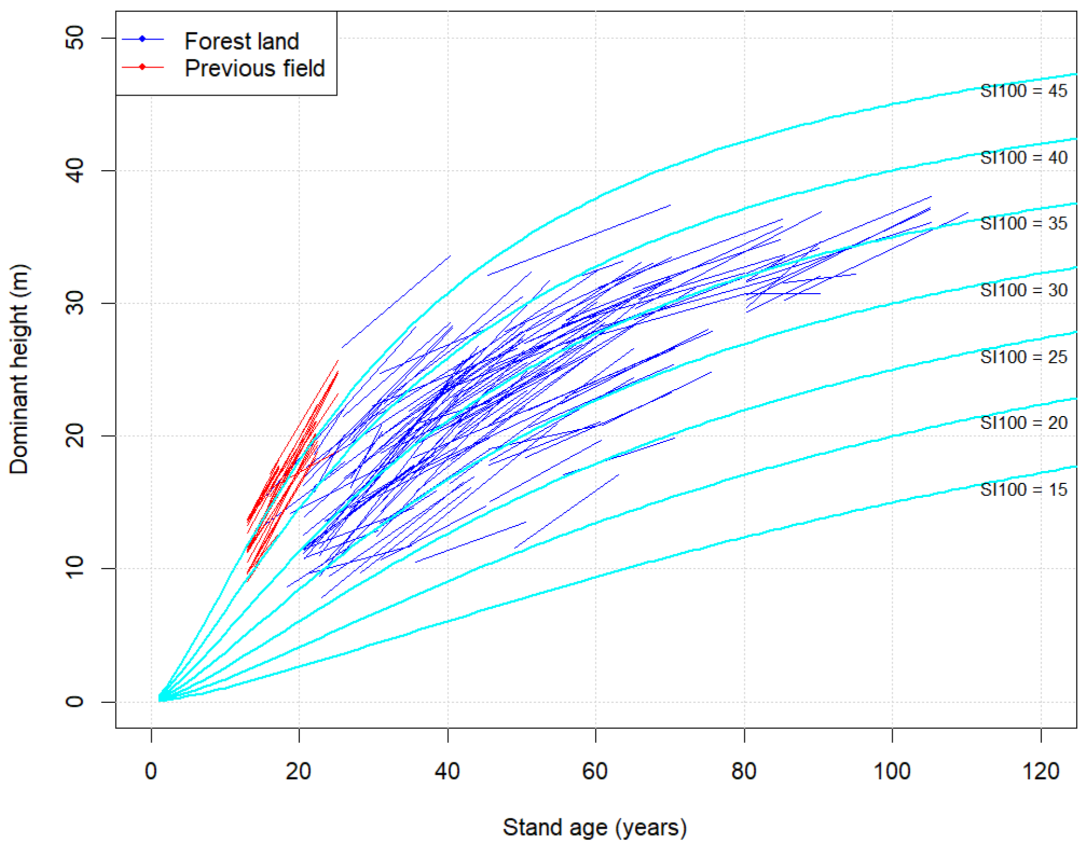


**Figure 1.** Silver birch dominant height growth on permanent plots and the model projection.

**Keywords**: *Hossfeld IV growth function, algebraic difference equation, parameter estimates.*

**References**

Elfving, B., Kiviste, A. (1997). Construction of site index equations for *Pinus sylvestris* L. using permanent plot data in Sweden. – Forest Ecology and Management 98(2), 125–134.

Kiviste, A., Hordo, M., Kangur, A., Kardakov, A., Laarmann, D., Lilleleht, A., Metslaid, S., Sims, A., Korjus, H. (2015). Monitoring and modeling of forest ecosystems: the Estonian Network of Forest Research Plots. – Forestry Studies |Metsanduslikud Uurimused 62, 26–38.

**Acknowledgements.** The study was supported by the Estonian Environmental Investment Centre (Project 18676). We are also grateful to Mari-Ann Tammiste for her contribution in the study.

# LINKING THE MEASUREMENT DATA OF THE SUBSTANCE FLOWS OF THE SMEAR ESTONIA MEASURING STATION WITH THE PLACE OF GROWTH

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SMEAR Estonia (Station for Measuring Ecosystem-Atmosphere Relations) is an important step towards the understanding how forest ecosystem and the atmosphere affect each other. The station provides long-term continuous fluxes measured using the eddy-covariance method. Parameters such as wind speed and direction are not controllable by human, but forest management methods are, thus the flux tower helps to assess how human activities affect forest ecosystem-atmosphere relationship. In this paper, the footprint for years 2015–2020 was calculated according to the wind speed and direction. Continuous 10 Hz measurements were taken from 30 m and 70 m height and averaged over half-hour intervals. Results showed that the footprint area calculated from 30 m over the six-year period differed only by 4.8%. From 70 m, this difference was only 1.6% over the six-year period. The average area for both 30 m and 70 m FFP was 77.88 ha and 3285.94 ha respectively. The growing stock of the forest was affected by forest management, but in general it grew by 2.8% for 30 m FFP by 2% for 70 m FFP. The main tree species growing in the area of the footprint are Scots pine, Norway spruce and Silver birch with some small amount of aspen and alder species. The dominant wind directions were ranging from west to south in 2015–2017 and in 2018–2020 from south-west to south-east.

**Table 1.** Land categories of the footprint area over the period of 2015–2020 from the height of 30 m

| Land type | Species | Area (ha) | Increment ($m^3$/ha/y) | Growing stock ($m^3$) |
|---|---|---|---|---|
| Forest land | *Alnus incana* | 0.13 | 0.49 | 7.62 |
| Forest land | *Alnus glutinosa* | 0.30 | 1.03 | 30.01 |
| Forest land | *Populus tremula* | 5.78 | 12.25 | 550.24 |
| Forest land | *Betula pendula* | 10.14 | 40.41 | 1671.66 |
| Forest land | *Picea abies* | 20.33 | 106.17 | 5442.69 |
| Forest land | *Pinus sylvestris* | 37.31 | 99.03 | 11080.39 |

| Land type | Species | Area (ha) | Increment ($m^3$/ha/y) | Growing stock ($m^3$) |
|---|---|---|---|---|
| Forest land | *Clear-cutted* | 0.20 | - | 0.00 |
| Forest isle | - | 0.40 | - | - |
| Buildings | - | 0.01 | - | - |
| Electric power transmission | - | 1.24 | - | - |
| Roads | - | 0.93 | - | - |
| Ditches | - | 0.53 | - | - |
| Clear area | *Clear-cutted* | 0.58 | - | - |
| Total | - | 77.88 | - | 18782.61 |
| Total forest area | - | 73.99 | - | - |

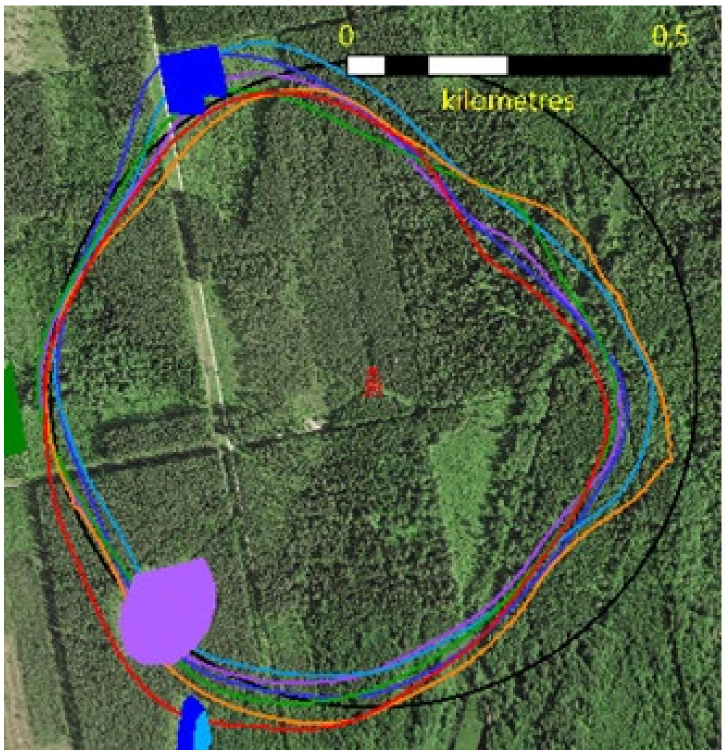


**Figure 2.** The contours of the footprint area for the years 2015–2020. It illustrates that the change in the footprint area differs from year to year and that this variability includes fraction of the land cover elements (e.g., clear-cut, road) or tree species alterations. Colored areas stand for clear-cuts. Blue, dark blue and purple colours mean that these areas were clear-cut in 2018, 2019 and 2020 respectively. Red in the middle is the location of the flux tower.

**Keywords**: *SMEAR Estonia, footprint, fluxes, forest ecosystem.*

# DIFFERENT REGENERATION METHODS OF SCOTS PINE IN A NATURE CONSIDERATION GRADIENT


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In order to meet societal demands such as recreation, providing jobs, maintaining biodiversity and to accommodate the increasing need of renewable raw material from the forest, adaptation of forest management is crucial. There is a big interest of how to optimize production and nature consideration, however the current knowledge is limited. The nature value of old Scots pine forests differ but many of the characteristics that can be found are crucial for a wide spectrum of insects, fungi, mosses, lichens and birds. Hence, an active management with nature consideration will be important to meet environmental goal. Thus, there is a clear need to increase the understanding about sustainable use of the forest and pin-point consequences of trade-offs between conventional and alternative forest management methods in old Scots pine forest. To meet this need, survival and growth of Scots pine seedlings regenerated by natural regeneration, direct seeding and planting, in site prepared and control (no site preparation) treatments have been monitored in harvested Scots pine stands with five different levels of left nature consideration – 3%, 10%, 30%, 50% and 50% + burnt. Results show that planted seedlings grew more rapidly than seedlings regenerated by sowing or natural regeneration, and that seedlings were tallest in 3% nature consideration for planted and direct seeded seedlings. Tallest natural regenerated seedlings were found in 10% nature consideration. Interestingly the growth difference of site prepared planted seedlings between the 3% nature consideration treatment and both 10% and 50% was rather small. Site preparation was positive both for survival and growth for all regeneration methods, especially for direct seeding, which had both very low germination rate and poor growth in the control site preparation treatment. The study confirms that site preparation is beneficial for the survival and growth for all regeneration methods, especially for direct seeding. Furthermore, higher levels of nature consideration only lead to a small decrease in seedling growth for planted seedlings.

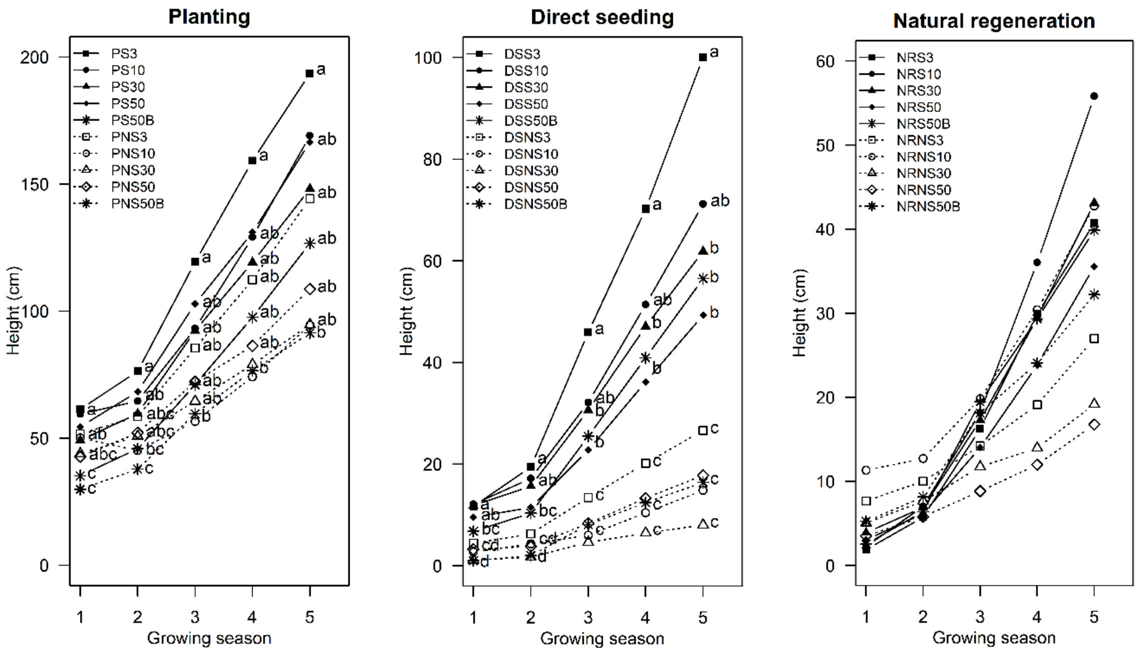


**Figure 3.** Heights (cm) for the three different regeneration methods: planting (P), direct seeding (DS) and natural regeneration (NR) in site prepared (S) and no site prepared (NS) treatment, in the five different nature consideration levels 3% (3), 10% (10), 30% (30), 50% (50) och 50% + burnt (50+B), after the five first growing seasons. Different letters next to an observed mean indicate significant differences within years according to the Tukey multiple comparison difference test.

**Keywords:** *Pinus sylvestris, planting, direct seeding, natural regeneration, site preparation, establishment.*

**Acknowledgements.** The authors want to thank the landowner Stora Enso for providing suitable sites, and staff and research technicians of Skogforsk in Ekebo and Uppsala, who helped to acquire measurements or contributed otherwise to this study. Special thanks are due to Landsbygdsprogrammet (LBP) for financial support.

# HEIGHT GROWTH MODELS FOR IMPROVED FOREST REPRODUCTIVE MATERIAL OF MAIN TREE SPECIES IN LATVIA

**Pauls Zeltiņš [1, 2], Kristaps Ozoliņš [1], Guntars Šņepsts [1], Jānis Donis [1], Arnis Gailis [1], Āris Jansons [1]**

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The breeding of economically important forest tree species in the Baltic Sea region has notably contributed to increased quantity and quality of wood available for bioeconomy. Accordingly, the altered stand dynamics of improved planting stock should be identified and incorporated in growth models to accurately reflect these gains. Such amended models can be used for assessment of different alternatives e.g. of strategies to increase the rate of carbon sequestration.

We used the generalized algebraic difference approach (GADA) to analyse height growth differences among forest reproductive material (FRM) categories with distinct improvement levels, and adjust existing growth models for Scots pine, Norway spruce and silver birch. Dynamic GADA form of King-Prodan height growth functions based on re-measured National Forest Inventory (NFI) plots in Latvia (representing unimproved material) were tested and modified to better predict growth of categories "qualified" and "tested" with different levels of genetic improvement. For modifications, data of height measurements from open-pollinated progeny trials in Latvia were used.

The incorporation of category-specific modifiers for model parameters improved accuracy of predictions. Both categories – 'qualified' and 'tested' – had steeper growth trajectories at young age comparing to unmodified function based solely on NFI data. The curve of category "tested" was mainly slightly above the one for "qualified" material. The tested growth functions with FRM category-specific modifications more precisely reflect the actual growth of improved stands, and may be easy to apply for practical use. Still, such predictions are limited to sites with medium and high site indices, where improved planting stock is typically used.

# GROWTH AND YIELD MODEL FOR LONG-TERM PROJECTION OF THE MAIN TREE SPECIES IN NORWAY

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**Background:** Growth and yield models are commonly used within decision support systems to predict forest development and explore management alternatives that can support forest managers and policymakers in their planning. Because the stand-level models need to be developed for individual species in the environment that they are planned to be grown in, they are traditionally built for forests with simple structures, i.e., even-aged, and single-species, which meet these criteria. However, not all forests meet these criteria, and we still need to project and quantify the growth and yield of such forests. Thus, the current study aimed to develop robust and biologically consistent stand-level models for even-aged unmanaged forest stands using the newest available data from the Norwegian national forest inventory. This represents an important alternative to the use of dedicated and closely monitored long-term experiments established in single species even-aged forests for the purpose of building these stand-level models.

**Material and methods:** For this study we used the data from Norwegian national forest inventory, which characterizes a wide range of tree sizes, ages and management intensities that are typical for the structurally heterogeneous forests found throughout Norway. For the analyses, plots located on productive forestlands, with no final felling or thinning during the study period were selected and based on the highest volume over bark were classified into three species groups: Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus sylvestris* L.), and birch (*Betula pubescens* Ehrh. and *Betula pendula* Roth). The model development process was initiated by testing or re-parametrizing the component equations of the most recent stand-level growth and yield model, suggested for even-aged Norway spruce, and followed by evaluating potential candidate models from the literature if any of the original or re-parameterized component equations did not provide result in unbiased short-term (residual analyses) and long-term (visual and subjective evaluation) predictions. During the model development, because we observed the ingrowth in half of the stands, we used two approaches to predict the stem density: (1) with one equation that accounts for the survival and ingrowth as a whole, (2) as the sum of two equations' outputs for survival and for ingrowth (count × probability).

**Results:** The final models consist of component equations for dominant height, stem density, survival (number of survived trees), ingrowth (number of recruited trees × the probability of recruitment), basal area, and volume development of stands that can extrapolate the biological dynamics of the main tree species in Norway. The new stand-level growth and yield model proposed similar component equations for the three main species group; however, they function based on the species-specific parameters for each species group. It is worth mentioning that we did not notice a substantial difference between the two approaches of predicting the total stem density.

**Conclusions:** The Norwegian forests are not always single species, homogenous, and even aged, and using the data with a small number of re-measurements and imbalanced in terms of stand age and site productivity was also a challenge. Nevertheless, we succeed to derive a reliable system of equations for predicting stand-level growth and yield of the structurally heterogeneous forests found throughout Norway. This system is relatively simple to use and has great potential to form the substance of the more complex systems where, for more particular objectives, other aspects such as natural disturbances, species mixture, and any management plan can be incorporated.

**Keywords:** *long-term simulation, volume, Norway spruce, Scots pine, ingrowth.*

The full study description can be found in:

Maleki, K., Astrup, R., Kuehne, C., McLean, JP., Antón-Fernández, C. (2022). Stand-level growth models for long-term projections of the main species groups in Norway. Scandinavian Journal of Forest Research, 1–14.

# USING HYBRID MODELLING TO PREDICT BASAL AREA AND EVALUATE EFFECTS OF CLIMATE CHANGE ON GROWTH OF NORWAY SPRUCE AND SCOTS PINE STANDS

**Martin Goude [1], Urban Nilsson [1], Euan Mason [2], Giulia Vico [3]**

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[2] *School of Forestry, University of Canterbury, Christchurch, New Zealand*

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Capturing the effects of climate change when modelling forest growth is essential for reliable long-term predictions and management choices. However, commonly used mensurational forest growth and yield models do not account for the role of climate change. This study develops hybrid physiological/mensurational basal area growth and yield models to incorporate eco-physiological aspects and capture climate responses. To include the effects of climate and site variation, we replaced time with light sums of photosynthetically active radiation, modified by monthly soil water, vapour pressure deficit, temperature, or frost days, and their combinations. We parameterised species-specific basal area models for Scots pine and Norway spruce based on permanent sample plot data from the Swedish National Forest Inventory and long-term forest experiments. The hybrid models had a good fit for both species' data but with no increase in precision compared with time-based mensurational models. A sensitivity analysis based on a 20-year simulation showed that the hybrid models could capture changes in growth in response to changes in precipitation and temperature. At sites where temperatures were cooler, and water availability was good, warmer temperatures positively affected basal area growth. At sites with less available soil water, these temperature effects were reduced or became negative because of increased evapotranspiration. A significant impact on productivity from climate change emerged when considering different climate scenarios. Hence, climate-sensitive models that can take local variations into account are necessary for accurate long-term

predictions and sustainable forest management.

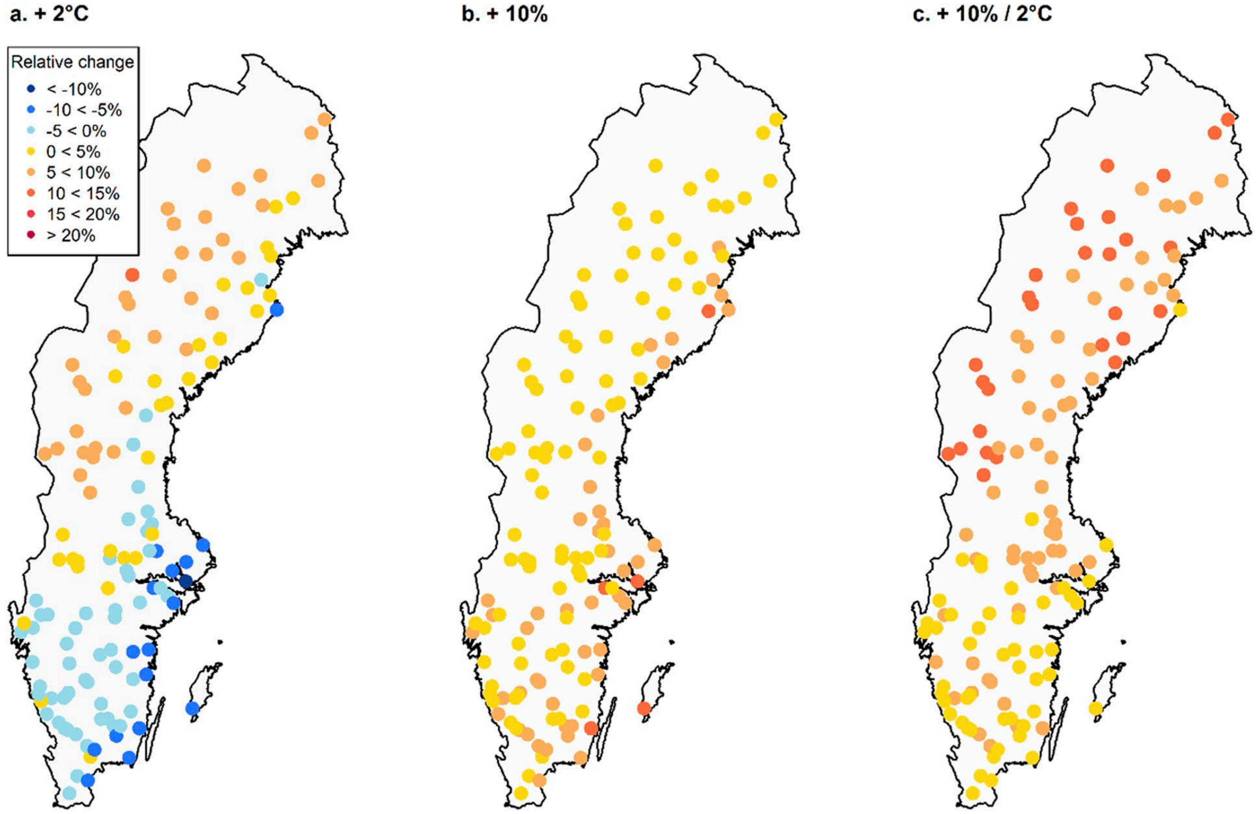


**Figure 4.** Relative change in basal area change (%) after a 20-year simulation with altered input climate data compared with current climate using the hybrid Norway spruce model. The dots represent 140 randomly selected permanent sample plots from the Swedish NFI. Scenarios: (a) = increased temperature by 2 °C, (b) = increased precipitation by 10%, and (c) = increased precipitation by 10% and increased temperature by 2 °C (Goude et al. 2022)

**Keywords:** *photosynthetically active radiation, forest modelling, boreal forests, growth and yield, long-term prediction.*

**References**

Goude, M., Nilsson, U., Mason, E., Vico, G. 2022. Using hybrid modelling to predict basal area and evaluate effects of climate change on growth of Norway spruce and Scots nine stands. Scand J Forest Res. Jan 2;37: 59–73.

**Acknowledgements.** The authors gratefully acknowledge the entire team at the Swedish National Forest Inventory and Unit for Field-based Forest Research, SLU, for providing field data and support. We also want to acknowledge the Swedish Meteorological and Hydrological Institute (SMHI) for providing monthly data on solar radiation and climate throughout Sweden.

# APPLICATION OF SONIC TOMOGRAPHY (PICUS 3 SONIC TOMOGRAPH) TO DETECT AND QUANTIFY HIDDEN WOOD DECAY IN ESTONIAN SPRUCE STANDS

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Tree mortality plays a critical role in forest development and function, but remains one of the least understood elements in growth and yield estimation. Economic damage caused by *Heterobasidion sp*. and *Armillaria sp*. is common problem in forestry. Second and older generation Norway spruce (*Picea abies* L. Karst.) stands growing on soils with high lime content and Scots pine (*Pinus sylvestris* L.) growing on fresh and temporarily dry sandy soils are most suspectible to fungal infection in Estonia. As the vast majority of local forests are managed, the risk of infection is increased due to exposed surfaces and stumps. External signs of fungal infection are often insufficient and may lead to inaccurate stand vitality estimation. Therefore, a more precise method in stand vitality valuation in Estonia is needed. The aim of the research was to assess the viability of the sound tomography in stand health evaluation. We hypothesized that the tomograph assessment is more accurate than the visual assessment for detecting decay damage in Norway spruce. The study was conducted in two study areas, which were located in middle-aged spruce stands dominated by Norway spruce. Study areas were selected in stands, which were damaged by bark stripping and designated for sanitation harvest by local forest managers in near future. A total of 50 sample trees were evaluated visually from a living tree, with PiCUS 3 Sonic Tomograph and from tree stump following the clear-cut (Figure 1). Bark stripping by wild life, cavities, crack, wind damage, fruiting bodies, resin flow and other visual signs were used to decide tree vitality in first phase of the study (visual assessment). Of the 50 sample trees examined, 23 were classified as healthy as no visible defects were recorded. Other 27 sample trees were classified according to severity of defect (minor, medium, major). Same sample trees were evaluated in the second phase

of the study with PiCUS 3 Sonic Tomograph. Of the 50 tomograms, 38 were assigned as healthy. Other 12 tomograms were classified according to solid wood percentage measured by tomograph. All trees were assessed for decay after clear-cut in last phase of the study. Of the 50 trees stumps examined, 26 were classified as healthy as decay damage in wood were recorded. Other 24 sample tree stumps were classified according to severity of defect. All available data on visual, tomograph and stump assessment were used to draft the data table, which was used as basis for contingency tables. The Chi-square test statistic and fisher's exact test are both used to evaluate whether there is a relation between the rows and columns in a contingency table (visual assessment compared to stump assessment and tomograph assessment compared to stump assessment). We found relationship ($p$-value $< 0.001$) between tomograph assessment and stump assessment, when major decay damage was present (Table 1). We did not discover relation between visual assessment and stump assessment, indicating that evaluating decay from external signs is not accurate according to our results. Our data also suggests that tomograph is not able to detect early stages of decay such as discoloration, since it has no relevant effect on wood structure.

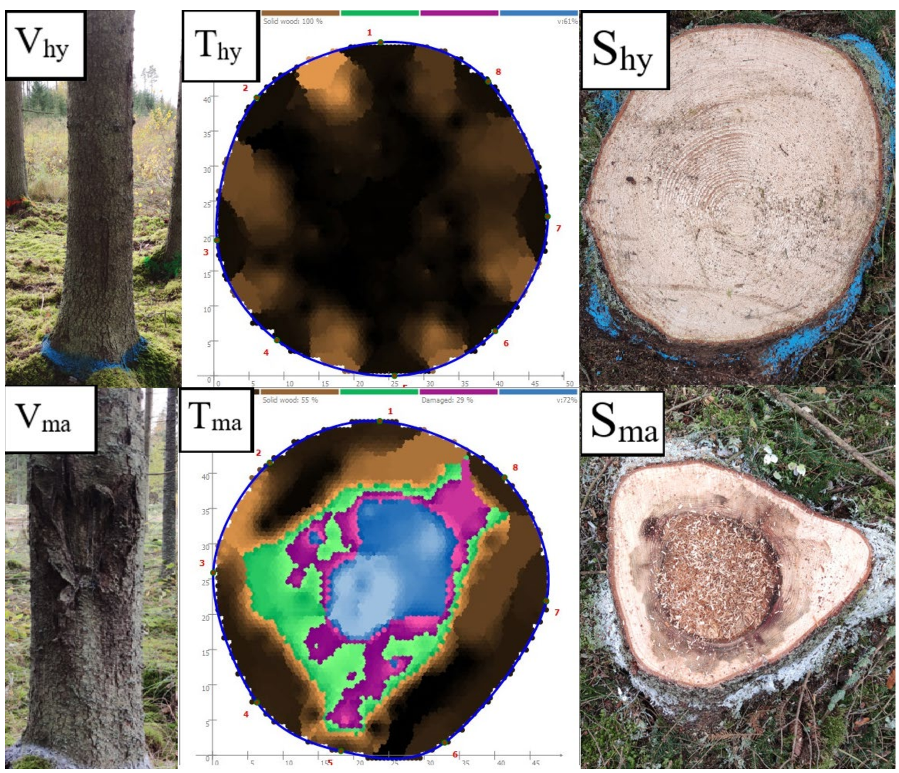


**Figure 5.** Examples of primary assessment classes (healthy sample tree $\mathbf{V_{hy}}$; healthy tomogram $\mathbf{T_{hy}}$; healthy tree stump $\mathbf{S_{hy}}$; sample tree with major defect $\mathbf{V_{ma}}$; tomogram with major defect $\mathbf{T_{ma}}$; tree stump with major defect $\mathbf{S_{ma}}$).

**Table 1.** Fisher's exact and chi-squared test results

| Contingency table | p-value (chisq.test) | p-value (fisher.test) |
|---|---|---|
| $S_{ma} + V_{ma}$ | 0.651 | 0.641 |
| $S_{ma} + T_{ma}$ | < 0.001 | < 0.001 |
| $S_{hy} + V_{hy}$ | 0.382 | 0.272 |
| $S_{hy} + T_{hy}$ | < 0.001 | < 0.001 |

**Keywords:** *mortality, sonic tomography, decay, rot, Picea abies.*

# THE YOUNG FOREST STANDS IN NORTHERN SWEDEN, NOW AND IN THE FUTURE – A HEUREKA ANALYSIS

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The situation for young forest stands in northern Sweden is critical, especially for young Scots pine stands, where many of them today are described as multi-damaged forests. Meaning that multiple damage agents are active in the forest stands simultaneously, resulting in severe damages. The prevalent cause for damage in young stands in northern Sweden are browsing and fungi which cause diseases such as resin-top disease (Cronartium flaccidum, Peridermium pini), snow blight (Phacidium infestans), scleroderris canker (Gremmeniella abietina) and pine twist rust (Melampsora pinitorqua). Individual attacks of any of the fungus or a heavy browsing pressure would alone cause severe damages and lead to reduction in survival, growth and quality of Scots pine trees (Björkman 1948; Martinsson 1985; Martinsson & Nilsson 1987; Bernhold 2008; Matala *et al.* 2020). The combination of these multiple damage agents worsens the situation for the young pine trees and lead to both short- and long-term ecological and economic consequences.

Scots pine and Norway spruce are the dominating tree species in Sweden, representing 43.3 % and 36.8 % of the total standing volume respectively (Nilsson et al. 2021). In northern Sweden Scots pine is more commonly used in regenerations than Norway spruce, almost 70 % of the recently regenerated areas in northern Sweden were established with Scots pine (Ara et al. 2022). However, when these regenerations reach a height of 1–4 m only 30–35 % of them is dominated by Scots pine (i.e., have more than 1500 Scots pine trees per hectare). This means that the aim and intention with the applied regeneration measures, creating Scots pine dominated stands, will not be realized. The questions that arise are therefore, what will these forests develop into and how will they differ from what was intentionally planned?

In this project there are three different scenarios, ÄBIN, SKA15 and potential. The ÄBIN-scenario represent a development of forest stands where browsing pressure and damages is considered. The SKA15-scenario is business as usual, and the potential-scenario represent development of forest stands without damage. The aim of the study was to compare these three different scenarios for the forest in northern Sweden during a 100 year-period and identify differences in growth, volume production and tree species composition. The simulations give insight into how the damaged forests in northern Sweden will develop in the future if current regeneration results continue (the ÄBIN-scenario) compared with modelled stand structure in young stands (the SKA15-scenario) and a hypothetical situation when all regenerations are successful (the potential-scenario). The development of the forests according to the three scenarios is simulated using the Heureka forest decision support system (DSS; Wikström et al. 2011) with data from the National Forest Inventory as starting values.

The first hypothesis is that the potential- and SKA15- scenarios will result in significantly higher growth and volume production compared to the ÄBIN-scenario. The second hypothesis is that potential- and SKA15-scenarios will result in more conifer-dominated forests and more monocultures, while the ÄBIN-scenario will result in more broadleaves and more mixed forests.

**Keywords**: *Pinus sylvestris, simulation, growth, tree species composition, multiple damages.*

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# EVALUATION OF GROWTH MODELS FOR MIXED FORESTS USED IN SWEDISH AND FINNISH DECISION SUPPORT SYSTEMS

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The interest for mixed stands has increased recently since they could provide higher benefits and positive externalities compared to monocultures, although the forest management is more complex and silvicultural prescriptions for them are still scarce. Growth simulations could be a power tool in this sense to develop correct guidelines for mixed stands. Heureka and Motti are two decision support systems commonly used for forest management in Sweden and Finland respectively. They were calibrated and used mostly on pure stands and, thus, how they would perform in mixed stands is currently uncertain. Here, we compiled a large common data base composed by well replicated experimental research sites of mixed stands from Sweden and Finland, to evaluate the performance of the growth models used in Heureka and Motti for mixtures. Basal area growth simulations were compared to observed values at stand level and absolute residual plots were visually examined for different stand mixtures: Norway spruce (Picea abies Karst.)-Birch (Betula spp), Scots pine (Pinus sylvestris L.)-Birch and Scots pine-Norway spruce. We observed that the basal area growth models studied in both decision support systems performed quite well for mixtures. Heureka predictions were no bias regardless species mixture stand composition, but Motti simulations were overestimated for Scots pine-Norway spruce mixture composition. Excepting the former mentioned case, Heureka and Motti could be utilized for forest growth simulation in both countries to evaluate new silvicultural prescription for mixtures in boreal forest.

**Keywords:** *mixed stands, forest decision support systems, Heureka, Motti, forest management.*

# BIOMASS HARVEST IN FIRST THINNING OF BIOMASS-DENSE STANDS AS AN ALTERNATIVE TO LATE PRE-COMMERCIAL THINNING

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Current environmental target in Sweden is to create a fossil free transport sector by 2030 and reach carbon neutrality by 2045, therefore all viable solutions to achieve the goal are being sought. In the European Union, forest biomass is just recently recognized as renewable source of energy while it is the second largest energy source in Sweden. However, there is a strong belief that it is possible to extract forest biomass more efficiently and to a higher extent. Potential of above-ground biomass from whole-tree harvesting could reach up to 6.1 M oven-dry t $yr^{-1}$. In addition, early harvesting in planted coniferous stands are of high interest for the future development of the target trees at final harvest, especially on sites with dense ingrowth of naturally regenerated broadleaves with less economical value. Early competition release for the target trees can be performed manually using brush-saws and with a thin-to waste strategy. Alternatively, the release can be automatized and combined with a commercial incentive by a whole-tree harvest. The mechanical harvest can then be made systematic or partly selective. The machine will harvest in striproads as it forwards through the stand combined with perpendicular corridors where the boom harvest trees along the way. Therefore, studies on potential sustainable biomass extraction have led to discussions on how whole-tree harvesting methods in early thinnings will effect the remaining target trees.

To assess the effects of different thinning patterns on the target trees, we analyze the data from a series of experiments with selective versus systematic whole-tree harvests in young plantations of Norway spruce. The experiments were established in southern Sweden when the mean height of target trees was 6 m, with three blocks and randomized four treatment plots (0.12 ha) per block. Measurements of diameter at breast height and sample tree heights, was made three times; before, directly after, and four to six years after the thinning. Initially, a representative number of the largest trees in each sample plot was selected and defined as dominant and co-dominant trees on each treatment plot, which would correspond to the around 600 trees ha$^{-1}$ (~200 stems of dominant trees and (~400 stems of co-dominant trees) at the time of final harvest.

The five treatments were:

A. Control plots without tree removal, all trees with dbh ≥ 4.5 cm was measured,

B. Manual selective removal of trees, 50 % of the basal area removed,

C. Mechanical systematic harvest of all trees, along 4 m wide strip roads and 1 m wide perpendicular corridors,

D. Mechanical systematic harvest of all trees, along 4 m wide strip roads and 2 m wide perpendicular corridors.

E. Mechanical systematic and partially selective harvest of all trees, along 4 m wide strip roads and flexible 1 m wide corridors.

Where the selective removal (B) was made with traditional pre-commercial thinning (PCT) with a brush saw. The mechanical thinning (C-E) was made with small-size harvester (Valmet 911) equipped with a multi-tree accumulating harvest-head (Bracke C16b) and using a boom-corridor thinning (BCT) method.

We analyzed the effect of the treatments on total periodic annual increment, PAI (m$^3$ ha$^{-1}$ year$^{-1}$) for dominant, co-dominant and all remaining trees. For data analysis we used linear mixed model where site characteristics are used as a random effect (models below). To assess the differences between the treatments, we use multiple pair-wise comparison of sample plot means.

$$PAI_{ij} = \beta_0 + \beta_1 Treatment_i + \beta_2 Volume_j + \varepsilon$$

Were, $PAI$ – periodic annual increment, $i$ – is a treatment index, $j$ – is site index and $\beta_0$ are estimated regression coefficients, $\varepsilon$ – random site characteristics.

We found significant differences in PAI of dominant trees between the control (A) and conventional (B) treatment. There was no significant difference in growth of the crop trees between traditional treatment B and mechanical harvest (C-E) and between control (A) and C to E treatments in all tested groups.

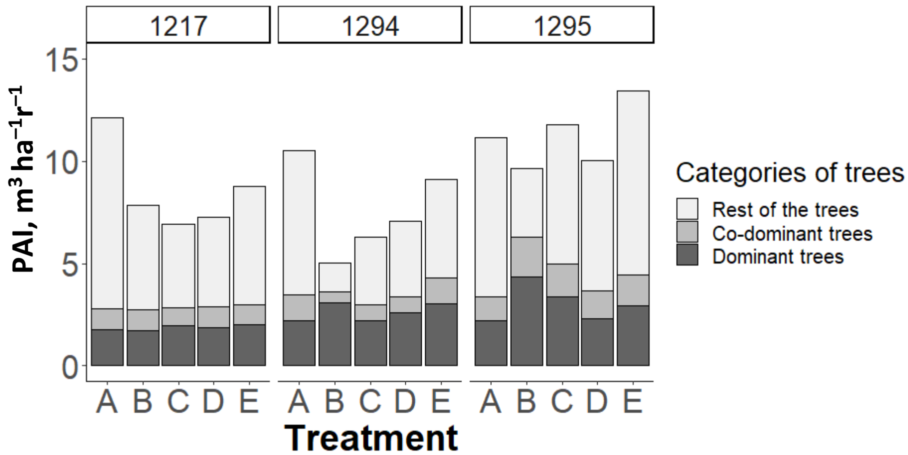


**Figure 1.** Periodic annual increment (PAI) of crop trees by treatments, in $m^3$ per ha per year.

**Keywords**: *small-diameter tress, whole-tree harvesting, biomass, thinning, PCT, boom-corridor thinning, BCT.*

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# APPLICATION OF NON-LINEAR MIXED MODELS IN GROWTH ESTIMATIONS

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For estimation of diameter-height relationships from single-tree-level data of observed diameter at breast height measurements we used non-linear mixed models. The non-linear mixed effects model approach has benefits in capturing inter-individual variability in data. This can be applied to estimate species specific growth estimates and ensemble growth estimates. The ability to allow for ensemble estimates makes it possible to reach a well-defined growth model even when the fixed model approach fails to produce a fit of a species.

In our work (Nigul et al. 2021), we applied the non-linear mixed effect model approach to two different growth curves, the Chapman-Richards model and the Näslund model. In both cases, we found possibilities to augment the single species estimations via the ensemble estimator in cases where the fixed approach failed.

We used data from the Järvselja old growth forest and of the old, but managed, forest stand at Laeva to conduct the modelling. In both cases, the data show clustering for some species which lead to difficulties in parameter estimation using fixed effect models only. For the data handling and modelling we used Jupyter Docker stack (https://jupyter-docker-stacks.readthedocs.io) with the IRkernel (https://github.com/IRkernel/IRkernel).

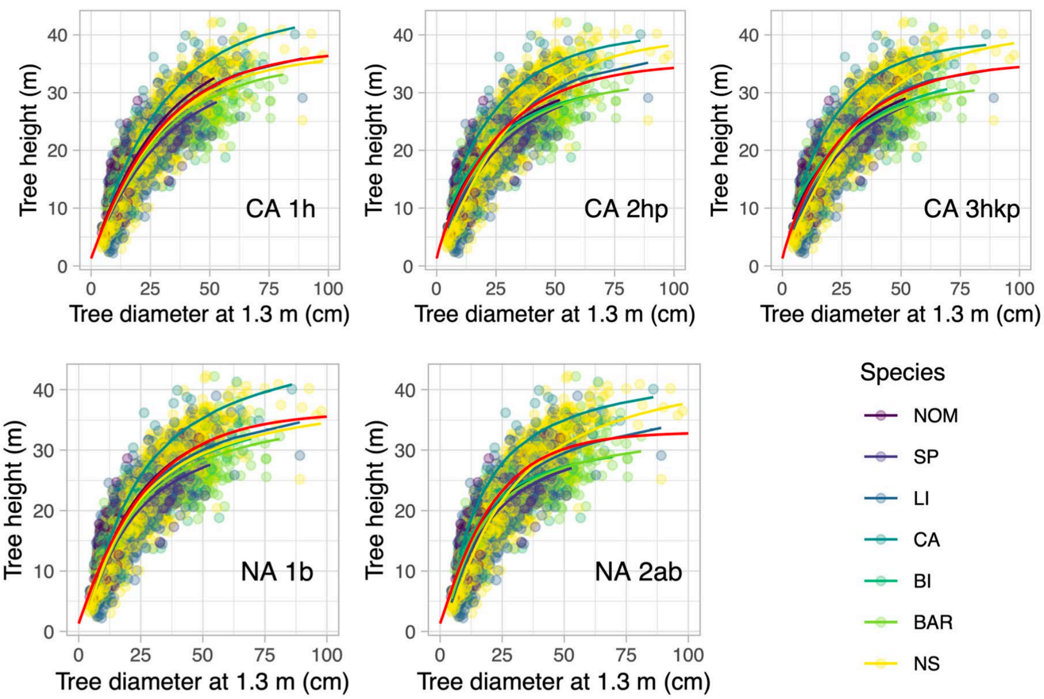


**Figure 6.** Chapman-Richards (CA) and Näslund (NA) models of the Järvselja old-growth forest diameter-height relation. The number tells how many parameters were used as random effects and the color codes denote the species, BI = birch (silver birch and downy birch (*Betula pubescens* Ehrh.)); NS = Norway spruce; BAR = black alder; SP = Scots pine; LI = lime family; AH = European ash (*Fraxinus excelsior* L.); NOM = Norway maple (*Acer platanoides* L.); CA = common aspen. The red line is the estimated ensemble model.

**Keywords:** *non-linear, mixed effect, growth models, old-growth forest, managed forest.*

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# DEVELOPMENT OF SPECIALLY ADAPTED LED LUMINAIRES FOR PROVIDING EFFICIENT AND ENERGY EFFICIENT TREE PROPAGATION AND ROOTING PROCESS

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Micropropagation of forest reproductive material is becoming more significant as means for seedling production and its results strongly depend on artificial lighting which can induce species-specific responses. Light-emitting diodes (LEDs) are becoming more popular as artificial lighting source because combinations of various spectral compositions and intensities in obtained luminaires can significantly affect seedling growth. Regarding micropropagation of woody plants *in vitro* effect of such combinations is slightly studied.

In this research we analysed morphological, physiological and anatomical characteristics of silver birch (*Betula pendula* Roth.) and hybrid aspen (*Populus tremuloides* Michx. × *P. tremula* L.) clone *in vitro* cultures under LED luminaires of three spectral compositions: (1) red and blue light (RB); (2) red, green and blue light (RGB); (3) red, green, blue, yellow and orange (RGBYO); Philips Master TL-D 36W warm white fluorescent lamps were used as control. Photon flux density for all luminaires was 40, 70 and 110 ± 10 μmol $m^2$ $s^{-1}$ with 16/8 h (day/night) photoperiod.

All morphological, physiological and anatomical characteristics were significantly affected by clone, while effect of light was both direct and clone specific. In general, morphological, physiological and anatomical characteristics showed different responses to different spectral compositions of both LED and fluorescent luminaires. Studies show that early development has long-term effect on seedling growth, thus luminaires with spectral composition and intensity individually adjusted for specific requirements of genotype groups could prove useful for sustainable micropropagation of forest reproductive material.

**Acknowledgements.** This research is supported by the European Regional Development Fund project: "Development of specially adapted LED luminaires for providing efficient and energy efficient tree propagation and rooting process" (No 1.1.1.1/18/A/138).

# GROWTH AND YIELD MODELS FOR CLONAL HYBRID ASPEN PLANTATION IN SOUTHERN FINLAND AND SWEDEN

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Hybrid aspen (*Populus tremula* L. × *P. tremuloides* Michx.) is a highly prospective tree species, with regards to bioenergy and timber production, especially in the region of Northern Europe. Although it was known as a fast growing species with importance, there is still lack of studies on the modelling issues from tree- to stand-level for growth and yield. The main objectives of this research were to offer the key findings from the recent publications and to share ongoing modelling issues on growth and yield of hybrid aspen. We used the repeatedly measured data of clonal hybrid aspen plantation in southern Finland. Also, Swedish data were additionally included for the models of stand characteristics. The experiments were orignially established to study the effect of different planting density (400 to 1600 trees/ha or 5.0 m × 5.0 m to 2.5 m × 2.5 m spacing) in Finland and clonal performance with thinning (light, moderate, and heavy) in Sweden. Considering the nested plot design of each experimental location, we thus applied the linear or nonlinear mixed-effect models depending on response variables, goals, and model types.

We have studied on several modelling topics including site index, diameter distribution, height-diameter allometry, and stand characteristics. Dominant height and site index models were successfully developed with the variable of initial planting density. The models indicated the dominant height grew faster with higher initial planting density within the range of fitted dataset with the age of 3–20 years. We finally proposed two types of models in line with the effect of initial planting density for general practical purpose. To suggest the optimal approach for diameter distribution, four kinds of stand diameter statistics were compared on 2-parameter Weibull function with parameter recovery method: arithmetic mean diameter (D), basal area weighted mean diameter (DG), median diameter (DM), and basal area weighted median diameter (DGM). With the goodness-of-fit statistics of Kolmogorov-Smirnov and error index as well as the plot

illustration, it figured out that DG was the most accurate and stable whereas DM showed the worst fit in the analysis.

Näslund's curve was fitted well to the height-diameter relationship with additional stand characteristics and so we finally provided two possible models. The first model included DG, basal area weighted mean height (HG), and stand basal area (BA) while trees per ha (TPH) was additionally included in the second model. Both options were appropriate for prediction, but still the first model can generally be more applicable considering the logical behaviour and sensitivity to DG and HG rather than BA and TPH. To develop the models for predicting the stand characteristics, BA, DG, and HG were targeted as response variables. We found that stand age and site index were highly significant to all the models. Also, TPH, 30-year average temperature sum, and dummy variable of thinning after 5 years were significant to BA and DG models. In case of HG model, dummy variables of agricultural land and clay soil were significant. Overall, it was considered that the developed models are highly practicable for clonal hybrid aspen planatation in southern Finland and Sweden.

**Keywords:** *Populus tremula × P. tremuloides; clonal plantation; Chapman-Richards function; Näslund's height curve; nonlinear mixed-effects model; Weibull distribution; parameter recovery.*

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**Acknowledgements.** Our authors highly acknowledged the Natural Resources Institute Finland (Luke) and Skogforsk, which provided empirical data for the analysis of this study. This study was carried out with the Academy of Finland Flagship Programme UNITE.

# NONLINEAR WEATHER-GROWTH RELATIONSHIPS OF NORWAY SPRUCE AND SCOTS PINE IN HEMIBOREAL FORESTS

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The accelerating climatic changes apparently are exceeding the rate of natural adaptation of populations of trees, which have often specialized to certain local conditions, thus highlighting the growing necessity for adaptive forest management, inclusion assisted gene flow. For this, a solid scientific background of expected effects is highly advantageous for increasing sustainability of forest productivity. Considering climate and meteorology among the main drivers of tree increment, weather-growth relationships can be highly informative regarding projections of sustainability and productivity. Weather-growth relationships of five provenances of Scots pine from the eastern Baltic region differing by productivity growing in five trials in Latvia and northern Germany were assessed using dendrochronological techniques. Considering the length of the climatic gradient, non-linear weather growth relationships were assessed using generalized additive mode. Meteorological conditions related to moisture availability were identified as the primary drivers of increment with conditions during the dormant period having secondary effects. The responses of increment to the identified meteorological drivers were nonlinear implying disproportional linkage with climate. The responses differed by provenances according to their field performance, however, in contrast to expectations, the more productive provenances were also more sensitive to meteorological fluctuations, particularly to extremes. This highlights that ability for rapid adjustments of increment according to current meteorological conditions to be highly advantageous trait under changing climate in longer term. Accordingly, assessment of productivity in combination with sensitivity is advantageous for increasing sustainability of forest growth, particularly when screening for provenances to supplement local breeding populations.

# CLIMATE CHANGE MITIGATION POTENTIAL OF AFFORESTATION IN ORGANIC SOILS IN FARMLANDS

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Afforestation of organic soils in croplands and grasslands is potentially the most significant measure to reach short term climate change mitigation targets in land use, land use change, forestry and agriculture sector in Latvia and to ensure implementation of the long term targets in the second half of the 21st century by combination of sustainable intensification of forestry and agriculture and afforestation of organic soils. The total implementation potential in Latvia is about 152 kha; however, nature conservation related restrictions (retaining of biologically valuable grasslands) may limit climate change mitigation potential of this measure.

Forest growth model can be used to estimate carbon stock changes in living and dead biomass, as well as in harvested wood products (HWP). Values typical for the highest forest site fertility classes can be used in calculation; however, the afforestation period and the rate of $CO_2$ removals depends from quality of soil preparation, planting material and early tending. The highest uncertainty of the effect of afforestation on greenhouse gas (GHG) emissions is characteristic for the first 2 decades after afforestation, which are the most important to prove the contribution to the short term climate change mitigation targets. Tier 2 methods can be used to estimate impact on soil carbon stock change and GHG emissions from soil. The net GHG reduction potential in case of 70 years long rotation is up to1855 tons $CO_2$ eq $ha^{-1}$ (26 tonnes $CO_2$ $ha^{-1}$ $yr^{-1}$). The net GHG reduction potential in case of 40 years long rotation is 1218 tonnes $CO_2$ eq $ha^{-1}$ (30 tonnes $CO_2$ $ha^{-1}$ $yr^{-1}$). However, in large scale natural disturbances and lack of proper management may reduce the proposed effect by up to 50%. Actual GHG emission reduction potential may smaller also because the GHG emissions from soil in cropland in grassland can be overestimated in temperate climate zone.

Areas suitable for the measure are marginal, low-valued grassland and cropland on organic soil where afforestation is permitted according to national and local regulations. The measure has long term effect, continuing for several rotations. The first peak of the net $CO_2$ removals in living and dead wood, litter and HWP in case of conventional management systems is 71–91 years according to the age based rotation periods, but for intensified plantation forest scenario it is 40–50 years. Even shorter accumulation period (20 years) till the first peak can be considered for poplar plantations.

Effect on soil depends from carbon stock in organic soil, respectively it depends from carbon stock in soil at steady state and difference in decomposition rate. Two alternatives are provided here to demonstrate different options – intensified and extensified coniferous forests. Use of conventional management systems for spruce or pine would lead to increase of $CO_2$ removals and reduction of GHG emissions by 79 mill. tons $CO_2$ in all carbon pools during 20-years period. Intensified management and shortening of rotation would lead to 90 mill. tons $CO_2$ removals during 20-years period. It should be noted that GHG emissions from soil in cropland and grassland may be overestimated, therefore the emission reduction might be smaller. GHG emissions from soil in nutrient-rich organic soils in forest land can also be smaller than the estimated emission rates, which will also affect GHG emission reduction rate.

Afforestation of organic soils in the most cases is restoration of natural ecosystem in previously deforested lands and in spite of potentially negative impact of species closely associated with artificial landscapes (cropland and grassland) afforestation contributes to formation of close-to-nature forest dominant ecosystems typical for Latvia. Efficient use of abandoned farmlands with organic soils, which are not producing any added value, contributes to social and economic sustainability and increase public value of the land since forest lands in Latvia are accessible to general public in contrast to non-forest lands.

Cost of GHG emission reduction, considering 20-years calculation period and 5% discount rate, in case of extensive management is 6 € $ton^{-1}$ $CO_2$. Total needed investments in current prices are 264– 282 mill. € depending from selected scenario (1740–1860 € $ha^{-1}$). Cost of emission reduction might change, depending from the actual emissions from soil in cropland, grassland and forest land.

Additional increment and outputs of roundwood and forest biofuel will create input to energy sector and wood processing industry. Wood ash can be utilized in afforested organic soils. Afforestation of large areas of organic soils might affect farm production potential, however, the most of organic soils are nutrient-poor and extensively utilized and can be substituted by underutilized mineral soils.

There is no dedicated support for afforestation of organic soils in in Latvia; however, it is not forbidden and organic soils can be afforested within the scope of climate change mitigation actions of Rural Development Program.

**Keywords:** *organic soil, afforestation, greenhouse gas emissions, climate change mitigation.*

**Acknowledgments.** The study is implemented within the scope of LIFE OrgBalt: "Demonstration of climate change mitigation potential of nutrients rich organic soils in Baltic States and Finland" (LIFE18 CCM/LV/001158).