NB NORD2020
FOREST OPERATIONS
FOR THE FUTURE

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SNS Nordic Forest Research

skogforsk

CONFERENCE PROCEEDINGS
edited by Rolf Björheden, Skogforsk and Ingeborg Callesen, IGN, University of Copenhagen

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OPENING SESSION

Foreword and welcome address

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First of all, welcome to this biannual assembly of experts in forest operations.

The conditions for science exchange and cooperation, which is the *raison d'etre* for the Nordic Baltic Network for Operations Research and Development, **NB NORD**, has certainly changed with the spread of Covid19.

New technologies have, however, made it possible for us to go ahead with our final joint conference. I very much hope that we will soon be able to arrange physical meetings, but also feel confident that the novel teleconferencing technologies will serve us well as we launch our impressive programme!

The conditions for forestry are changing – can forestry change with them?

For a very long time, forestry could develop at loose reins. There were demands, for sure, but these demands concerned the quality, volume and cost of output. The mode of operation – *how* the demands were met - was a secondary issue. A large part of the population were rural dwellers with a well-established utilitarian stance towards the exploitation of natural resources. City folks had other things on their minds, than how insect populations were affected by their consumption of fuelwood, boards and battens.

In the last 50 -60 years, however this has changed. Forestry is now subject to the scrutiny of a vocal, and sometimes eloquent, well educated, resourceful and environmentally concerned public. While the spokesmen of this opinion are sometimes very critical, they ultimately represent the patrons of forestry, our clients. We are well advised to listen to and decode these messages. For any successful business, it is always good to know one's customers!

And there is no cause to use only the darkest colours of the palette when sketching the future for forestry. The current visions for global development, e.g. as they are expressed in the UN Sustainable Development Goals include moving towards a bioeconomy with cascading, circular material flows for production of sustainable goods and services.

In a SWOT analysis of the forest sector, such visions provide **Opportunities,** since forestry definitely has the possibility to be sustainably managed as well as the capacity to fulfill very large basic material needs of a growing global population. If we convincingly show that we meet the requirements, this will be a factor of **Strength** for forestry, since the nature of the industry include decentralized production and support to the rural economies that are currently under hard pressure.

But at the same time, the new environmental concerns may be described as *Threats* to forestry, as long as we neglect or deny the problems coupled to unsustainable production practices: detrimental effects on biodiversity, to the output of ecosystem services other than raw materials, degradation of soils and loss of productivity etc.

The *Weakness* of forestry as an industry may well be that we are burdened by the tradition of primarily looking for increased productivity as a means to upholding profitability, and that we are not used to engaging in a dialogue with the customers with the aim of developing our business to comply with the changing demands and needs.

When we look through the list of contributions to this conference, we are, however, reassured. Many of the presentations address the classical (and still necessary) basic topics of increasing efficiency, reducing waste and improving quality of the supplied products. But the contributions dealing with improving forest operations with respect to the fundamental criticism from the environmentally concerned opinion are just as many. Clearly, forestry *can* change!

We believe that gradually ameliorating the negative effects and risks of our industry, be it soil productivity, water quality, conservation of natural, biodiverse ecosystems, recreational needs or improved working conditions and attractiveness are important. If we fail, we risk to lose our current "license to operate".

From the list of topics to this Conference, *Forest Operations for the Future,* it is clear that forest operations research in the Nordic Baltic area and elsewhere is fully committed to this process. The conference sets a door ajar for anyone interested in how forest operations will evolve in the future!

Very welcome to NB NORD2020!

Rolf Björheden

NB NORD Co-ordinator

Skogforsk, Sweden

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Conference organizer
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Forest operations for the future in Skogforsk's R&I strategy 2021-2024

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Skogforsk's mission is to develop and provide knowledge that promotes sustainable development in forestry for the benefit of society. Our main guiding document is the *Research and Innovation strategy* (R&I), which has just been revised. The new strategy was developed in close collaboration with partner companies considering needs in the sector in relation to megatrends and developments in the surrounding world.

Six main research areas are defined, e.g. systems for forest operations, value chains, digitalisation and silviculture. More specific examples include R&I on fossil-free operations, remote control and automation, advanced tools using machine data in combination with other data sources, and data communication.

As compared with the predecessor the new strategy highlights climate-related issues, and stresses digitalisation and automation as enablers with rapid development. Research cooperation across disciplines and countries is emphasized, particularly with Nordic and European partners.

A transition to forest-based bioeconomy requires R&I focusing on sustainable growth of more biomass and value creation in supply chains enabling use of the full biomass potential. Efficiency should go hand in hand with considerations to nature and working environment. Disturbance and variations due to climate, weather and market must be handled.

Clearly, to be successful forest operations cannot be an isolated area of research, but cooperation with other fields and disciplines is necessary. This also underlines the importance of producing syntheses based on existing research to facilitate decision-making and deeper understanding of common problems in research related to forestry.

Forest operations for the future in Skogforsk's R&I strategy 2021-2024

Carbon balance of Nordic-Baltic forestry

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Keywords: *Climate change, carbon dioxide, biomass production, forestry*

Background

The complex processes driving global climate are not yet fully understood. But sophisticated climate models strongly support the theory that 'greenhouse gases' contribute to global warming. Today, it is accepted that the carbon dioxide levels in the atmosphere is influencing the climate, through the greenhouse effect. The atmospheric level of CO_2 has risen by 40 percent in the last century, mainly due to human activities such as deforestation and accelerating mobilization of fossil carbon sources.

The climate issue, thus, largely becomes a matter of managing and controlling the carbon flows. This gives forest management a key role, because forests have the potential to capture large quantities of carbon dioxide from the atmosphere and store carbon through their increment. Products based on forest biomass also store carbon and can reduce the use of carbon from fossil sources.

It has become increasingly important to evaluate the impact of forestry on the carbon balance and, thus, the climate. How does forestry affect the dynamics of the carbon cycle? What management strategies and approaches are feasible options when adding the perspective of carbon sequestration and mitigation of climate change to that of ecologic, economic, and social sustainability?

This study concerns the carbon balance of forests in the Nordic-Baltic region, denoting Denmark, Norway, Sweden, Finland, Estonia, Latvia, and Lithuania. The 33 million inhabitants of these seven northern countries make up 5.5 per cent of the total European population, but the 74 million hectares of forest in the region correspond to 35 percent of the continents[1] total forested area. A long tradition of forestry and a rich supply of woody biomass has made forestry an important part of the region's economy. The regions cold climate, high welfare and energy intensive industry contribute to emissions above the European average: 6.8 compared to 6.4 t CO2/capita. The region's territorial emissions are 220 M t CO_2eq/year.

Carbon dynamics of natural vs sustainably managed working boreal forests

In a natural forest, increment and decomposition balance over time, apart from a small proportion of organic carbon transferred to the soil. Therefore, a natural forest is practically climate neutral from a carbon balance point-of-view.

Forests cover 74 million hectares of the Nordic-Baltic region, of which around ¼ (over 18 million hectares) are excluded from forestry, mainly for environmental reasons. The large forest resource of the region makes forest management practices important for the EU climate policy and for the contribution of the European continent to fighting the rising levels of carbon dioxide in the atmosphere. No other sector manages such large flows of carbon as those resulting from annual forest growth, logging, and manufacture on wood-based products. The forest sector's influence on the atmospheric carbon dioxide content can be summarized as follows:

- Net growth of forests assimilates carbon dioxide from the atmosphere.
- The carbon is stored in the biomass of the trees and in the forest soil.
- Products based on woody biomass prolong the carbon storage period, and substitute for fossil-based products, thus reducing the supply of "fossil" carbon dioxide to the atmosphere.

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[1] Excluding Russia

Material and Methods

This meta-analysis is based on assessment of previous research and on compilation of official national and international statistics concerning emissions, basic forest and forestry data. Conversion factors are based on data from scientifically published reports. The material has been complemented with a query to experts from the respective countries participating in the NB NORD CAR.

The calculations of emissions from forest operations are based on average energy consumption per work unit (hectare, kilometer, cubic metre etc) as reported in various studies. The most complete and current (2002-2016) datasets have been found for Finnish, Norwegian and Swedish forestry. Since these three countries represent 80 per cent of the regional inventory and 82 percent of the annual harvesting, the figures are believed to be reasonably accurate.

A carbon balance for the Nordic-Baltic forests

This section elaborates the effect of Nordic-Baltic forests on the concentration of atmospheric carbon dioxide. The carbon balance varies widely between different areas and forest types, depending on climatic gradients, soil moisture, soil type, management, etc. The data presented here are based on averages for whole countries and cannot be expected to represent smaller regions.

To elaborate a carbon balance for the Nordic-Baltic forests, we need information on

- The standing inventory, converted to the amount of carbon stored in the trees' biomass
- The proportion of softwood and hardwood respectively (the proportion of carbon in the biomass differs, mainly due to different lignin content)
- Store of Soil Organic Carbon (SOC) in the forest soils
- Inventory dynamics (net effect of growth, felling and other loss)
- Impact of forestry on SOC
- The carbon dioxide emissions by forest operations

Carbon pool in forests and forest soils

The total biomass on all forest land in the NB region added to 9.46 billion m^3st ob, including 548 M m^3st ob (6 %) dead standing trees. This volume was recalculated into a corresponding figure for the total dry biomass of the whole trees; 7.28 billion t DM.

Of the total biomass, deciduous trees make up 24.6 %, with a carbon content of 48 % while the remaining coniferous biomass has an assumed carbon content of 52 %. The carbon fixated by the region's forests could thus be calculated to 13.6 billion t CO_2eq.

A portion of the carbon fixated through photosynthesis is transferred to the forest soil during the decomposition of litter and dead trees. Over time the pool of SOC becomes significant. Large differences in climate, vegetation, humidity and soil conditions affect the conditions for both growth and degradation. The average SOC levels vary from around 40 tonnes of carbon per hectare in the north to over 160 tonnes in the southern and western parts of the region. The average SOC stock on the region's forest soils computed to 93.9 t C/ha, i.e. a total SOC stock in forest soils of 7 billion tonnes corresponding to over 25.7 billion tonnes as CO_2eq.

The total carbon in tree biomass and soil organic carbon corresponded to 39.3 billion tonnes CO_2eq.

Carbon flux in the Nordic Baltic forests

The carbon stock levels in forests are affected by dynamic processes such as yield, harvesting and other loss of biomass. Management practices and policies will also impact the carbon stock in biomass and soil. A long-term flux found in the national forestry statistics is the very significant increase of the carbon pool of the standing inventory. The inventory has doubled from approximately 4 billion m^3st ob in the early 1900's to the current 8.9 billion m^3st ob, in spite of the short term flux in the form of extensive annual harvesting which has extracted around 9 billion m^3st ob from the region's forests during the same period.

The current regional flux due to annual yield, harvesting and other losses of the Nordic-Baltic region's forests in terms of CO_2eq is presented in Table 1. The region's forests annually assimilate over 450 M t CO_2eq of which almost 80 M t are added to the forest inventory after deduction for annual felling and other losses.

Table 1. Annual yield, harvesting, other loss and inventory change in the NB region as m^3st ob, and as t CO_2eq.

	Annual yield (all forest land)	Annual harvesting	Other loss	Annual net inventory change
m^3st ob/yr	314 319 000	218 236 000	41 219 000	+ 54 864 000
t CO_2eq	**451 603 000**	**313 555 000**	**59 221 000**	**+ 78 827 000**

The dynamics of soil organic carbon (SOC) are also affected by forestry. When a stand is harvested, the continuous supply of organic carbon to the soil is interrupted. After harvesting, SOC increases as a result of the large amounts of felling residues, especially root systems, which decompose after felling. During the plant and young forest phase, SOC levels decrease as a result of a low litterfall. It will not reach the level that prevailed at the time of felling until the new forest has reached an age of about 30 years.

The average stock of SOC in forest soils, 94 tonnes C/ha, has been accumulated following the Quaternary glaciation, a period of some 10,000 years. Representing the SOC formation as a linear process, an annual average of 9.4 kg C/ha has been stored in the forest land. A crude estimate of the loss of annual build-up of SOC would then be that 30 years are lost, corresponding to about 282 kg of C/ha and rotation period. The rotation periods in the NB region vary from some 50 to 150 years. If an area-based average of 100 years is assumed, forestry, through its felling, reduces the accumulation of SOC on working forest land by -2,5 to -3 kg C/ha (Table 2).

Table 2. Annual formation of SOC, on forest soils of the Nordic Baltic region as t C/year and as t CO2eq/year.

	Working forest land	Excluded forest land	All forest land
SOC formation, kg C/ha, yr	6,6	9,4	7,0
Total SOC formation, t C/year	372 000	171 000	543 000
Total SOC formation, as t CO_2eq/year	**1 365 000**	**628 000**	**1 993 000**

Forest operations entail emissions of carbon dioxide, not only from forest machines of various kinds, transports, and forest road maintenance, but also from greenhouses where plants are grown, from the production of fertilizers etc. The size of the emissions depends partly on the amount of work (as area, volume etc.) but is also affected by regional conditions such as tree size and transport distance.

An annual regional logging volume of 218 million m^3st ob was assumed. Another 15 million m^3s of forest residues added. The energy use was transformed into litres of diesel per harvested m^3st ob. (One litre of diesel was assumed to emit 2,64 kg CO_2 when combusted). The results, presented in Table 3 show that the total energy consumption of forestry in the region corresponds to 913 000 m^3 diesel, or 4,3 l diesel per harvested m^3st ob. Silvicultural treatments account for 6 %, logging and terrain transportation for 41 % while secondary transportation and forest roads contribute 53 % of the total energy consumption. Expressed in terms of CO2eq-emissions, forest operations emit around 2,4 million tonnes CO_2eq/year.

Table 3. Annual use of energy and emissions of carbon dioxide in forest operations in the Nordic Baltic region.

	Energy use as m^3 diesel	Per cent	Emissions, t CO_2eq
Silviculture	53 930	5,9	142 375
Logging and terrain transportation	376 233	41,2	993 255
Secondary transportation and forest roads	482 412	52,9	1 273 568
Total	**912 575**	**100**	**2 409 199**

The carbon balance of Nordic Baltic forests
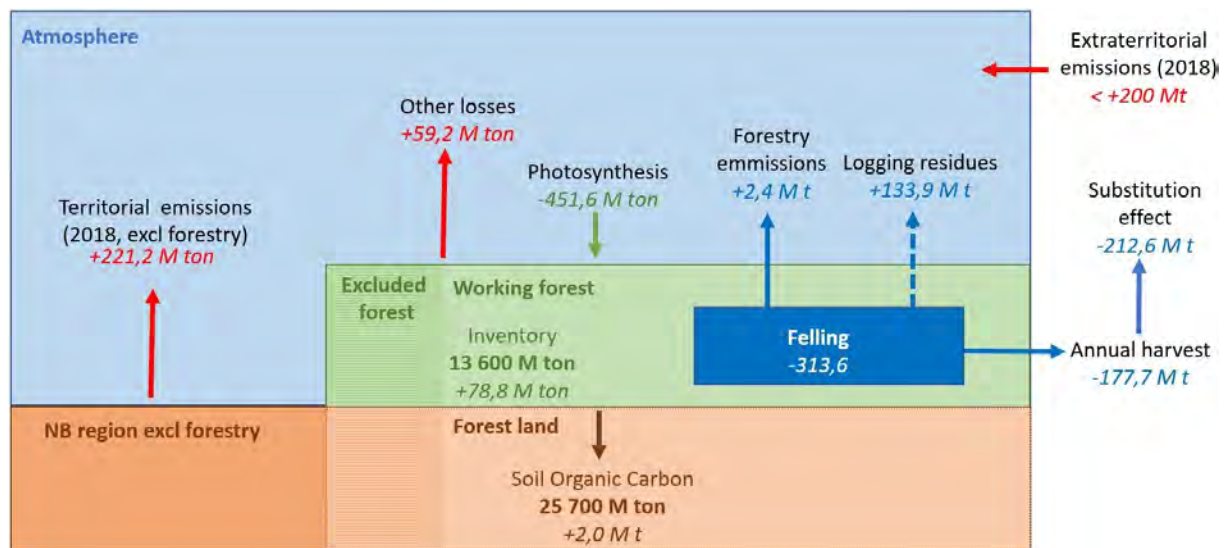
Figure 1. Carbon pools and annual flux of carbon (as M t CO₂eq) in the Nordic Baltic region.

As seen in Figure 1, the net effect of the forest sector is that some 80 M t CO_2eq/year add to the carbon pools in vegetation and soil and another 180 M t CO_2eq/year are extracted as feedstock for the industries if the forest sector. The products of the forest sector reduce the fossil emission rate by approximately 210 M t CO_2eq/year. These figures should be compared to the annual emissions from the region: territorial emissions of 221 M t CO_2eq/year and extraterritorial emissions just under 200 M t CO_2eq/year.

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Various official forest statistics from the NB NORD member countries.

Future research and innovation needs within forest operations the coming four years – a Swedish perspective

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The presentation will address past, recent, and future R&D in forest operations at Skogforsk, specially the R&D needs expressed by members of the board and advisory groups for the coming four years period.

Skogforsk, the forestry research institute of Sweden, refresh its research agenda every fourth year. Since the start in 1992 the institute has been lucky to gain confidence from both member companies and government to refresh its research agenda and financing every fourth year. Skogforsks budget for areas related to secondary production is approximately fifty percent of the total and the area of forest operations holds a budget of approximately SEK 40 million, 0r 30 man-years.

For the coming four years period the board has specially pointed at R&D-efforts addressing operations which are automated, remote controlled and fossil free. Mechanized silviculture, i.e. automated, high precision scarification gains extra focus due to recent problems to attract workforce during the Covid-crisis.

Keywords: Research and innovation needs, automation, remote control, fossil free

Opportunities for forestry automation using a custom off-road machine

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Introduction

As we speak, the world undergoes disruptive transformation in many transport sectors towards increased autonomy. In the automotive industry for example, where autonomous driving is a billion-dollar industry, the self-driving car is forecasted to be on the market with full autonomy at the earliest 2021 (Fagella 2019). In forestry, machines are operated manually with an operator situated on the machine, where in other industries teleoperation and automatic controls have found its way to practice (Parker et al. 2016). Such transformation in forestry is still lagging although R&D-activities have been conducted to make some operations less operator dependent. Full automation of machine navigation and implements for forestry operations are still years away. At Luleå University of Technology (LTU), a fully reconfigurable "open-source", 10 tonne off-road machine has been manufactured serving as a platform for research in autonomous forest operations (Fig. 1.).

Figure 1. The final realisation of the customisable off-road machine, June 2020.

Initially, the needs to develop such machine were expressed by researchers and companies throughout northern Sweden. Those interviews showed the necessity of a platform for R&D and testing of autonomous forest operations as a solution for the underlying needs for streamlining the whole value-chain (Lideskog et al. 2015), reduce machine size to lessen rut formations (Björheden & Lundström 2018), reduce operator injuries which is relatively high (Swedish Work Environment Authority 2018) and serve as a R&D driver in an industry sector where large endeavours in technology development are hard to finance.

With these needs in mind, the off-road machine was designed and manufactured at LTU and is now going to be used in several research projects focused on crane automation, scarification with soil inversion technique, terrain object identification and avoidance, and more.

In this paper, general opportunities by utilisation of this off-road platform both for researchers and companies working with forest automation development is identified. In addition, an adaptable soil inversion device has newly been developed and manufactured at LTU and is the first device to be

tested having the off-road machine as base. The design and functionality of the device will also be reported.

Material and methods

Developing a modular off-road machine

In 2014, an idea was formed by people at the Swedish University of Agricultural Sciences (SLU), the Cluster of Forest Technology and LTU, who envisioned a machine that was the clean slate needed to reshape today's view of how forest machines could and should be designed, given the emerging technologies of teleoperation, automated forest equipment and autonomous navigation. As Swedish forest technology companies got involved in the needfinding process, an image of a modular, reconfigurable machine was made that would enable researchers to easily configure the machine for different testing scenarios, such as scarification, planting, crane work, and at the same time work with autonomous navigation (initial design, see Fig. 2. left).

In 2017, funding was provided by the Kempe Foundations and LTU's Lab fund to design and manufacture the machine. A group of mechanical engineering students were given the task, which in early 2018 was finalised with a manufactured chassis structure (Fig 2. right) and with 3D models of the entire machine. During the next two years, the machine took shape while hydraulics, electronics and control systems were added.

Figure 2. Left: Conceptual design visualised by Pontus Gaversjö. Right: Custom chassis manufactured and assembled.

In parallel, a development process was initialised with an objective to find a control system that was suitable to use for a wide audience of researchers and developers, as well as being a foundation for automation development. Again, researchers were consulted, and benchmarks of existing solutions were conducted to find a system suitable. One problem is that the sector of software and hardware solutions for autonomous navigation and control is rapidly changing, which forces one to choose technology that is competitive many years to come.

Development of a scarification device with soil inversion technique

From a collaborative workshop including LTU and the Cluster of Forest Technology a student project was initiated 2019 where a device for reduced soil impact scarification was to be developed. A prerequisite for the device was that emerging technologies of obstacle detection was utilised during operation, which enables increased precision of where microsites can be created more optimally, avoiding stones, stumps, slash etc. Furthermore, a design allowing for design parameters to be changed easily was required.

Results and discussion

The forest machine research platform

The resulting machine is a 10-tonne vehicle with a control system that uses state-of-the-art hardware and software, with specifications shown in Table 1.

Table 1. Off-road machine and scarifier hardware specifications.

Specification	Value
Weight	10 tonne
Power	129kW
Payload	3000 kg
Tractive force	66 kN
Transmission	Hydrostatic
Hydraulic pressure, auxiliaries (max)	350 Bar
Hydraulic flow, auxiliaries (at 2000rpm)	287 l/min
Steering	Hydraulic, articulated
Machine internal control hardware	UEIdaq and MATLAB/Simulink
Machine navigation hardware	Nvidia Jetson AGX Xavier
Exteroceptive machine sensors	Sick Lidar 24 layer,
	Mynteye Stereo camera
	L5 Navigation GNSS
Exteroceptive crane navigation sensors	Zed Stereo camera
	e-con systems RGB camera
Crane	Cranab FC8dt
Crane reach	10 m
Scarifier reach	4.5 m

To divide – and simplify – the tasks, a data acquisition and control module is used for internal machine control and another computer for high-level autonomous navigation tasks. The machine control system is built as seen schematically in Fig. 3.
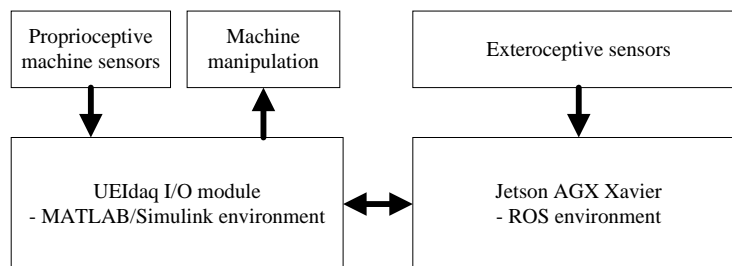
Figure 3. Overview of the machine control system.

For machine control and proprioceptive sensing, a data acquisition and control module from UEIdaq is used. To program it, MATLAB/Simulink is used as high-level programming language, which is commonly used throughout engineering fields. Proprioceptive sensors include fully sensorised joints and hydraulic pressure sensors, which can be acquired and processed in real-time, as well as acting upon retrieved steering commands from the autonomous navigation control located on an Nvidia Jetson AGX Xavier hardware. The Jetson Xavier is used to create and deploy robotics control, which includes development environments for state-of-the-art obstacle detection, autonomous navigation etc.

In addition to the physical machine, a full virtual model of the geometry has been made, as well as simulation models of the machine's drivetrain and work hydraulics. This means that the machine and added tools can be tested in a simulated environment before having the need to manufacture them

and validate the functionality fully. In addition, terrain models can be utilised to evaluate to measure productivity, fuel economy, soil damage or the machine mobility (Nordberg et al. 2014).

Device for scarification using a soil inversion technique

The device for scarification was designed according to Fig. 4. and is recently manufactured to be tested in-field in September 2020. The device has a shovel (red colour, Fig. 4.) that is dug into the ground (Fig. 4., left) by vertical crane movement (arrow, Fig. 4., left). A frame (black colour Fig. 4., middle) is thereby pressed onto the ground and then used to shear the topmost soil layer while the shovel rotates towards the end position (Fig. 4. right). While rotation towards the end position is executed, the entire scarifier simultaneously travels forward (arrow, Fig. 4., right) to ensure that the now up-side-down turf falls into the hole previously made.

The scarifier has several design parameters that can be altered: the shearing frame can be altered to change the gap; the shovel can be exchanged rapidly to various shapes and sizes. In addition, all the movements can be programmed to optimise the execution.
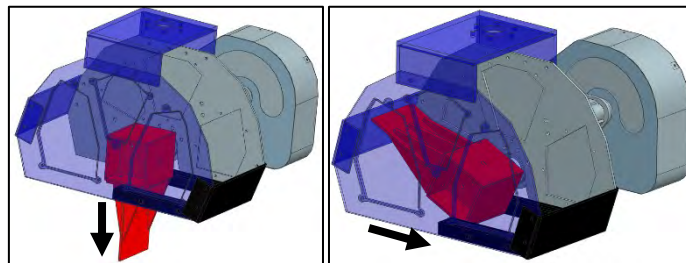
Figure 4. 3D rendering of scarifier with soil inversion technique.

The base machine and crane will be programmed such way that a continuous forward machine movement is allowed. While the device (positioned on the boom tip, Fig. 5.) positions itself on suitable microsites and conducts scarification, the crane moves to enable the scarifier to stand still in relation to the ground.

Figure 5. 3D rendering of a newly developed scarifier with soil inversion technique, here mounted on a modified Cranab FC8 forwarder crane and the off-road machine.

This allows scarification in up to five "rows" (compare with the working procedure of a disc trencher or mounder), but execution is heavily dependent on the machine's travel speed, due to the inherent speed limitations of scarifier and crane actuation, see work procedure in Fig. 6. As a starting point, only some 2-3 meters of sideways movement is feasible.
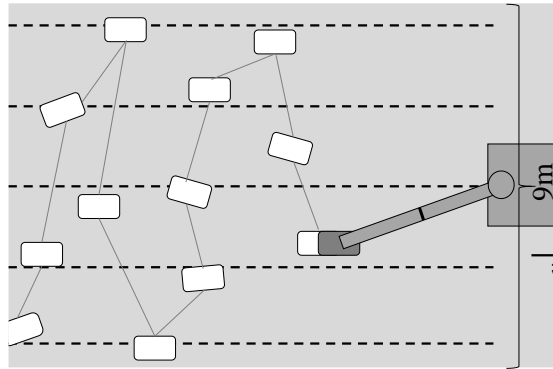
Figure 6. Scarification device work procedure.

General opportunities for research and development

The main usage and advantage of this machine lies in its modular design. The chassis front- and rear end can be removed and changed if new machine designs or e.g. drivetrains is to be tested. The rear-end comprises a frame section where electrics and hydraulics are prepared for auxiliary equipment to be exchanged. Current drivetrain is also adapted for high hydraulic output required by e.g. a double-crane system. Machine control is also done on a basis of having it reconfigurable and "open-source", using industry standard software and platforms.

Conclusions

- A modular forestry machine has been designed and manufactured enabling real tests of autonomous systems.
- A scarification device using soil inversion was designed and manufactured enabling real tests and swift design parameter and programmatic changes.

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Economic potential of tele-extraction of roundwood in the Nordic CTL system

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Mechanization of harvest and extraction of roundwood have historically cut costs rapidly as the need for manual labour steadily decreased. Ongoing efforts since the 90:s have continued to increase the work- and cost efficiency. However, machinery and work methods have basically stayed the same. Many believe that the next major technology leap will include automation, and that tele-operation, i.e. when a machine is operated remotely, might be a step along that way. This study aim to model combinations of tele-operation and automation within forwarding, and evaluate their potential in productivity and cost efficiency. The outset was an assumption of autonomous driving during terrain transportation with and without load, and tele-operation of loading and unloading. To assess the effects of such a setup, Discrete Event Simulation was applied with the AnyLogic software. About 1 100 actual harvest sites from different parts of Sweden was used as input data for the model, with sizes ranging from 0.2 to 57 ha and 20 to 1 500 meters extraction distance. Scenarios with different numbers of tele-operators for a fleet of forwarders was tested, as well as different levels of costs, driving speeds, and extraction distances. Preliminary results show that a set of 10 forwarders operated by eight tele-operators reach normal productivity, leading to a 5% decrease in average forwarding cost per m3 solid wood. A 30% increase of the operator cost further differentiated the average forwarding cost between standard- and tele-extraction by 2 percent points. This model creates significant possibilities for future evaluation of different scenarios along the lines of automation and tele-operations.

***Keywords:** tele-extraction harvest roundwood logging CTL*

SESSION 1 - TRANSPORTS, ROADS AND LOGISTICS

Optimised positioning of landings and routing of terrain transportation

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Introduction

In Scandinavia, the forest road network is dense. In Sweden there are 430 000 km of private roads of which about half is forest roads. Most forest operations occur adjacent to these roads and landings are placed along the roadside. New private roads are built, motivated by reduced total costs and accessibility, if the terrain transportation of logs from harvest areas exceeds about 500 meters.

According to Germain R.H. (2005) harvest access systems (forest roads, trails, and landings) account for 90% of the erosion and sedimentation during harvesting activities. A well-planned harvest access system can reduce the surface area disturbed by logging, thereby decreasing the potential for erosion and sedimentation. Several forest companies in Scandinavia adopt tailor made methods, e.g the so-called "Correct method" at Stora Enso AB, to plan the harvest access to minimize the impact on water bodies and streams as well as rut formations in the soil.

Forest landings are used in different ways and their design are not well defined. In countries using the CTL harvesting technique, wood assortments are placed in piles at roadside. According to Skogforsk (2013) the equation for estimating the length of the landing are based on total volume (m3) under bark (m3ub) and number of products (e.g. sawn timber and pulpwood of different species).

Equation 1: $Length = \frac{Expected\ Volume\ (m3ub)}{10} + 5\ x\ number\ of\ products$

The length is necessary both for efficient logging operations and to enable multiple trucks to load simultaneously.

The Transport administration of Sweden published instructions (2016) for landings along public and private roads. On public roads, there are recommendations for distances to cross-roads, crests or bends. Potential leakage to streams or water bodies should be avoided. On private roads the landing shall be placed 1.5-3 meters from the road and at least 2-6 meters away from powerlines. No landings should be placed in areas under environmental consideration or at cultural heritage sites. All landing sites should be agreed by the landowner. Figure 1 illustrates appropriate landing sites in green and not suitable areas in red or blue. Blue areas are inappropriate due to steep terrain.

Flisberg et al. (2020) introduced an optimization model for the layout of the main extraction routes for forwarding operations. The model uses forest volume estimates from LiDAR (Light Detection and ranging) data together with a digital elevation model (DEM), depth-to-water maps (DTW) from Murphy (2008), and known environmental considerations as well as cultural heritages (no-go areas) for a terrain route network that improves the productivity and reduces negative impact on soil and water. The model needs

stand boundaries and landing sites for each harvest area. However, the position and the number of landings is critical as they are the starting point for the extraction routes.
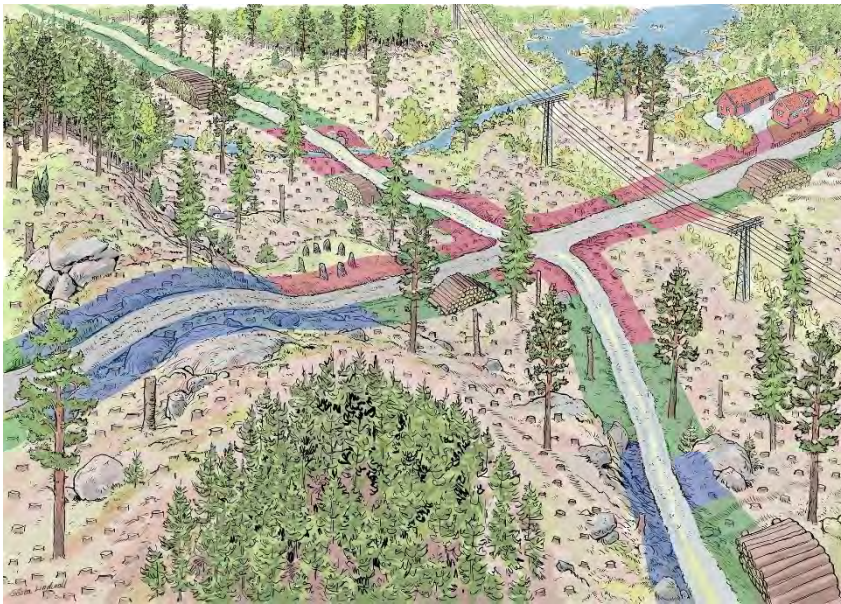
Figure 1. Illustration of suitable landing zones (green), not suitable zones (red) and inappropriate zones (blue) along forest roads. © Skogforsk, Gösta Lindwall

Normally in Scandinavia a forest professional defines the stand boundary using the stand database or delineates it in dialogue with the forest owner. Then the landing site is determined with subjective methods with no alternative scenarios to consider. Figure 2 (left) presents an example in Scandinavian forestry where the stand boundaries and forest roads are clearly identified, but not obvious where to put the landing or to include several landings. When DTW maps and no-go areas are added (Figure 2, right) the location of landings as well as the routing of the main extraction routes gets even more complicated.
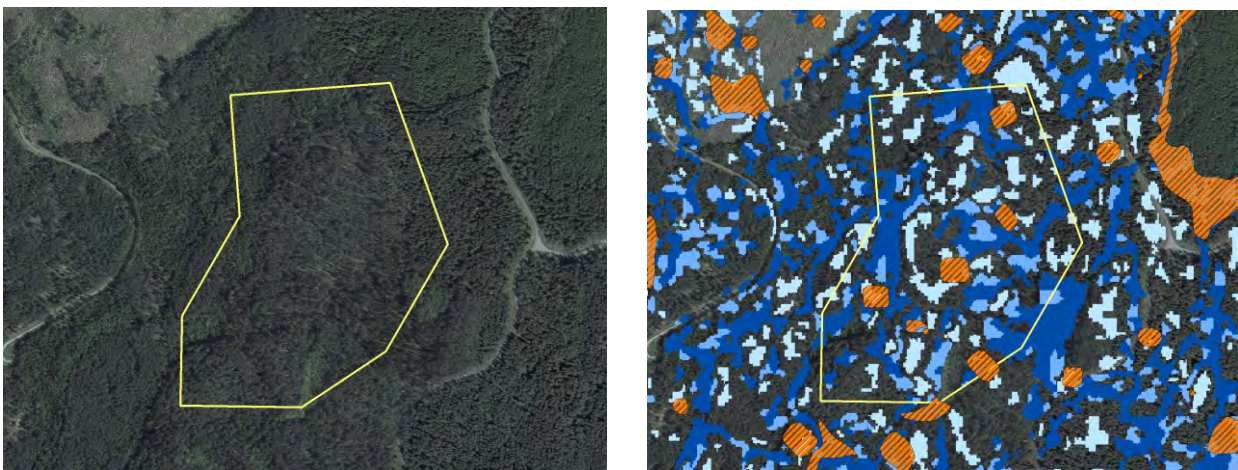
Figure 2. Harvesting unit with nearby forest roads (left). Harvesting unit with environmental considerations (orange) and DTW map in bluish colours (right).

The planning problem consists of three questions, (a) where to put the landings, (b) how additional landings would contribute and (c) where to put the main extraction routes. All this considering detailed data about variations in volume, terrain, and ground wetness as well considerations for environment and cultural heritages.

Our solution approach that aim to answer the stated questions starts with locating suitable landing zones along the forest roads and include those in an optimization model taking the available detailed data in consideration. A modified model from Flisberg et al. (2020) is solved multiple times to generate a set of scenario solutions from which the best solution is selected.

Material and methods

To model possible landing sites multiple input are used, see Table 1. Along the private roads, 12x12 meter grid cells were buffered on both sides of the road to make room for both logs and forwarder unloading operations. The timber truck reaches the logs from roadside. To avoid too steep terrain, the DEM range must be less than 2 meters in the grid cell and not more than 2 meters from the road altitude. Only grid cells on forestland was accepted (landings on agricultural land or gardens requires approval) and with appropriate distance from crossings, water streams and power lines. Any intersection with environmental consideration or cultural heritage was ruled out. The layer including potential landing sites was model in geographical information systems, GIS.

Table 1. Input data for possible landing sites

Information	Source	Type	Buffer (m)
DEM	Lantmäteriet	Raster, 2 meter	0
Water bodies and streams	Lantmäteriet	Vector	6
Power lines	Lantmäteriet	Vector	6
Land use (forest)	Lantmäteriet	Vector	0
Buildings and facilities	Lantmäteriet	Vector	15
Private roads and crossings	Swedish Transport Administration	Vector (lines)	30
Environmental considerations	Swedish Environmental Protection Agency, Swedish Forest Agency	Vector (polygons)	0
Cultural heritage	Swedish National Heritage Board	Vector (points, lines, and polygons)	5 (for points and lines)

Our study area is in southern Sweden, with 13 smallholder harvesting units. They were all harvested by contractors to Södra, a large economic forest association in southern Sweden prior to the study. The harvester production files (*.hpr) included the positions and volume of each harvested tree referred as the actual harvested volume. The forwarding routing was collected in StanForD (*.fpr files) data standard for forest machine communication with new Komatsu forwarders able to have their position recorded frequently. This data was used to locate the used landings site(s) and to validate the optimization model.

The input data for the optimization model, Table 2, was similar to Flisberg (2020) with the addition of the potential landing sites. The forest volume was based in LiDAR data collected in 2011 and 2012, but the variation within the harvesting units assumed to be unchanged.

Table 2. Input data used in the optimization model

Information	Source	Type
Potential landing sites	See table 2	Vector
DEM	Lantmäteriet	Raster, 2 meter
Forest volume	Swedish Forest Agency	Raster, 12.5 meter
Harvesting site boundaries	Södra	
DTW map	Södra	Raster, 2 meter
Environmental considerations	Swedish Environmental Protection Agency, Swedish Forest Agency	Vector
Cultural heritage	Swedish National Heritage Board	Vector

Optimization model

To minimize the total driving distance, but also to avoid steep terrain and impact on soil and water, an optimization model was further developed based on Flisberg et al (2020). The revised model includes a more sophisticated description of how the forest volume is distributed along the suitable landing zones. The model data comprises possible landing areas possible to store all harvested volume, detailed digital terrain model, depth-to-water maps and forest volume all derived from lidar data available nationwide. The information is supplemented with the extent of the stand, the position of the landing(s), nature and culture conservation sites, and any known unavoidable crossings in the terrain, e.g. streams. The overall model is a network design problem where arcs describes the routes and flows the number of loads the forwarder uses the arcs. A critical requirement of the model is fast solution times. Hence, a decomposition method based on Lagrangian relaxian is used to define subproblems that can be very efficiently solved by specifically designed subroutines. To validate the model, five different scenarios were run on the harvesting units. To analyze the usefulness, both estimated volume (Lidar estimates) and actual production volume from harvesters are included and optimized landings versus used landings.

Validated scenarios:

1. Model with estimated volume and one optimized landing
2. Model with estimated volume and two optimized landings
3. Model with volume from harvester and one optimized landing
4. Model with volume from harvester and two optimized landing
5. Model with volume from harvester with used landing(s)

Results
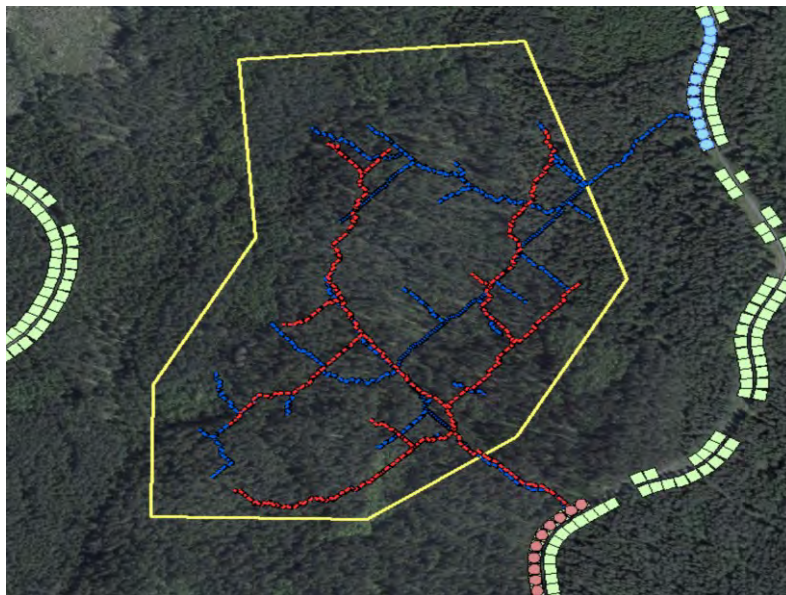
Figure 3. Results from the optimization model with one landing in red (including used landings) and two landings in blue.

Figure 3 is an example of the results with optimized landings and how much area is needed to store the volume. An example from the preliminary results from the landing- and route optimization are described in Table 3. When comparing scenario 1 and 2, the addition of another landing reduces the total forwarding distance to 83% compared to using only one landing. When comparing the actual harvested volume (scenario 3 and 4), the total forwarding distance is reduced to 85% when using two landings. When comparing the actual use landing(s) (scenario 5) to the optimized solution with two landings (scenario 4) the total forwarding distance would decrease from 255 to 220 km for all 13 harvesting units when using optimized landings. Additional results will include the proportion of the main extraction route in wet areas and steeper slopes as well as the actual forwarding distance.

Table 3. Results from two harvest areas and the five scenarios

Id	Scenario	Volume origin	Position of landings	Number of landings	Area ha	Volume m3	Mean forwarding distance (m)	Forwarding distance volume weighted (m)	Total forwarding distance km
7147_1	1	Lidar	Optimized	1	5,1	1032	184,7	244,4	33,1
7147_1	2	Lidar	Optimized	2	5,1	1032	148,5	199,5	28,0
7147_1	3	Hpr	Optimized	1	5,1	1046	184,6	242,9	32,9
7147_1	4	Hpr	Optimized	2	5,1	1046	146,2	193,4	26,6
7147_1	5	Hpr	Actual	1	5,1	1046	186,9	247,4	32,2
7147_2	1	Lidar	Optimized	1	1,4	306	305,3	418,0	16,3
7147_2	2	Lidar	Optimized	2	1,4	306	305,3	418,0	16,3
7147_2	3	Hpr	Optimized	1	1,4	351	304,7	421,5	17,7
7147_2	4	Hpr	Optimized	2	1,4	351	304,7	421,5	17,7
7147_2	5	Hpr	Actual	1	1,4	351	474,2	569,5	23,4

Discussion

The high level of details available in data describing the forest and the terrain with different datasets opens the opportunity for operational decision support in forestry. The mapping of suitable landing sites included in a model open for a more automated operational forest operations planning. The optimization model developed can cope with a wide range of input data and provides results that significantly reduces the forwarding distance reducing both costs and emissions. Compared to the results in Flisberg (2020), the possibility to propose landing sites for one or two landing sites is a significant improvement to rationalize the planning of extraction routes as only the stand boundaries are needed for each harvesting unit which makes it possible to run the model for multiple planned cuttings at once and not identify landings sites in advance. It is also a useful tool to communicate with forest owners for the different scenarios and to identify savings in terrain transportation.

Further research should include a larger variety of harvesting units. In this study they are relatively small and larger reductions in forwarding distance are likely to occur in larger stands. For those areas it might also be interesting to allow even more landing sites. It would be possible to include information on the distribution of tree species as this might influence how they are forwarded into piles at roadside with different products.

The model could also be useful in operations if information from the harvester on the geographical distribution of products over the harvesting site is included. Then each forwarding round could be suggested, and the total forwarding operations optimized.

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The effect of adhering snow on the load capacity of a timber truck

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In wintertime, the payload capacity of a timber truck is reduced by snow that accumulates on the structures of the truck. The aim of this study was to quantify the potential payload loss due to snow and winter accessories and to predict the loss with weather variables. Tare weights of eight timber trucks were collected at mill receptions in Finland over a one-year period. Trip-wise and monthly loss of potential payload was estimated using the tare measurements in summer months as a reference. Each load was also connected with weather data at the location and time of delivery and payload loss explained by the weather data with the aid of regression models. The maximum loss of payload varied between 1560 kg and 3100 kg depending on the truck. On a monthly basis, the highest extra loads occurred in January, when the median values varied between 760 kg and 2180 kg. Over the year, the payload loss equalled from 0.5% to 1.5% (from 1.9% and 5.1% in January) of the total number of loads in the study. Payload loss was found to increase with decreasing temperature, increasing relative humidity and increasing precipitation. Although the average payload loss was not very high, the biggest losses occur just when the capacity is in full use. Big differences were also found in the tare weights between the trucks. The results of the study give incentive to develop truck and trailer structures that limit the adherence of snow.

Keywords: *forestry logistics; payload; tare weight; weather data*

Predicting forest road´s bearing capacity using smart sensing technology

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Introduction

Water within the construction layers of unpaved forest roads limits its bearing capacity. This automatically leads to limited trafficability as well as restricted overall access to the forest. Even highly compacted and well-constructed forest roads have limited access during spring in the Northern hemisphere. This is especially true of the thawing season when unpaved forest roads are very sensitive in case of excessive strain due to low bearing capacity (Daniel et al. 2018 & Vuorimies et al. 2015). Furthermore, heavy rain could also lead to considerable water penetration into the forest roads' layers. Recovering saturated forest roads or single road sections until they dry up again will lead to necessary closings. Depending on the amount of precipitation, this will take several days or even weeks and cause bottlenecks in the logistics of forest enterprises, especially if it happens unexpectedly.

Once the limit of moisture content within the construction layers reaches a certain level, the bearing capacity of forest roads will not withstand the requirements of heavy traffic anymore, and the surface layer or even the subgrade could fail. Thus, it will subsequently lead to high costs of maintenance or even restoration. Only properly constructed and well-maintained forest road networks enable the cost-efficient production of sustainably produced timber.

Accessibility of forest roads throughout the whole year is crucial for an efficient wood supply chain, particularly for timber harvesting operations and transport activities. In this respect, detailed knowledge about the actual road status or seasonal accessibility is of vital importance, as it directly influences all forest management activities. A smart prediction model in the form of a traffic light could prevent high costs of maintenance activities due to overloading a weak and moist forest road.

Monitoring soil moisture in agriculture and forestry-related applications combined with varying emphasis has been widely reported. A variety of sensing technologies for different approaches is available for this purpose. Their use ranges from soil columns under laboratory conditions to field experiments or even large monitoring setups under the natural environment (Rowlandson et al. 2013). However, one of the most well-known and described sensors in use covering the soil moisture is the so-called Hydra Probe out of the group of time domain reflectometry (TDR) manufactured by Stevens Water Monitoring Systems, Portland, OR.

This study aims to develop a smart sensor-based model to predict forest roads' bearing capacity. To determine the needed modelling parameters, a measurement approach for the field is suggested and is tested under real conditions. This should enable one to identify and study the influences of harsh weather conditions and its effects on the bearing capacity and trafficability of unpaved forest roads the whole year

round. With further development, this should ensure the smart use of and effective access to forest roads and avoid extra maintenance costs of roads used excessively.

Material and methods

The investigated road segment is located 35 km north of Ybbs/Donau in Lower Austria (48°22'N, 15°02'E); it is relatively flat, more or less open on all directions and surrounded only by young, natural regeneration. The road section is found within the geological formation of Weinsberg Granit, which is used as the construction material of the studied road section.

The measuring equipment at the site consists of an energy-autonomous, meteorological weather station that senses rainfall, wind speed and direction, relative humidity with air temperature, solar radiation and snow height. The weather station is further linked with three soil moisture sensors (Hydra Probes), installed alongside the carriageway of the examined road section. Hydra Probes were installed by bringing in the sensors from the side into the road in depths of 21 cm, 43 cm and 62 cm, respectively. All compiled data were transferred to the Institute of Forest Engineering` server once daily via GSM data communication (Figure 1).
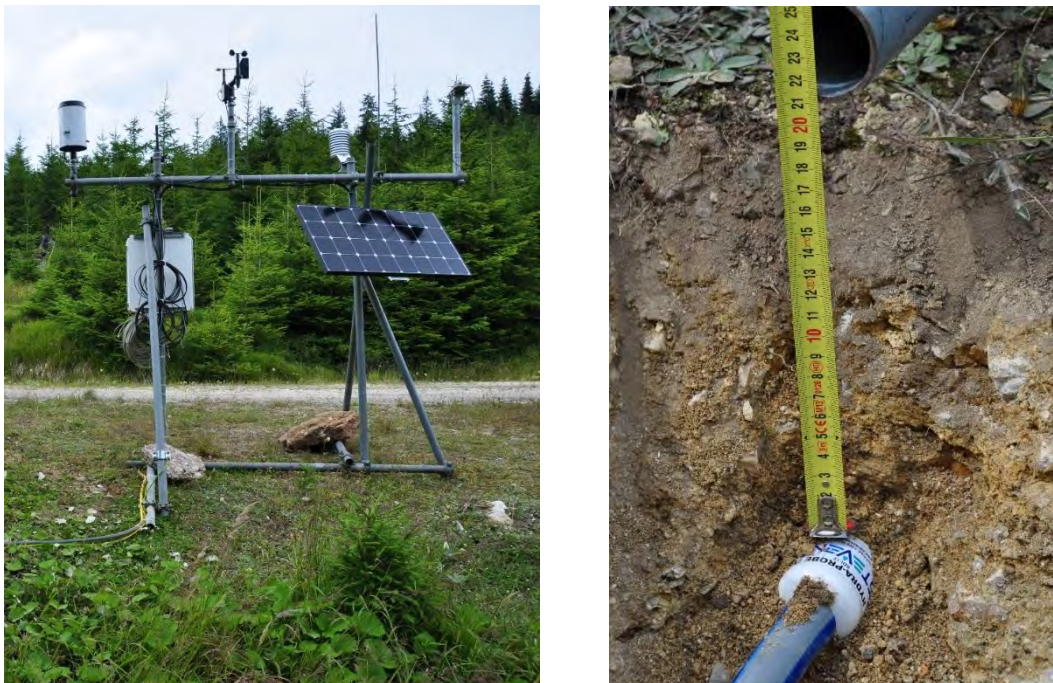
Figure 1. The energy-autonomous meteorological weather station (left) with linked soil moisture sensors at 21 cm depth (right) (Fritz, 2019).

The sensors, from Stevens Water Monitoring Systems, use SDI-12 communications protocol and are capable of recording data on temperature, conductivity, salinity, dielectric permittivity and moisture. Regarding calibration of the sensors according to the investigated soil type, the sensor could either use preconfigured calibration functions from the manufacturer or own developed functions based on the analyzed material onsite. For this field trial, the sensor´s setting for sand was applied.

Road's bearing capacity is monitored with the LFWD TerraTest 3000 GPS every week or every second week and after heavy rainfall, depending on the weather conditions. To avoid measurements at the same point, a measurement grid was applied for each data set. Starting from the weather station, all the measurements were done in both directions. The data set includes the bearing capacity of both driving lanes as a data pair (Figure 2).
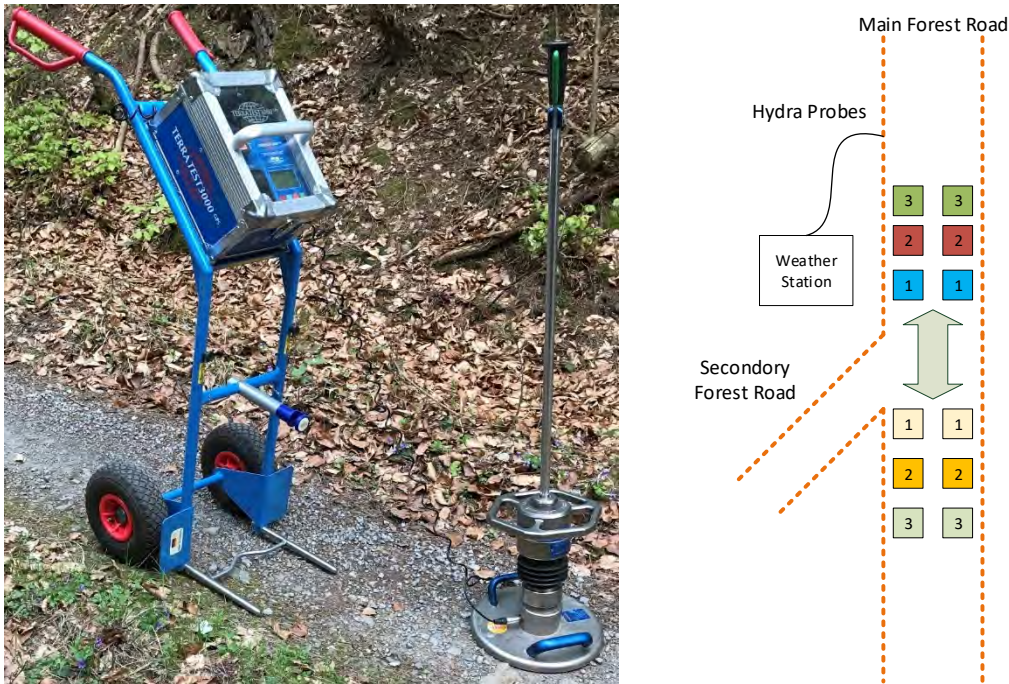
Figure 2. Light Falling Weight Deflectometer (LFWD) TerraTest 3000 GPS (left) and sample grid for monitoring forest road´s bearing capacity with the LFWD (right).

In addition, the construction material from the investigated road segment at the site was analyzed according to the standard ÖNORM EN ISO 17892 (4). Compared to standardized grading curves from Fuller and Thomson (1907) for high appropriate road construction material, the analyzed material shows high proportions of clay and silt.
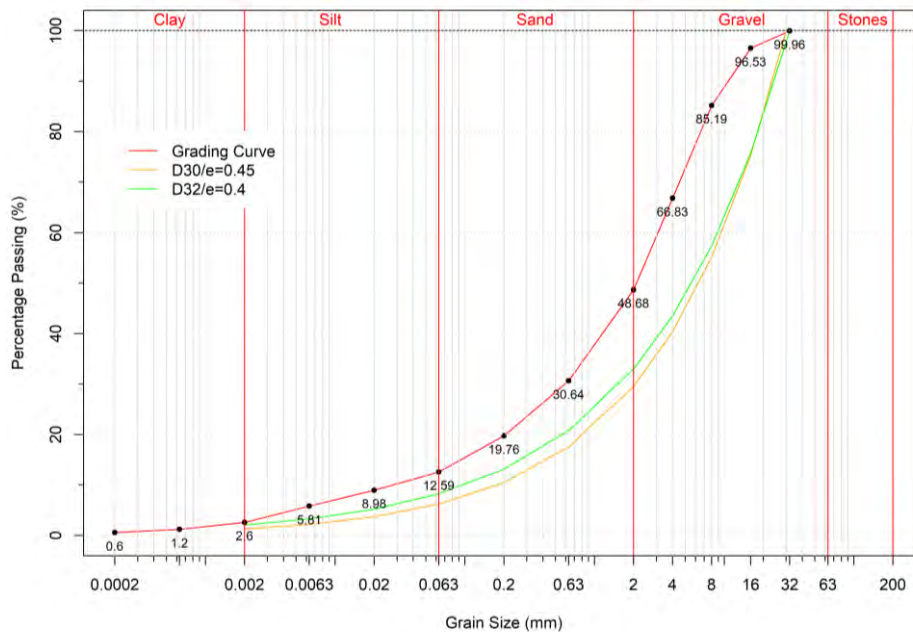
Figure 3. Grading curve from the site compared to standardized material suggested by Fuller and Thomson (1907).

Results and discussion

The experimental setup and installation for monitoring harsh weather conditions on forest roads' bearing capacity started on 5th July 2018 and is still running. Only during short time periods, data recording was interrupted due to technical reasons. Temperature curves for the installed Hydra

Probes including air show a typical development since the summer of 2018. The deeper the sensor is installed, the more smoothened the temperature curve gets due to the lesser influence of air temperature. Neither of the Hydra Probes were frozen in, which could be explained by the snow coverage at low temperatures (Figure 4).
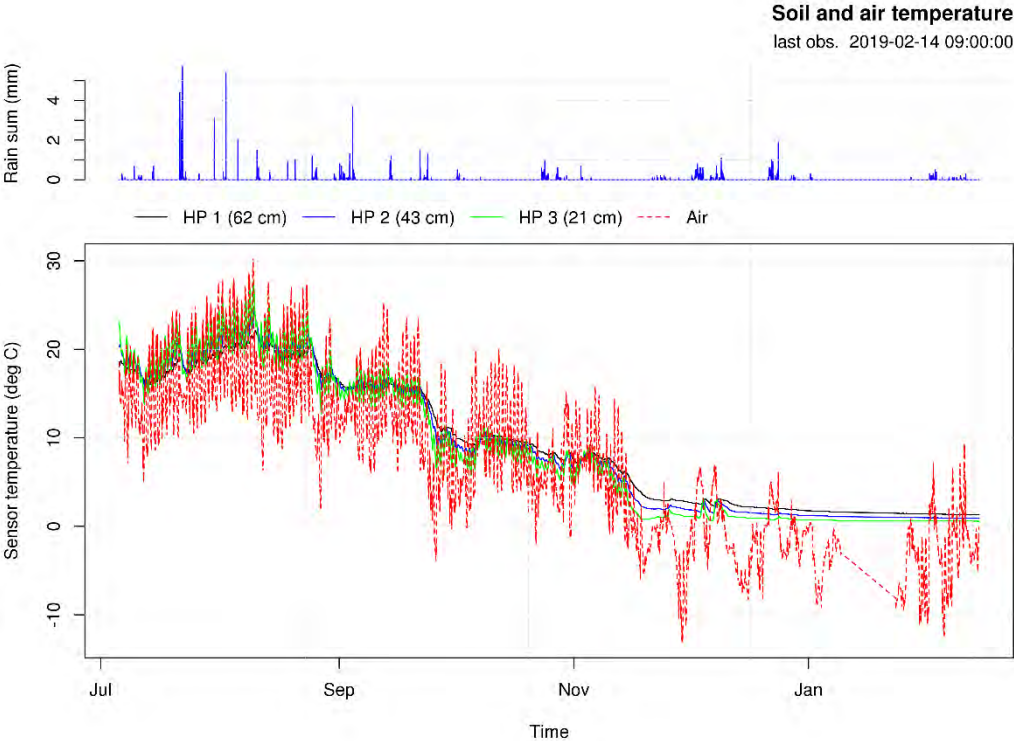
Figure 4. Logged soil temperature of all three installed Hydra Probes combined with air temperature and rain

Immediately after installing the sensors, the first heavy rain event occurred at the site with 85.7 mm from 21st to 22nd July 2018. Forest roads' bearing capacity dropped already in the evening of 21st below 40 MN/m² and was the lowest with 34 MN/m² on 22nd July at 17:00. On the following day, it started to increase again and reached 85 MN/m² on 25th July 2018. The following spells of rainfall also reduced the bearing capacity in the same way.

However, rainfall directly influences the water content within the construction layers of the analyzed road section. Hydra Probe Sensors respond faster after rain due to water infiltration and show delayed return to the starting point. HP 3 shows irregular spikes in the diagram, which could result from improper contact of the sensor plate with the material (Figure 5 & Figure 6).
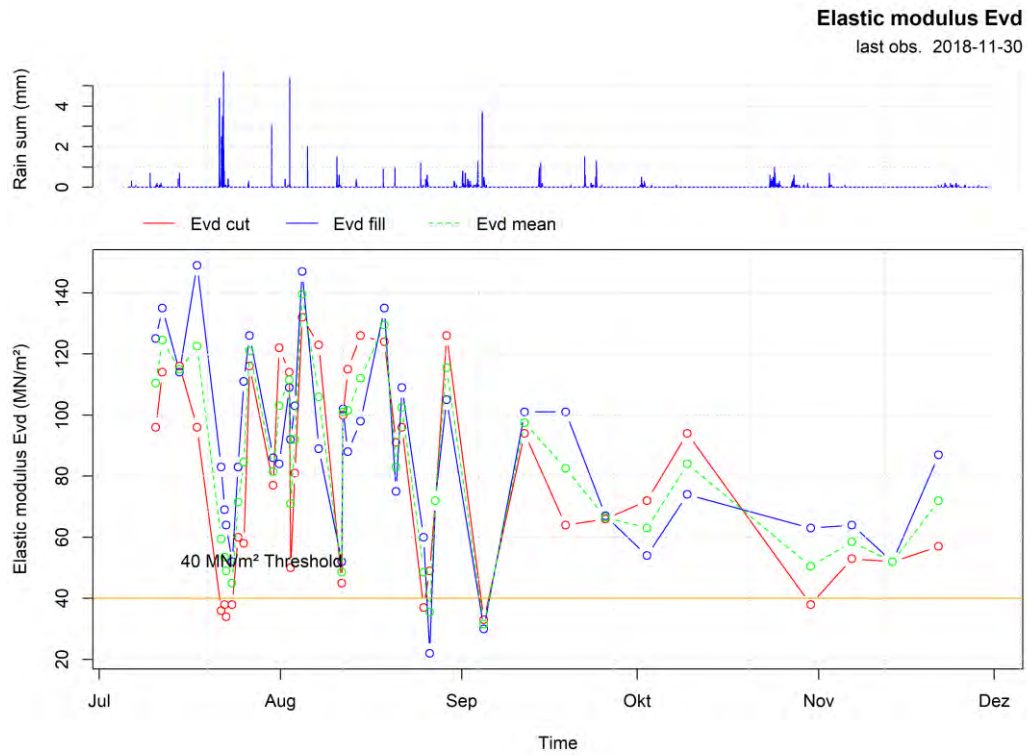
Figure 5: Measured road bearing capacity combined with recording of precipitation
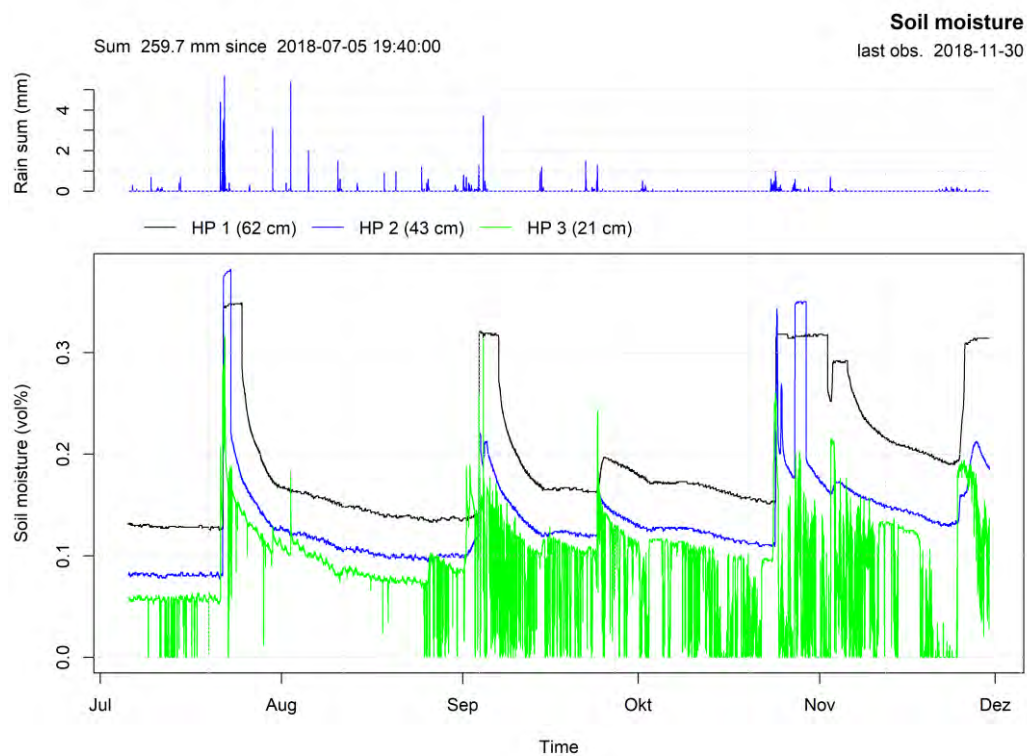
Figure 6: Logged soil moisture of the installed Hydra Probes combined with rain

Conclusions

The described field trial has laid the foundation to set up the first trials to analyze the impact of harsh weather conditions on forest roads' bearing capacity. More importantly, the use of smart monitoring technology enables the analysis of the effects of weather on the long-term bearing capacity of road networks. Sustainable and cost-efficient forest management could benefit from a better understanding of the physical influences of weather on forest roads' trafficability. This could support forest owners and decision-makers in scheduling transport activities to reduce maintenance costs.

The actual set up only represents one site in AUT with specific geological conditions and construction guidelines. However, after successful testing, the number of experimental setups could be increased to set up a network and cover at least a certain region. Measurements with the LFWD are still done manually every week or when there are events. In the future, this could be replaced by automatically and remotely recording the bearing capacity during ongoing traffic in combination with rutting detection.

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Seasonal variation in transport lead times and pulpwood freshness in a coastal geography

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Seasonal variation in production and transport pace leads to corresponding variation in transport lead times. Standardized limits for winter and summer lead times are generally considered sufficient to meet pulpwood freshness criteria. Seasonal drying rates at the landing, however, can vary considerably between supply areas due to variation in climatic factors and on-site exposure situation.

This study analyses a three-year time series to compare moisture content levels for pulpwood deliveries between the outer and inner coast along the Atlantic coastline. The work was done in three steps;

1) Estimation of transport lead times based on daily harvest and transport reporting,

2) Modelling of season-specific lead time limits for two different thresholds of moisture content, and

 3) Follow-up of deliveries exceeding modelled lead-time limits. The modelling of drying rates was done by adapting Skogforsks TorkCalc for use with local weather station data.

The results visualize seasonal trends for lead times per supply area, both in relation to harvest and transport dates. Modelled lead-time limits (drying to a threshold of 50 % MC) varied between seasons (winter, spring, summer, fall) and areas, ranging from 4 to 30 weeks. Lead time limits were shorter for the lower altitudes on the outer coast due to higher temperatures and lower humidity. The differences in lead time limits between the outer and inner coast was greatest during the fall (21 weeks) diminishing through winter (6 weeks) towards summer and spring (2 weeks). Even though actual lead-times were shorter on the outer coast, the proportion of deliveries exceeding the modelled lead-time limits was higher than for the inner coast. Weather-driven modelling may therefore be useful for prioritizing the allocation of transport capacity when pulpwood freshness is critical.

Keywords: *logging truck transport, transport management, seasonality, weather conditions*

Transport costing models – a common Nordic-Baltic framework

NB-Nord Road and Transport Group

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Transport cost calculations are fundamental for most types of transport research. Applications can range from estimating the cost benefits of developing transport technologies (e.g. increased truck GVWs) to comparing profitability between alternative infrastructure investments (e.g. rail or sea terminals). Most stakeholders rely on a favourite spreadsheet, however these vary considerably with respect to functionality, resolution and transparency.

During 2019 and 2020 the NB-Nord Road and Transport group has worked towards a common Nordic-Baltic costing framework for road, rail and sea transport. The goal has been to propose a general model per transport method which is user-friendly, while retaining the necessary resolution and functionality to model actual costs for specific transport orders or contracts. The models are to be published in a short handbook by the end of 2020. The handbook provides: a) complete explanation of its formulas, b) calculation examples and c) a corresponding excel spreadsheet.

The models were validated through national comparisons of market prices and calculated costs for a selection of transport orders. Sensitivity analysis is supported by the accompanying spreadsheet. The truck costing model accepts up to 3 road types with specified driving speeds and diesel consumptions. It also includes a function for estimating profitability levels where transport tariffs and driving distance distributions are available. The rail model is created for systems with up to 3 terminals with specified cycle element times. It includes links to national network statements for rail hire and traction current costs. The shipping model is relatively simple given the use of time-charter (TC) day rates for varying vessel capacities. It includes links to international sources for bunker costs.

Keywords: *costing, handbook, logging truck, timber train, short-sea shipping*

New bio-based industries – a Norwegian case study exploring roundwood supply, transport solutions and cost-competitiveness

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Emerging value chains for bio-char, -chemicals, -fuel and -plastic contribute to product diversification and potential market development for the forest sector. These new products, however, also compete for raw materials with existing mills. This study models the development of relevant roundwood supply volumes and costs for new and existing mills under various future scenarios in a Norwegian case-study region.

The study area covers Norway's south-east coast where regional consumption is driven by four smaller mills producing paper, board and pellets. Regional oversupply is delivered primarily by rail to long-term customers outside of the region. Marginal volumes are shipped by vessel to export markets. Four new potential mill locations for bio-fuel or bio-plastic production were being considered by investors in the region. The standard mill was assumed to consume 550 000 m^3/yr of spruce and pine pulp/energy wood, supplemented by a lesser volume of chips.

A multimodal variant of the standard transport problem was developed to compare minimum-cost solutions for roundwood flows between future scenarios for supply, demand and multimodal infrastructure. The model and scenarios were specified, tested and validated with stakeholders over a one-year period. Supply volumes per assortment and species were based on 10-year average harvesting statistics with adjustment according to long-term regional prognoses from the national forest inventory. The current regional oversupply was found to be insufficient to meet the demand for the standard mill. Most future scenarios assumed, therefore, reduced rail deliveries to the current long-term customers outside of the region.

Transport costs for truck, rail and vessel were tracked between scenarios, both for the system and each mill. Average system cost with current mill demand was 145-150 NOK/m^3. Average system costs with a new bio-fuel/plastic mill in the region were reduced to 110-135 NOK/m^3. There was considerable variation in system and mill-specific costs, dependent on the scenario defined. Much of this variation was driven by the alternative new mill locations, primarily driven by local variations in harvesting intensity (m^3/km^2/yr) and the corresponding need for multimodal solutions to reach the necessary mill supply volumes. The effect of the new mills on existing wood flows varied and was dependent on their location in relation to rail terminals being used by long-term customers outside of the region.

Future projections of regional supply indicate stable or reduced volumes of the relevant spruce roundwood assortments during the first 20 years and increased volumes of pine and deciduous pulpwood. The scenarios tested in this study specified new mill demand in terms of spruce and pine only. Utilization of deciduous species would enable increased regional processing capacity, but at a higher transport cost per consumed unit.

Forest road availability – inferences from logging truck delivery messages

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There are numerous approaches for quantifying seasonal availability for forest roads. With the increasing occurrence of frost-free winters, new methods are needed to track and predict road availability based on actual weather conditions. This paper examines actual road use based on logging truck delivery messages in order to infer trends for road bearing capacity and seasonal availability. The study area was chosen because of its coastal climate and variation in transport lead times. The data consists of three years of delivery messages (n=33 000). Message dates and landing coordinates were used to join individual loads with weather and road network data as well as DTM variables and quaternary surface deposits. Deliveries were also tracked per sales contract to calculate transport intensity (m^3/week/contract) and average load volume (m^3/delivery).

Deliveries were classified according to elevation zone, weekly snow depth, precipitation, and temperature. Most forest roads in the area were constructed with the available surface deposits so a simple research question was formulated; "For each combination of weather conditions, which forest road material (deposit type) did the weekly volumes originate from?". Based on the similarity of delivery trends per individual deposit type (n=14), three aggregated groups were used for further analysis. The groups indicate the texture characteristic associated with bearing capacity; friction textures (FR; codes 11/12, 15/20/30 and 72 or 101/110/130), cohesion textures (CO; codes 41/43, 42 and 50) and organic materials (OR: code 90).

The analysis focused on snow-free periods with above-zero temperatures. The proportion of weekly transport volume collected from roads on cohesion deposits (CO) increased with reduced precipitation and increased temperature. The weekly % of volumes transported over frictional deposits (FR) was greatest during periods with temperatures between 0 and 5 degrees (Celsius) and periods with precipitation greater than 5 mm/day. The effect of precipitation on % of weekly volume originating from roads of friction deposits (FR) was most pronounced for contracts with higher transport intensities (m^3/week).

Keywords: logging truck transport, weekly road selection, weather conditions

SESSION 2 – DATA AND SENSORS

Continuous surface assessments of wheel rutting compared to discrete point measurements – do the benefits justify the efforts?

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Keywords: wheel rutting, proximal measurement, forwarder, UAV.

Introduction

Newer methods and technologies are being applied in assessing the extent and the severity of wheel rutting after machine traffic in connection with forest operations. Some examples of these include LiDAR scanning from a harvester or forwarder (Salmivaara et al., 2018), from personal laser scanners Astrup et al. (202x), terrestrial laser scanners (Koreň et al., 2014), from time-of-flight cameras (Melander & Ritala, 2018), as well as from photogrammetry interpretation of RGB images both from hand-held (Pierzchała et al., 2016) and UAV based imagery (Talbot et al., 2017). These scans produce high resolution continuous-surface models, but the question is whether the amount of work required in setting up, scanning and especially in processing the data is justified by the information they contribute to rut depth estimation.

Materials and methods

In the present work, we measured the differences between 4 forwarder - steel track configurations. Each forwarder traversed a 20 m straight section (figure 1) followed by a 20 m curved section. Between 3 and 5 replications were measured for each treatment and configuration. We compared the information obtained from assessing rut depth with UAV based photogrammetry to discrete manual measurements using a laser level and measuring staff.
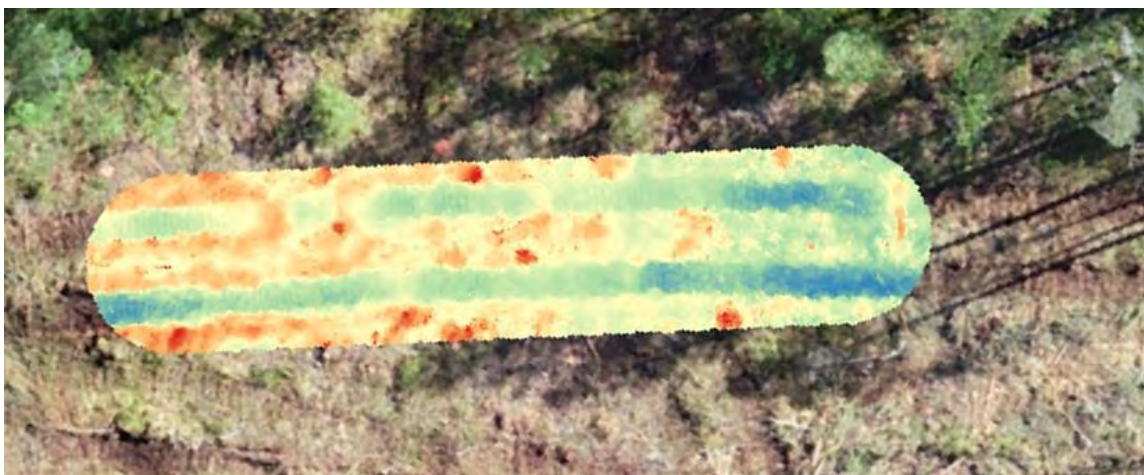
Figure 1. One of the 20 m continuous surface models developed from UAV imagery.

Results

This presentation includes a numeric comparison of the rut depth estimates obtained from both the surface models and the manually measured points. The presentation further includes a discussion on these results as well as an overview of the challenges experienced, the resource use in data capture and processing, as well as the relative merits of each method of rut measurement.

Direct Multi-Tree Stem Detection and Analysis from Terrestrial Lidar Data

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Introduction

Since the rapid development of scanning technologies, massive and accurate 3D point clouds can be created easily and quickly. Therefore, more and more computer vision and graphics applications have used such scanners. Application domains such as autonomous driving (Cao und Wang 2020), construction (Puri und Turkan 2020), and forestry (Tusa et al. 2020) are just a few instances of increasing utilization of these scanning technologies. The focus of this paper is on the application of sensing technology and 3D point clouds in forestry.

An essential task in any forest characterization and management activity is to have a precise forest inventory and biophysical parameter estimation. Forest fire model, forest ecosystem modeling, and timber and wildlife habitat management are few examples of which having an accurate forest inventory estimation is inevitable (Harikumar et al. 2019). The time-consuming and expensive process of detection and measurement of standing trees and timber present is also vital in other forestry applications such as decision support systems in wood supply (Müller et al. 2019).

Remote sensing (RS) techniques with the ability of quantifying forest structure in both vertical and horizontal dimensions and in large landscapes, such as lidar (Light Detection and Ranging) or radar (Radio Detection and Ranging), are considered alternative or complementary methods to circumvent the difficulty of field techniques (Ferraz et al. 2016). Numerous works have been reported in the past decade on the application of lidar technology in forest data collection. Lidar sensors have the advantage of creating a high-density point cloud which results in possibility for extensive analysis as well as several automation processes such as tree stem detection, measurement, and modelling. Currently, lidar technology is widely used to extract tree location, tree height, diameter at breast height (DBH), tree crown and tree species classification, etc. (Fan et al. 2020). It also provides basic data for tree volume, biomass and carbon stock estimation. Figure 1 shows a point cloud collected from a terrestrial lidar in a forest.

Current progress in tree stem analysis from terrestrial lidar data

Remote sensing tools and methods have been continuously improving and can be used as technologies to aid foresters in obtaining necessary parameters to improve management decision-making. In the last decades, one of the main studied technologies is the application of lidar sensors which work by tracking the emission and return of laser pulses, determining the sensor-target distance based on the return time lag. Over the past few decades, lidar technology has been implemented to measure and analyze common forest parameters (Beland et al. 2019; Nelson et al. 1988; Nelson 2013). The methods for automatically extracting tree stem measurements from ground-based laser data mainly include Hough transform (Liu et al. 2018b), circle fitting algorithm (Cao et al. 2017), and cylinder fitting algorithm (Juraj et al. 2017). In order to improve the extraction precision of tree height, most studies have employed the circle fitting method to determine the growth direction of the tree trunk, and calculate the tree height along the growth direction of the tree trunk (Olofsson et al. 2014). In order to improve the efficiency of the algorithm, the method of extracting DBH based on circle detection or circle fitting needs to rasterize the point cloud data, which reduces the availability of data and the extraction accuracy (Liu et al. 2018a).
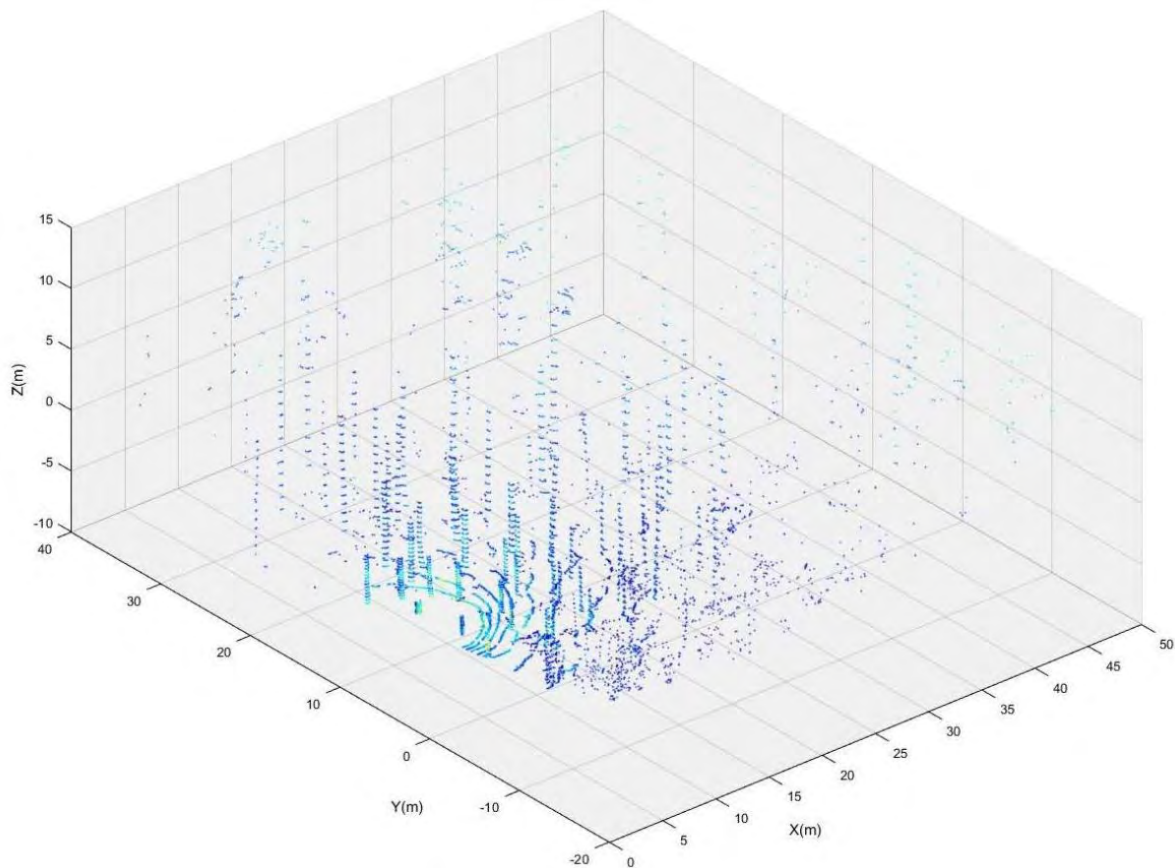
Figure 1. Lidar point cloud of a forest collected by a handheld sensor platform in Ås, Norway.

To improve the efficiency and accuracy of forest resource surveys, this study proposes a sensor-fusion platform and a point cloud processing approach for direct multiple tree stem detection, location estimation and dimension analysis. A combined handheld platform of lidar, IMU and camera was set up for accurate positioning, mapping and tree detection. Then, a point cloud processing algorithm was designed to analyze the resulted point cloud from the lidar. The proposed method is based on unsupervised clustering of the data points to automatically detect the number of trees without any prior estimation. Once the tree clusters were defined, the algorithm can detect and remove noise from the data, categorizing individual trees and localizing the sensor platform accordingly. Furthermore, a ground point detection and separation algorithm were designed to remove the ground points and measure the DBH of each tree.

Material and methods
The proposed approach starts by limiting the large obtained point cloud to a specific range. The restricted point cloud will be subject to a noise reduction algorithm to remove outliers from the data. Then the resulted data points will go through a process for detection and removal of the ground points. Next, the point cloud will be classified using a segmentation algorithm. The resulted data, which is a set of trees, will be evaluated to detect individual trees stems and to measure the diameter, distance and direction of each tree stem. These processes are presented in the following sections.

Point cloud pre-processing
Raw 3D point clouds obtained directly from acquisition devices such as laser scanners are regularly contaminated with noise and outliers. The first stage of most point cloud processing approaches typically involves cleaning such raw point clouds by discarding the outlier samples and denoising the remaining points to reveal the (unknown) scanned surface. The clean output is then used for a range

of applications like surface reconstruction, shape matching, and model retrieval (Rakotosaona et al. 2020). The resulted point cloud from our data collection goes through a noise reduction method which returns a filtered point cloud in which the outliers had been removed. This process consists of computing the mean (μ) and standard deviation (σ) of distances to the k closest neighbors and discarding the points which are located outside ($\mu \pm \alpha.\sigma$). We implemented this method with α=0.8 and k=20. These values were chosen based on the size and density of our point clouds.

Ground points detection
The resulted denoised point cloud goes through a ground point detection process which fits a plane to the point cloud. The plane is described by a distance threshold $dmax$ as the maximum allowed distance from an inlier point to the plane, and a reference vector [xrv,yrv,zv]that describes the plane orientation. The implementation results indicate $dmax$=0.5 (m) and [xrv,yrv,zv]=[0,0,1] to be best values based on our resulted point clouds. This approach is based on the MSAC algorithm (Torr und Zisserman 2000) which uses a fitness function to select the inlier points and a constant weight for the outliers.

Unsupervised clustering
The proposed clustering method segments a point cloud into clusters, with a minimum Euclidean distance of δmin between points from different clusters. This method works by employing a global version of the k-means clustering algorithm (Yuan und Yang 2019). It is an incremental approach to clustering that dynamically adds one cluster center at a time through a deterministic global search procedure. This procedure works by running a k-means algorithm M times where M is a function of the size of the dataset N.

Tree stem detection and measurement
The tree-stem detection and measuring works by applying a set of multiple standard circle-fit functions to each cluster at different heights with a maximum distance of $hmax$ between each two segments. To measure the right value for DBH, the segment with the closest distance from the ground points to $hDBH$=1.3 m was selected.

Figure 2. The handheld sensor platform used for data collection which consists of a lidar, an IMU and a camera. Data collection took place in a small forest.

Data collection
A simple handheld sensor platform was prepared for the data collection consisting of a Velodyne VLP-16 lidar, a PhidgetSpatial Precision 3/3/3 IMU and a Logitech camera as shown in Figure 2. The

lidar was mainly used for data collection and IMU and camera were used for performing SLAM, which will not be discussed in this paper. The platform was held by an operator walking in a small forest in Norway. An instance of the performance of the proposed approach on a collected point cloud is presented in Figure 3.
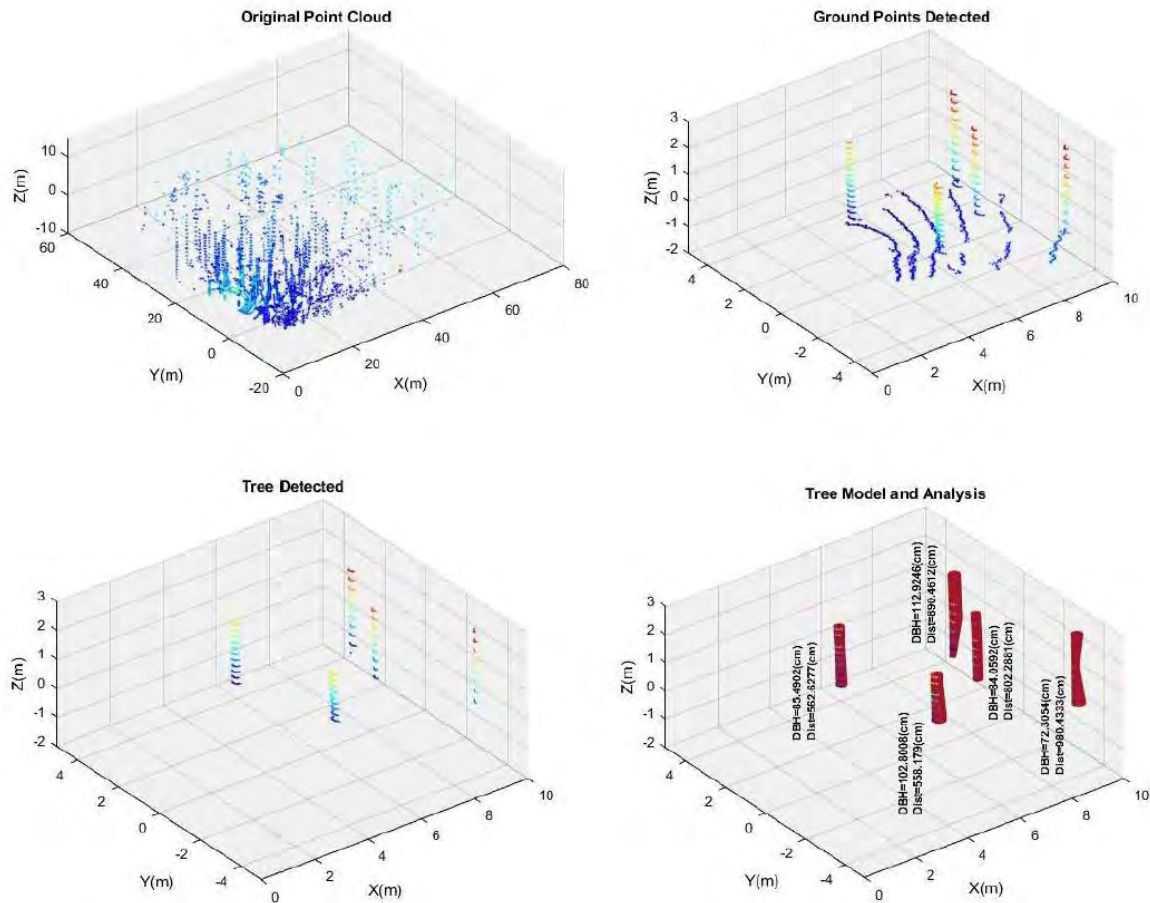
Figure 3. Summary of the proposed point cloud processing approach on a point cloud obtained during the data collection.

Results and discussion

Figure 4 shows the data collection site where a large point cloud was collected. It took around two hours of walking to cover the whole area. However, the objective was not to cover the entire forest but to prepare a dense point cloud.

Figure 4. A small forest was selected for data collection located in Ås, Norway.

After collecting the data and running the proposed processing approach on it, three main values were extracted from the results. First the number of trees were calculated in 10 different selected base positions of the sensor platform where the actual values have been recorded during the data collection. Next variable was the DBH which has been measured manually for 50 randomly selected trees during the data collection. The last variable was the location of the detected trees which consists of the x and y coordinates of 50 randomly selected trees that have been measured manually during the data collection. Figure 5 presents a comparative illustration of the actual values and the resulted values from the proposed approach.
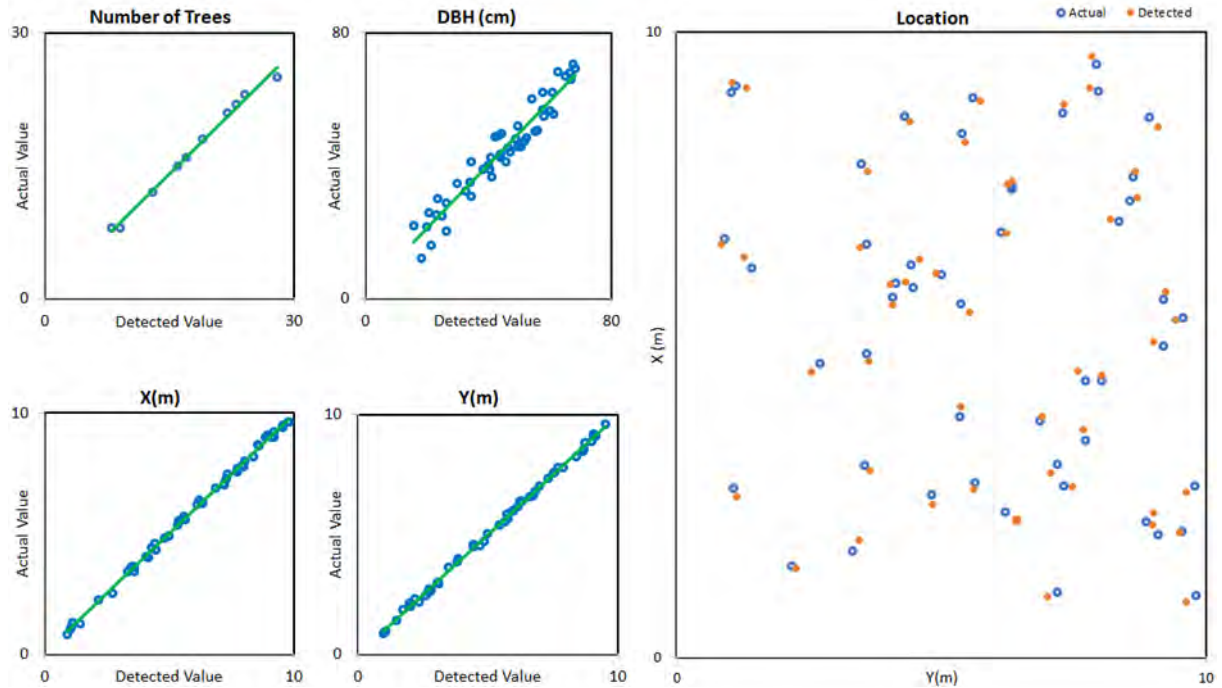
Figure 5. Comparative graphs of the actual values versus the resulted values from the proposed method. The graph on the right shows the actual and extracted locations of 50 randomly selected trees.

Table 1 summarizes the performance of the proposed approach in terms of absolute error percentage, mean absolute error, mean squared error, and maximum error.

Table 1. Performance of the proposed approach.

Value	$\overline{Error}\%$ [a]	MAE [b]	MSE [c]	$Error_{max}$
Number of Trees	6%	1.1	1.7	3
DBH (cm)	9.16%	3.40	15.18	16
X(m)	2.51%	0.10	0.01	0.20
Y(m)	2.59%	0.10	0.01	0.18

[a] $\frac{1}{N}\sum|Error|/Actual$ [b] *Mean absolute error.*   [c] *Mean squared error.*

Conclusion

In this paper, a 3D point cloud processing approach is presented to detect and analyze tee stem in forests. The propose method consists of four processes including point cloud pre-processing, ground points detection and removal, point cloud segmentation, and finally tree steam detection and analysis. The resulted method was implemented on a set of 3D point cloud collected in a small forest in Ås, Norway. The results were compared against the ground truth data collected manually. The results show high levels of accuracy in detecting the number of trees within the visible range of the sensor platform, as well as individual tree stem location and dimensions with the average accuracy levels of 94% for the number of trees, 92% for location, and 91% for DBH.

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Methods for harvest site delineation based on machine positions in harvester stem reports

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Knowing the area and specific location of a harvested site is essential for evaluation the result of the harvest. It will enable estimation of tree density and volume density of the logging, as well as estimating other site characteristics like mean slope, terrain roughness, fragmentation, etc. It is therefore also essential for explaining the performance of machine and crew.

The area and location of a specific harvest may be set in many ways, e.g. walking the border of the area with a gps, delineating the area using a map and good skills in orienteering, or delineating from post-harvest orthophotos.

In the present work we test out two approaches for determining the harvest site area using the base machine position tied to each stem in StanForD reports. The actual harvest area was determined using orthophotos or drone image derived orthomosaics. Candidate areas to compare with the actual area was established using pure buffering or a mix of triangulation and buffering around these base machine points. A large number of candidate areas was made using various buffer distances and triangle leg length limitations. The fit of the modelled area was evaluated using the difference in modelled area and true area, as well as the mean distance between the modelled border and the true border.

Then the best settings for both approaches was identified, and these were used to establish the final candidate modelled harvest area. The fit of this modelled area was tested for the relation to slope, size of area and the shape of the polygons.

Keywords: *StanForD, harvester, stand shape, GIS, UAV.*

Automatic detection of work elements and disadvantageous work practices in mechanized forestry

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Introduction

The work presented here is a part of the Advanced Virtual Aptitude and Training Application in Real-time (AVATAR) project which aims to increase operational efficiency and job satisfaction in mechanized timber harvesting by providing feedback to operators based on machine data. This extended abstract is a report of a work in progress, therefore there are no final results.

Operating a forest machine is a complex task requiring considerable time to master. This leads to large differences in productivity and output quality between the operators. Training provided by method instructors is a one way to improve operator performance, but the training is rarely available to operators. If the instructor aid was readily available to operators at any point of time, there could be potential for continuous learning and improvement. The work presented here aims to establish a method for automatic detection of disadvantageous work practices aiming to give feedback to operators. In this extended abstract *work practices* means the way in which a work task is performed.

The method works in two steps where the first step is an automatic time study based on machine data that divides the work into elements with a high level of detail. The second step is an analysis of specific work practices using the work-element division from the first step. This abstract describes the principals of the automatic time study for harvesters and forwarders and gives an example of detection of a disadvantageous work practice.

For the automatic system we rely on sensor technology and machine data that is available in machines today or that can be technologically accessible soon. So far though, the data has been collected from a real-time machine simulator.

What is described as disadvantageous work practices was identified by interviewing forest machine instructors and forestry-school teachers. A total of 16 interviews were carried out in Sweden, Norway, and Germany.

Material and methods

Machine simulator

The data used in development has been collected from a real time forest machine simulator. It is based on a Komatsu training simulator that has been adapted for research purposes. One such adaptation that is used in this project is the continuous (30 Hz) logging of a multitude of machine data. An observer view from the simulator is presented in Figure 7.

Figure 7. Screenshot from the simulator.

Describing work practices

The development of working skills and efficient work methods through experience is sometimes called tacit or implicit knowledge. This is to distinguish it from knowledge that have been well documented and therefore can be passed on to others. Implicit knowledge cannot easily be passed on from someone who holds it without successfully going through a process of making it explicit. For forest machine operators much of the working skills and methods that they use exists to them as implicit knowledge. There is, however, a group of professionals who have as their specialty to analyse and understand forest machine work. They make that knowledge explicit and to pass it on to others. They work either as teachers at forestry schools or as instructors for professional operators. Their knowledge often comes both from their own experience as machine operators and from seeing and helping many operators with varying experience and skill levels and using different work practices. In this study, interviews with such instructors or teachers were the source of descriptions of disadvantageous work practices. Previously, different approaches have been taken to characterize and detect efficient or inefficient use of forest machines. Ovaskainen et al. (2004) used a manual time study in combination with observation of predetermined detailed work technique characteristics of a group of harvester operators to determine what characterized efficient work. Palander et al. (2012) used John Deere's machine data analysis tool, TimberLink, to automatically detect work elements and then used statistical methods to determine what work element that most accounted for the difference in performance within a group of operators.

For the present study, the interviews were of a semi-structured type where the instructors had plenty of room to elaborate on their thoughts about typically good or bad work practices. The interviewer had prepared questions to stimulate such reasoning and to check for that all elements of work had been covered. Also, for the sake of completeness, the concept of work practices was divided into two aspects: work method and operator skill.

Work method here refers to how an operator structures the work. For a harvester examples of aspects of the work method are in which order the trees are felled, how the machine is positioned in relation to those trees and to the piles where the logs are placed. For a forwarder examples of aspects of the work method are how the machine is positioned in relation to the log piles that are being picked up and how the different assortments are placed in the load space.

Operator skill here refers to an operator's ability to manoeuvre the machine, for example crane movement. Speed, smoothness, "flow", short boom-tip path and precision are aspects of skill in

crane use. For a harvester, one aspect of operator skill is to what degree the operator succeeds in felling the trees in the intended direction.

While these aspects were used during the interviews and were found to be useful there is no clear-cut definitions and they affect each other to a high degree. All interviews were transcribed and abbreviated in a joint document to allow for overview of the results and to judge importance and suitability for automatic detection.

Work element definitions and their identification

The meaning of the notations for the work element definitions in this work may differ from traditional definitions with similar notation. The following sections provide a description of what each work element represents. The more exact definition and how the algorithms identify each work element is also explained. An important difference compared to manual time studies is that work elements can occur simultaneously. Another difference is that not all time is necessarily attributed to a work element. Consequently, gaps may occur between work elements.

Harvester work elements

The harvester-work element identifier handles a total of six work elements, defined as:

- Moving – is when the harvester is moving, i.e. the wheels are rotating.
- Fell cut – starts when the saw is activated while the harvester head is upright position and holding a tree. The element ends when the harvester head has been removed from the stump or the feeding of the stem starts.
- Crane in – starts after Fell-cut and is finished at the start of the first *crosscut*. Note that Crane in therefore includes the feeding of the first log through the harvester head.
- Processing – starts with the feeding of the stem and ends after the last *crosscut* of the stem.
- Crosscut – while the saw is active during processing.
- Crane out – starts after processing and ends on start of next Fell-cut. Note that the positioning of the harvester head to the stem is included in this work element.

Forwarder work elements

The forwarder-work element identifier handles a total of six work elements defined as:

- Moving – is generated when the forwarder is moving, i.e. the wheels are rotating.
- Adjusting – when the grapple is inside the load-space, and neither Crane-out nor Crane-in movement is identified.
- Crane out during loading – starts when an empty grapple leaves the load space and ends when the crane scale registers a weight.
- Crane in during loading – starts at the end of crane out movement and ends when grapple reaches the load-space.
- Crane out during unloading – starts when a **non-empty** grapple (i.e. weight is registered) leaves the load-space, and it ends when the grapple is empty again (i.e. no weight registered).
- Crane in during unloading – starts when crane-out movement ends, and it ends when the grapple enters the load-space.

State-machines for work element identification

Finite-state machines are a concept for building automated processes based on a fixed (finite) set of states. In this concept "state" means a way of being at a particular time (web: Cambridge dictionary,

2020). Note that *state-machine* is a general concept and mathematical model totally unrelated to any actual *forestry machine*.

Each state can have some action happening upon entering or exiting the state. The state machine transitions from one state to another when a well-defined condition is met. A state machine only has one active state at any given time, and it will stay in this state until a transition condition is met. "Stay" in this sense means to continuously checking all outgoing transition conditions for a match. One state can have many transition paths with different conditions leading to other states. One extension of the state-machine concept is to allow for several independent machines to operate in parallel. The resulting system thus have more than one active state, namely one for each sub state machine.

In this work the concept of parallel finite state machines has been used to build the logic to identify work elements. The transitions between states is done by well-defined situations that can be identified from sensors and machine operator inputs, i.e. control signals. The recorded data is processed sample by sample and the state-machines check for transition conditions in the data. Current time is the time corresponding to the sample being processed at a specific instance. All actions performed by the state machines involve handling the work elements. The possible actions done by the state-machines on the work elements are:

- Start – set current time as the start of a new work element and mark it as *running.*
- Stop – set current time as the end of the work element and mark it as *stopped*.
- Save – add the work element to a list of saved elements.
- Pause – mark work element as *stopped.*
- Resume – mark work element as *running.*

Each type of work element is stored in a separate list. The purpose of the state machine concept is therefore to pre-process the data to ease further analysis. The concept is one way to allow separation of the somewhat complex task of analysing sensor data in the purpose of work element identification. One important aspect is that it provides the system with a "memory" of what previous conditions have led to a certain position (state) where a more limited set of possibilities are relevant to check for.

Harvester state-machine work element tracker

The harvester has three parallel state-machines to perform tracking of the work elements defined in the section **Harvester work elements**:

1. Moving tracker – a low complexity state-machine that use wheel angular velocity to determine movement. The state diagram is illustrated in Figure 8 along with descriptions of the state diagram notations used in this work.
2. Felling tracker – a three state state-machine that tracks Fell-cut and Crane-in.
3. Processing tracker – a six state state-machine that tracks Processing, Cross cut and Crane out.

Forwarder state-machine work element tracker

The forwarder has two parallel state-machines to perform tracking of the work elements defined in the section **Forwarder work elements**:

1. Moving tracker – (same as harvester) a low complexity state-machine that use wheel angular velocity to determine movement. The state diagram is illustrated Figure 2 along with descriptions of the state diagram notations used in this work.
2. Loading/unloading tracker – has eight states and tracks all other forwarder work elements.
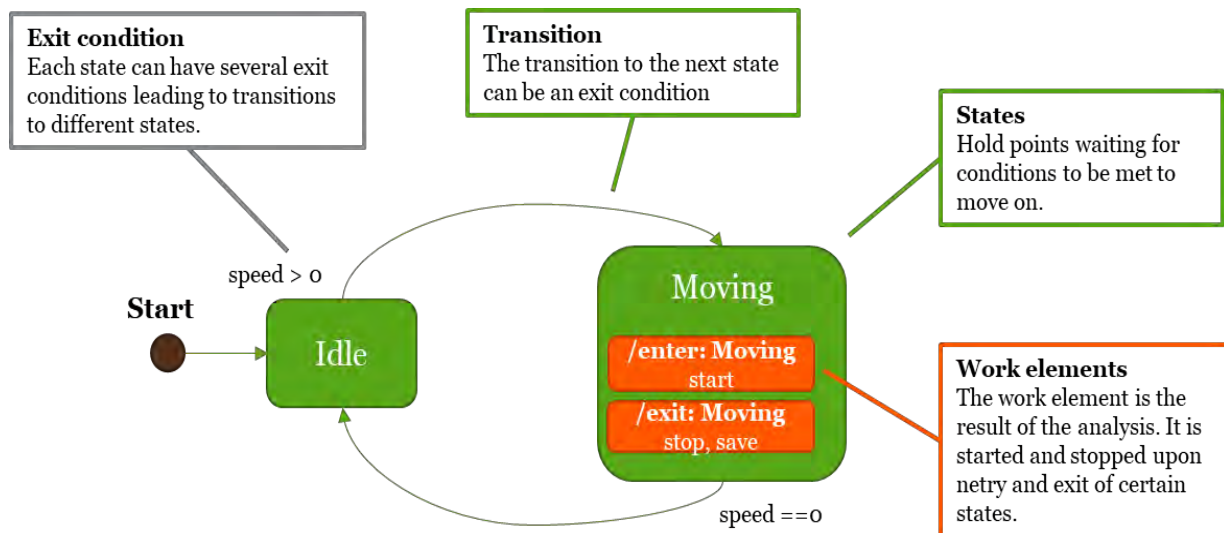
Figure 8. The Move tracker state-machine. This machine is used in both the harvester and forwarder analysis. Description of the parts have been added.

Example of work practice analysis

The analysis is based on the interviews where several instructors commented that it is common for operators to have the crane speed set too high. This results in poor precision and that the operators need to spend a lot of time adjusting the position of the harvester head or grapple at the stem or pile. Therefore, this analysis that shows what proportion of time in the *crane out* work element is spent at different sections of the boom-tip path has been chosen as an example. This analysis is one possible way to capture this behaviour to some degree. The analysis will allow for benchmarking and comparisons between operators as a basis for giving feedback and for following up on the effects.

For each *crane out* cycle, the distance of boom-tip travel path is normalized as 0-100 % where the starting position is 0. The *crane out* distance is sorted into 10 bins evenly distributed from 0-100%. The number of position samples in each bin corresponds to the time spent in each bin. Since all data are evenly sampled, the number of samples in each bin divided by the total number of samples, provides a percentage of the time spent in each bin.

The results from all *crane out* element of the simulator session are then averaged. In addition, the standard deviation for the same dataset is also determined. This results in an operator specific dataset, providing a description of the accuracy and crane movement planning in statistical terms. An operator with the crane speed turned up too high is likely to have a pronounced tail to the right side of the mean. Excessive crane speed is likely to decrease precision when positioning the harvester head or grapple.

This analysis was performed for the *crane out* work element of the harvester and for *crane out during loading* for the forwarder.

Python scripts

The state-machines and all data processing has been performed using Python[2] scripts. The developed code depends on external packages: pandas[3], numpy[4] for data import and processing, and matplotlib[5] was used for graph generation. The work elements were pre-processed from the csv-files and the obtained work element object arrays were saved to disk using pickle. In addition, the glob, os and yaml packages were used.

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[2] Python Software Foundation, http://www.python.org
[3] McKinney (2010), https://pandas.pydata.org
[4] van der Walt (2011), https://numpy.org
[5] Hunter (2007), https://matplotlib.org

Results and discussion

Since the presented work is still in progress, these are preliminary results given as examples of what can be achieved. The presented data is based on simulator sessions done by one operator.

Harvester

An example of work element division of a 500 s long session in the simulator is presented in **Error! R eference source not found.**. We compared automatically identified work elements to video material from the same session and we found that the automatic identifications were correct, though with one exception. The video material revealed that a failed *fell-cut* can erroneously start recording of the *crane in* element (see the two circled peaks in Figure 3). However, the algorithms quickly recover as the second *fell cut* and following work elements are registered correctly. The cost of the failed *fell cut* to the accuracy of the time study will be one erroneously detected *fell cut* and *crane in,* respectively.

The results of work practice analysis of the element *crane out* is exemplified in Figure 9.
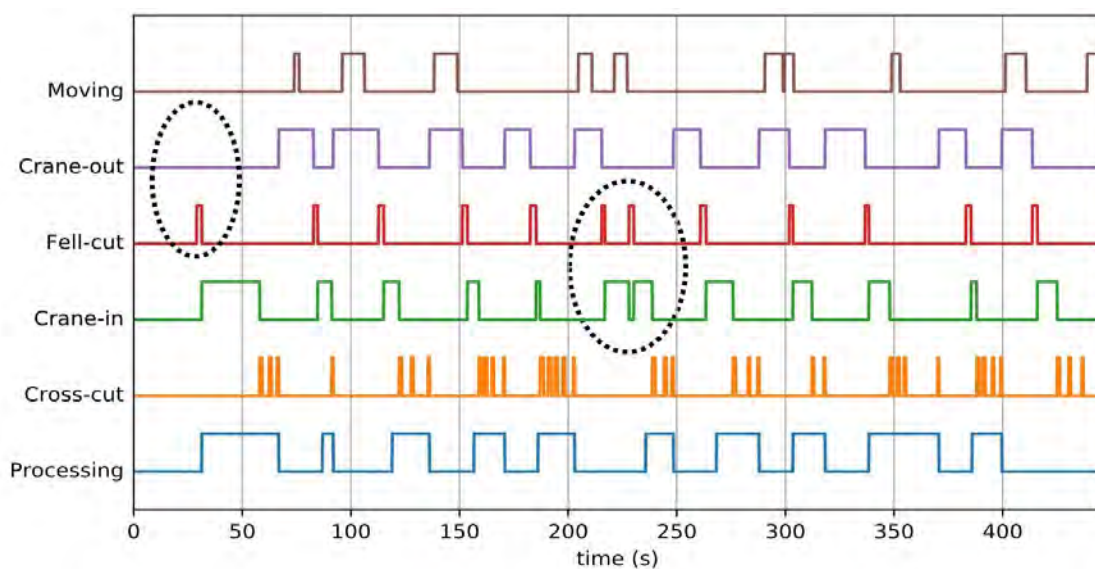
Figure 3. Example of work element division from a 500 s long session in the simulator. Each peak represents the identification and duration of a work element. There are for example 10 identified crane out work elements in the diagram. The dashed oval of the first fell-cut points out a missing crane out at the start of the identification algorithms. The dashed oval at 225 s highlight a failed fell cut mistaken by the algorithm.
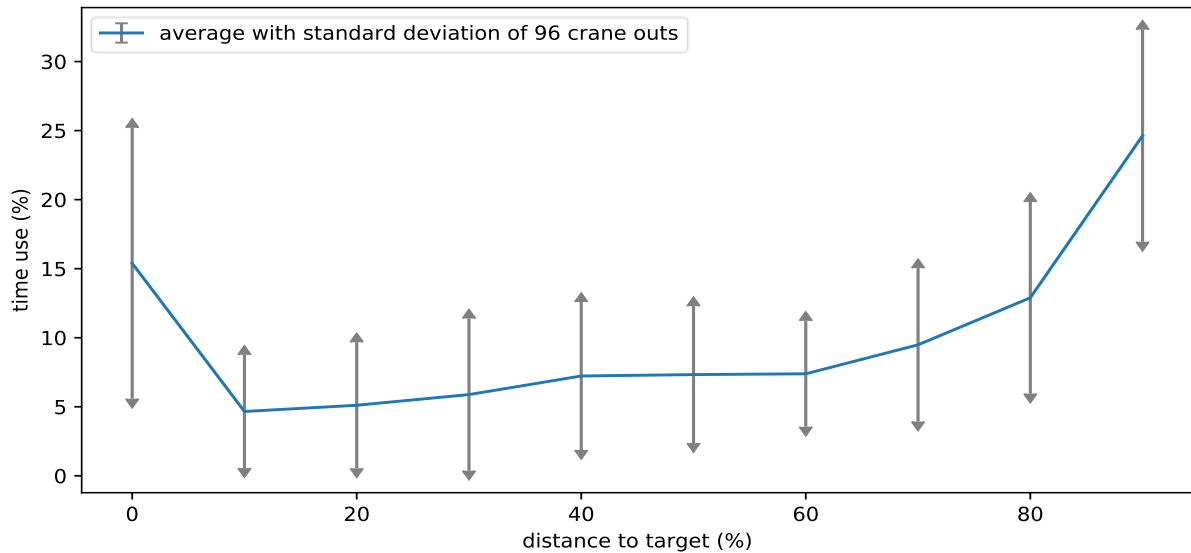
Figure 9. Example of work practice analysis. The distribution of time spent at different parts of the crane out movement for the harvester. The 96 crane out elements were processed from a 3400 s long simulator session.

Forwarder

An example of work element division from a 800 s long session with the forwarder in the simulator is presented in Figure 10. Figure 11 represents the same work practice analysis for the *crane out during loading* for the forwarder.
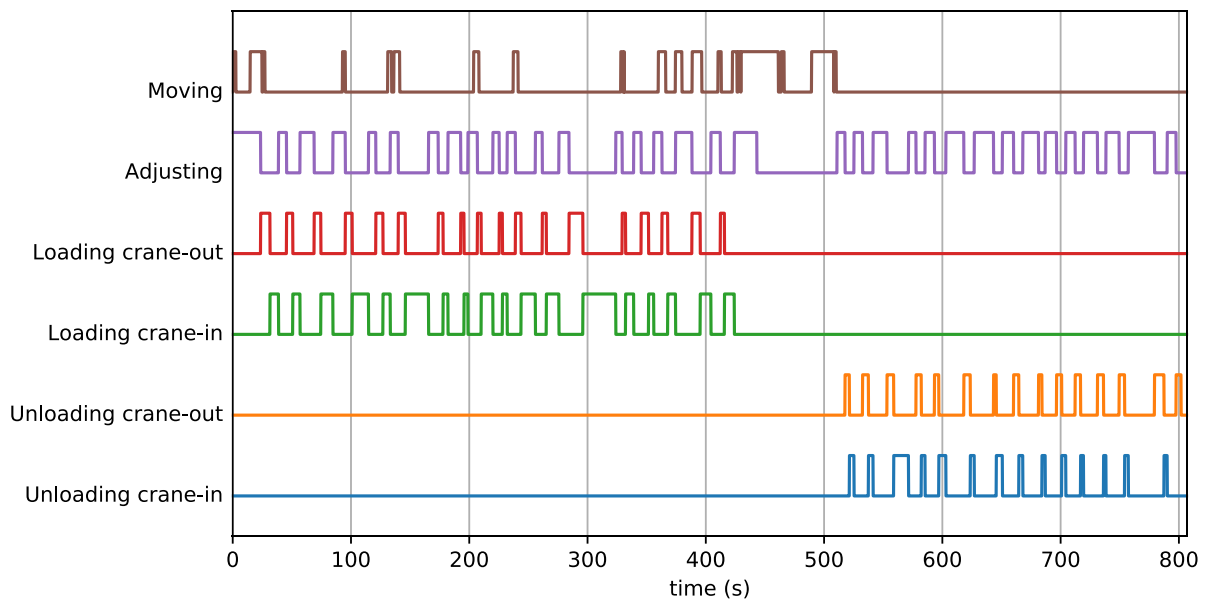
Figure 10. Example of forwarder work element division from an 800 s long session in the simulator. Each peak represents an identified work element.
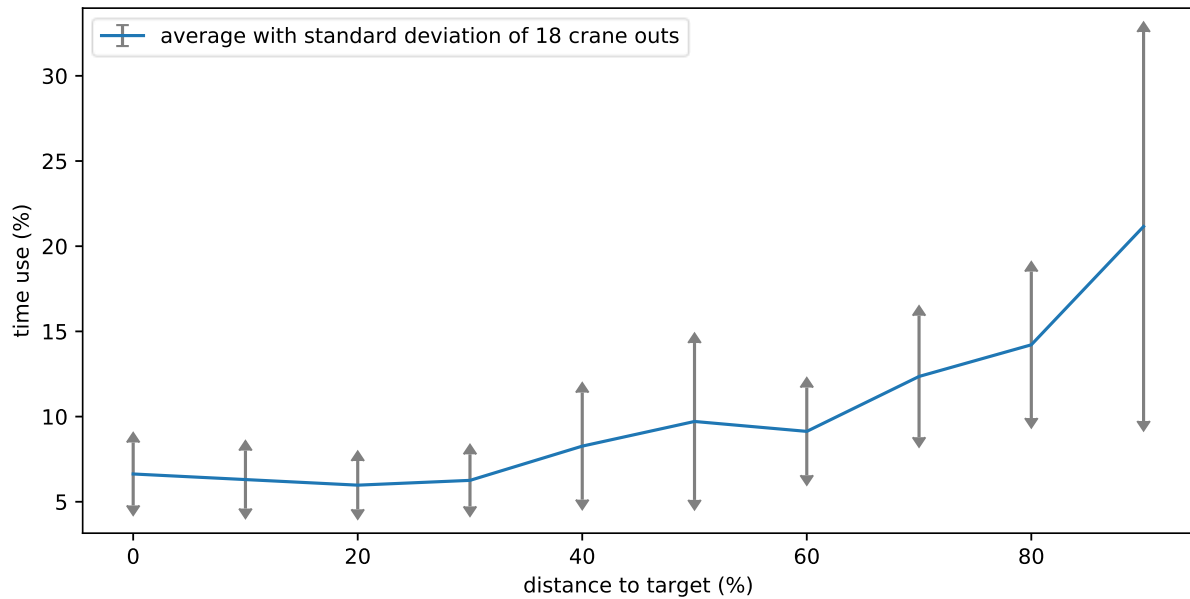
Figure 11. The distribution of time spent at different parts of the crane-out movement for the forwarder.

Conclusions

The presented method for automatic work element identification shows promising results as a basis for further analysis of operator work practice with the goal of giving constructive and specific feedback. It is still a work in progress and actual usability is yet to be determined.

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Comparison of ALS models for the estimation of forest height and wood volume

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The National Forest Inventory (NFI) provide accurate information about forest and woodland resources in many countries and advancement in remote sensing technologies in recent decades, especially in airborne laser scanning (ALS) provide high accuracy data about environment in regional scale. This study looks into different parameters for ALS scanners used in Latvia for country scale laser measurements and is trying to understand which metrics are best suited for estimates of forest inventory variables in hemiboreal forests. NFI data is used as groundtruth and forest inventory variables such as tree height, wood volume and organic carbon stocks are investigated.

Keywords: NFI, ALS, carbon stocks

Measuring Log Piles at Roadside with Photo-optical Mono Camera Systems

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Determination of the stacked volume of log piles at forest roadside is decisive for further logistics processes in Germany. Manual measuring of log piles is time consuming and precision of volume determination is dissatisfying. Recently the use of mono camera systems on smartphone or tablet devices therefore has been on the rise. According to German regulations measuring devices and their legal use have to be certified by conformity assessment. Reliability and validity of log pile measuring by mono camera systems have to be identified and major factors that might affect accuracy have to be revealed.

In order to obtain information on the predictable accuracy of these new measurement systems, most common products available on market were tested in a round robin test using a standardized stacked log pile. Additionally several log piles at forest roadside were rechecked in a repetition test procedure. The baseline for the experimental set-up to determine the measurement accuracy has been the draft requirements of the PTB (the National Metrology Institute of Germany) for photo-optical measuring devices for the designation of front areas on log piles. Trial scope, evaluation and results of this test procedure will be presented.

Keywords: *Measurement, Log piles, Photo-optical Camera Systems,*

Stanfordclassicr: R-package parsing data hidden in StanForD classic forest machine reports to readable datasets

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Despite the xml-based StanForD2010 standard for forest machine data was launched in 2011, many forest machines are still reporting on the former standard. Researchers aiming to utilize forest machine reports in their work will sooner or later have machines from this population in their project and get a bunch of reports based on the former "StanForD classic" standard. An up-prepared human is likely to find these reports rather hard to read and tedious to decode.

Stanfordclassicr is an r-package simplifying the task to read these reports. The main functions take one file filename as argument, reads the file and organize the data in a structure of tables. The output data structure aims to imitate the structure and naming conventions in StanForD2010. People familiar with the new standard will therefore easily understand the structure and content made by this parser. People familiar with R will also easily wrap these functions in a loop function to read a bunch of Stanford classic reports at once.

The package also provides a bunch of example reports. For the moment there are production reports (pri, stm, prd, prl), quality assurance (ktr) and machine monitoring (drf) from a few machine brands. The StanFord2010 counterpart of these reports (like hpr, fpr, hqc and mom) are also put into the package. The core documentation for StanForD classic and StanForD2010 files is also provided. Organizing both reports and documentation like this simplifies the work to further develop and validate the package.

The package can be downloaded from github.com, a platform making it easy to for fellows to download the source of the package and contribute to the package. The package works well for harvester production reports (pri, prd, stm), but is not complete for quality control (ktr) and machine monitoring (drf). Package development is made ad hoc as the need for fetching and organizing data from StanForD classic reports shows up in ongoing projects.

Keywords: *StanForD classic, StanForD2010, parsing of data, R*

Measurement of Boulder Fraction in Forest Land by Ground Penetrating Radar

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Today there is no efficient and accurate method to measure the occurrence and size of boulders in forest land. Research in other areas has shown the potential of Ground Penetrating Radar (GPR) to show various objects hidden under ground. The aim of this study was to qualitatively compare GPR and common manual methods for boulder detection. The measurements where done with two GPR systems in the same scarification tracks as with a manual soil probe. The study has shown that in a radargram we can distinguish between larger structures such as rock outcrops and larger boulders. The study encourages to do some mathematical treatment of the radiograms to show the frequency and size of boulders over larger areas.

Keywords: *Ground Penetrating Radar, GPR, Boulder fraction, Radiogram, Soil probe.*

Measurement of Boulder Fraction in Forest Land by Ground Penetrating Radar

Forest data acquisition with the application Arboreal Forest - measurement precision, accuracy and efficiency

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The aim was to quantify and investigate Arboreal Forest's (AF) measurement errors in different type of stands compared to conventional instruments, but also evaluate the time efficiency during control assessment. The data material included 646 sample trees (5 stands, 42 sample plots) inventoried with both AF and reference tools. Errors were quantified at tree-, plot- and stand level. A time study was conducted with ten sample plots. Relative RMSE (root mean square error) of diameter measurements with AF was 7,1% (1,2 cm) with a systematic underestimation of -2,3% (-0,4 cm). Corresponding RMSE value for height measurements were 3,0% (0,5 m) with a systematic underestimation of -1,4% (-0,2 m), respectively. Relative average RMSE based on all sample plots regarding the stand variables; basal area, mean basal area weighted diameter, mean basal area weighted height, number of stems and volume on bark was 11%, 5%, 3%, 10% and 13 %, respectively. Control assessment with AF was on average 15% more time consuming compared to conventional instruments, however height measurements was performed faster with the application in all cases. Like other instruments, AF is affected by the user's subjective estimation of the root and treetop position while measuring height and further studies on user effects are therefore required.

Keywords: *Forest inventory, augmented reality, forest technology, measurement error, forest estimation.*

SESSION 3 – IMPACT AND ORGANIZATION

Wheel rutting: preliminary investigations of soil redox potential and automated monitoring of their presence using machine learning and high-resolution LiDAR data

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Keywords: open geodata, DEM, NFI, soil health, forest soil, ecosystem services and functions

Introduction and aim

Fully mechanized forest operations involve tractors, harvesters and forwarders driving outside forest roads in forest stands. Soils have highly different soil strength depending on soil moisture content, parent material, and soil development (Forestry Commission, 1991, Horn et al. 2004, Schaffer et al. 2012, Nawaz et al. 2013). Operations planning take soil type, season and recent weather into account to secure sufficient soil strength and to minimize soil compaction and deformation, i.e. wheel rutting.

Most forests have a network of tracks that allow access from forest roads, passing of ditches and convenient passage through the forest stand to minimize risk of damage by wounding tree bark and root systems. The stand age determines the need for operations, i.e. whether it is thinning operations in middle-aged stands or final felling and replanting. In the stand replacement phase the number of machine hours per hectare and year may be substantial, and the risk of severe rutting and compaction is more pronounced. Taken together, these factors imply that clear and visible homogeneous wheel ruts are not likely to be present in every forest stand. Furthermore, severely rutted areas may be harrowed after operations for improved visual appearance and trafficability. To exemplify by two extremes in managed forest: No wheel ruts will occur in forests that were always managed during deep soil freezing or dry soil conditions on loamy soils, and heavy rutting will occur on wet, plastic, loamy soil or peat soil after a final felling.

Wheel ruts are formed when the wheel pressure and traction force cause compaction and deformation of the soil surface. Soil porosity and pore connectivity is decreased, and transport of air and water is thereby slowing down and may cause lack of oxygen (Ampoorter et al., 2012; Ampoorter et al., 2010) that can be monitored by measurement of the redox potential, Eh (Vorenhout, 2011). Soil water saturation depends on precipitation and evapotranspiration history, soil porosity in the unsaturated zone and groundwater level. Loamy soils may be particularly sensitive to compaction and deformation, since the air-filled pore space is relatively small in comparison with sandy soils in the compacted state (Kolka et al. 2012). Sap flow in roots near the soil surface (Nadezhdina et al., 2006) and presence of deeper roots may be negatively affected by compaction and rutting (von Wilpert & Schaffer, 2006).

Nationwide open geodata imagery from recent airborne laser scanning campaigns (2014 and 2015) have made digital terrain models with 0.4 x 0.4 m resolution available (kortforsyningen.dk). In forest and nature management the mapping of trafficability is of interest to machine entrepreneurs that carry out year-round operations with tractors and forwarders that can weigh up to 30+ tons in

loaded condition. Tractor wheel ruts are clearly visible on hill-shaded manipulations of the DEMs, and the length and depth can be quantified by manual annotation. The data can be used for monitoring of wheel rutting as indicating potential areas with anaerobic soil processes. The area of rutted and compacted soil is an indicator of threats to soil health, which is part of the Sustainable Development Goals (UN 2015).

The aim of this study is to report preliminary results from ongoing work that seeks to a) explore the soil environment in and around wheel tracks and b) to develop an algorithm that can automate the quantification of the length and depth of wheel ruts per hectare in forest.

We hypothesize that an algorithm using a Hessian matrix image analysis (Frangi et al. 1998) can filter out wheel tracks from the nation-wide DEM product DTM0.4. The length of wheel tracks per ha and the distributional estimates of wheel track depths can thus be estimated. We further explore the soil redox potential around a wheel rut on a flat loamy soil to examine the aeration status indicated by the redox potential.

Materials and methods

The extent of wheel rutting was visually assessed on 418 national forest inventory (NFI) plots with hill-shaded digital elevation model images, and 64% had visible tracks to some degree (Callesen et al 2019). The ICP Forest monitoring site Vestskoven (55.700˚N, 12.348˚E, Figure 1b) had a pattern of wheel ruts orthogonal (west to east) to the clear signs of former north-south going soil tilling of the afforested arable land.

Soil redox potential was measured in one spot at the site in a preliminary investigation. Platinum sensors (N=14) and a Ag+/AgCl reference electrode were connected via a Hypnos (III) logger (Vorenhout, 2011), that recorded soil temperature and redox potential in mV during winter and spring 20 20.

(a)

(b)
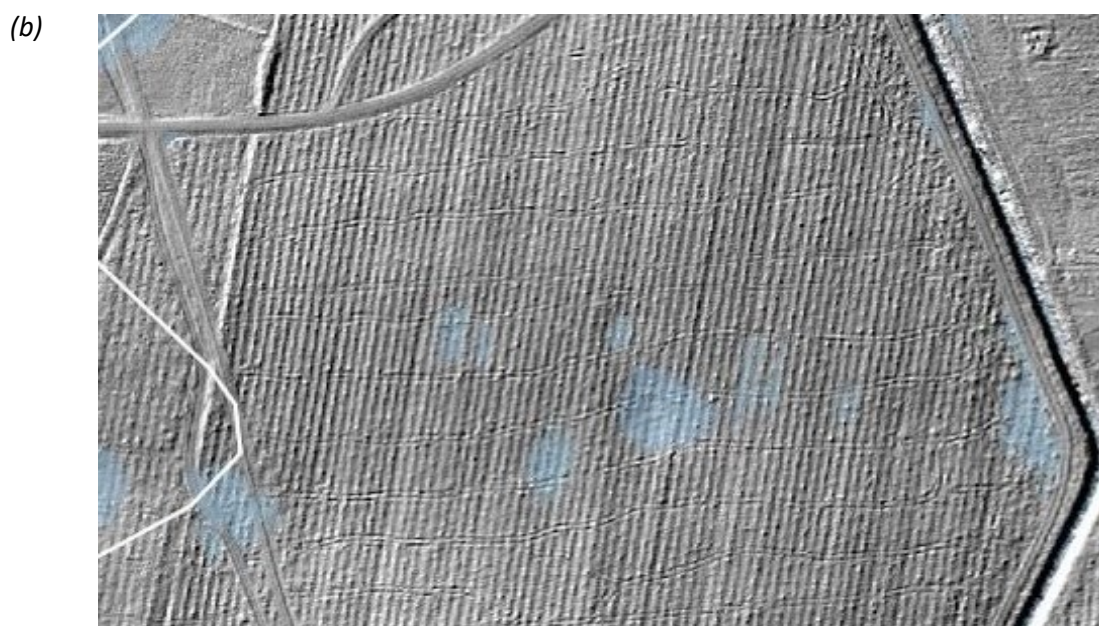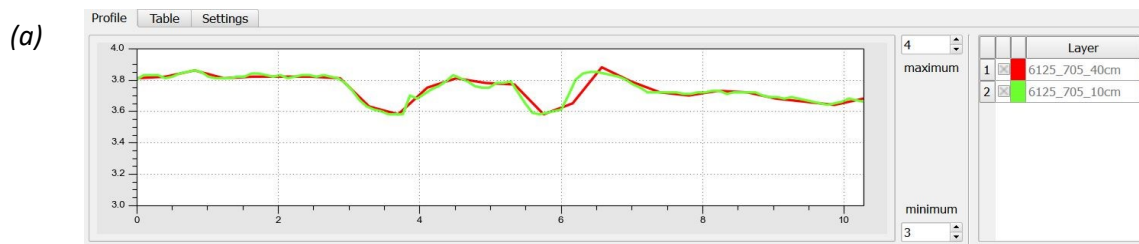
Figure 1a. Examples of a 2D profile from point cloud LiDAR data using 10 cm and 40 cm raster resolution. 1b. Wheel ruts and ditches visible on a hill-shaded DEM (DTM0.4 m model (45° angle with azimuth 270°) left to right in picture and former soil treatment up - down. Blue spots are terrain depressions with no surface runoff modeled on the DEM

Preparation of DEM images

Data computation steps and analysis steps used Python 3.x. The terrain model (DTM0.4) is processed point cloud data and distributed publically by SFDE (Styrelsen for dataforsyning og effektivisering). In post scanning processing steps e.g. flying birds, masts and buildings that would produce artefacts and spikes in the terrain model are removed. The accuracy of the model is from a few cm and up to 0.5 m. The data are aligned into 1 x 1 km seamless tiles. Each file in the geotiff format represents one square kilometer which is ca. 10 MB of data (x, y, z) packed in 1 GB zip-files for download (10 x 10 km packages) and contains x, y and z coordinates in the EPSG 25832 UTM32N CRS. 100 x 100 m files were extracted with sites 50 meters from the point location.

Theory

A line of raster points that is directed across a wheel track (see Figure 1a) will be part of an approximate parabola in the direction orthogonal to the track and be approximately flat in the direction along the track. These conditions may be inspected by computing the Hessian matrix containing the second order image derivatives at suitable scales. The eigenvalue and eigenvector pairs for the Hessian may allow detection of wheel track points since they will ideally be characterized by one high, positive eigenvalue (giving the curvature of the parabola) and one absolute small value (the curvature of the flat direction). The simultaneous fulfilment of these conditions of an eigenvector of a multiscale dataset will generate a classification that can be used for extraction of the points that are candidates for single wheel tracks in a given area. In image analysis, this operation is an example of a ridge detector.

In order to detect wheel track pairs and to distinguish these from ditches, a second ridge detector was used on the output on the first ridge detector. Ideally, the first ridge detector would result in two ridges for the two wheel tracks with a ditch in-between. This ditch may be detected using a ridge detector as above, just using a higher scale since the distance between the wheels is mostly larger than the wheel width.

The key parameters in the ridge detectors are the scale at which the derivatives in the Hessian matrix are computed. For the first ridge detector, multiple scales between 0.1 to 0.5 m were used. For the second ridge detector, multiple scales between 0.5 and 5.0 m were used. Following the classical multi-scale feature detector setup [Lindeberg: https://link.springer.com/article/10.1023/A:1008045108935], the most appropriate scale is selected at each location, ideally allowing detection of tracks within these intervals.

Experiments

The wheel rut detector was developed and tested using a set of artificially generated images where lines (corresponding to ditches) and parallel line pairs (corresponding to wheel ruts) were inserted. The base image was set to a fiducial height, lines and line pairs at different widths were subtracted, and then finally some random noise was added.

Five forest stands of each a few hectares on sandy soil and loamy soils were selected to represent strata of landscape types in Denmark, Table 1.

Sites used in testing the algorithm

Name	Landscape element	Parent material	Forest stand characteristics
Klit	Dune	Aeolian sand	Not assessed
Hede	Outwash plain	Glaciofluvial sand	Spruce, age
Sorø, ICOS§	Young moraine	Loamy calcareous till	Beech, 100 years
Giesegaard	Young moraine	Lacustrine clay	Oak
Vemmetofte 858	Young moraine	Loamy calcareous till	Oak

§ https://www.icos-cp.eu/

Results

The automated wheel rut detection algorithm was successful for the artificial images, with limited noise levels.

However, the algorithm was unsuccessful in clearly identifying ruts in the five test cases. Parts of the ruts where correctly detected, but even more pieces were incorrectly detected.

Redox potential measurements in and around wheel tracks at the site Vestskoven showed that 50% of the sensors (those placed in the wheel rut) were continuously in the anoxic redox potential regime below 400 mV from February to late March 2020. After this time the redox potential was more variable in the aerobic (> 400 mV) as well as the anaerobic (<400 mV) range. Such shifting redox potentials may favor the production of the non-CO_2 greenhouse gasses nitrous oxide and methane.
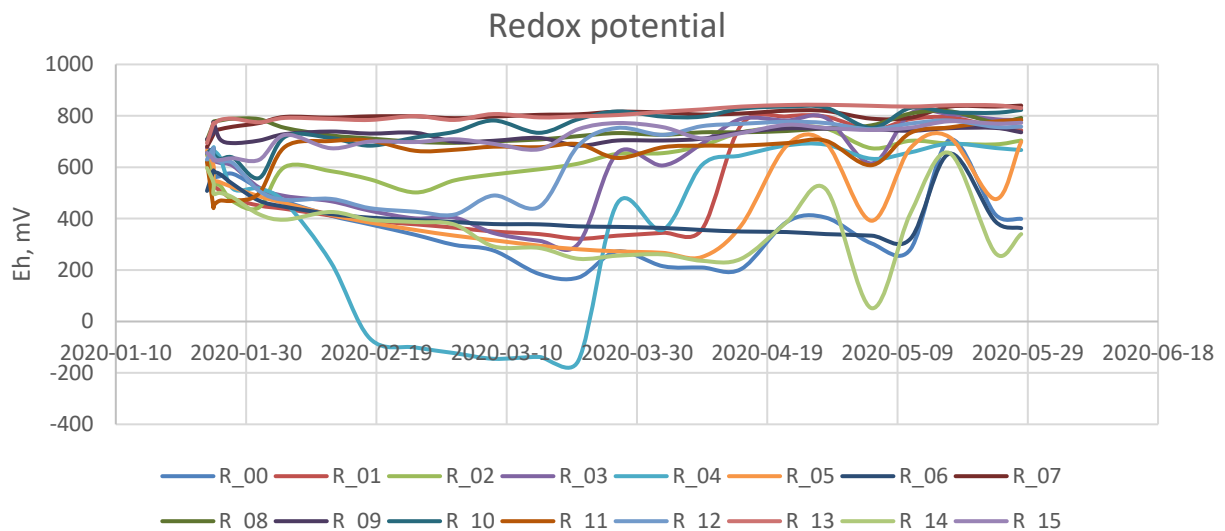
Figure 2. Measurements of redox potentials (Eh). Weekly values filtered out of a dataset of 15 min interval measurements.

Discussion

Types of noise in DEMs and how to deal with it

Regular patterns can be filtered out. These are ditches following channel networks and terrain, and a regular pattern of tilling (Figure 1b). Other shapes such as animal burrowing mounds and tree stumps should not qualify for the ridge filter, and thus not be sources of noise.

Further work

There are sufficient ground points for increasing the resolution of the DEM by smoothing. This could also be a way to improve detection success.

A third step is manual annotation of ruts and training of a model with the annotated image files. We believe that a supervised learning method trained on LiDAR images with manually annotated wheel ruts would be very likely to successfully detect the ruts in unseen images.

The area of soil with compacted, anoxic and shifting oxic/anoxic surface soil conditions caused by wheel rutting is not negligible.

These preliminary studies indicate that 4-6% of the area may be compacted and rutted within a forest site, and that wheel ruts are prevalent in NFI monitoring sites (Callesen et al. 2019). Based on preliminary measurements of a wheel rut, it appears that soil aeration is poor and redox potentials are shifting. Compacted soil may be a source of methane when flooded, and a source of laughing gas when shifting redox potentials occur. This should be included in monitoring, reporting and verification of greenhouse gas budgets in managed forest.

Conclusion

High resolution LiDAR scanning data can be used to monitor wheel ruts in forest. A ridge detection filter was not successful in automating the detection of ruts on multiple files for the ease of monitoring. Further developments with annotated datasets and DEMs with higher resolution are needed. Redox measurements showed that soil environment is anaerobic in and near wheel ruts, and these conditions are known to limit growth and stimulate non-CO_2 greenhouse gas exchange. Therefore, the area and aeration status of wheel ruts should be studied more extensively.

Acknowledgements

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Mapping soil trafficability with statistical models and machine learning algorithms

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Introduction

Ground-based harvesting and extraction requires trafficable terrain. The main factors that affect vehicle movement are slope, soil bearing capacity, the frequency and size of obstacles, and the skidding road network. Those factors can easily be measured on a single plot, but quantitatively describing their spatial and temporal variabilities is much more challenging. For example, soil bearing capacity is not a constant value, but changes periodically because of meteorological conditions such as precipitation or snowfall. Therefore, soil trafficability maps are not available yet.

To fill this gap, we present a method for mapping soil trafficability that is based on statistical models. The models are based on a survey of the Swiss national forest inventory (NFI), on which about 3500 sample-plots were assessed for trafficability (under good conditions, temporal aspect is not considered in this first step), which can be taken as response variable. On the other hand, more than 50 measured and modelled soil properties are available, which are serving as predictor variables. Statistical models, such as logistic regression or random forest were used for prediction.

Material and methods

Response variable

The response describes the property whether the soil on a NFI sample is trafficable with ordinary forestry machinery and can take the values 0 (not trafficable) of 1 (trafficable). The used response variable is based considerably on data of the NFI. The NFI consists of a systematic 1.41 km x 1.41 km sampling grid covering the whole country, resulting in about 6500 plots in the forest (Brändli and Hägeli 2019). Historically, the NFI was developed to measure the forest condition by collecting information about e.g. standing volume or tree species distribution. In the meantime, however, more and more characteristics have been added to the recording. Now, even a wide range of information on forest road networks and timber harvesting are available. In the context of this publication, the survey of timber harvesting and forest opening up is of particular interest (Keller 2013). Unfortunately, the property, if a site is trafficable is not asked directly. However, based on other survey attributes, trafficability can be derived. One such attribute used is the survey of the extraction means (MID 362) (Table 1), which reports the means used in timber extraction for each plot. Another relevant attribute is the site type (MID 222), which contains information about wet soils. Further, we incorporated also the survey of the skidding trails (MID 355) and the harvesting means (MID 352) to derive trafficability.

Table 2: Attributes of the NFI survey MID 362 on extraction means. All means that are used for timber extraction are reported for each plot.

# ID	Extraction mean	Trafficable (y / n / u)
1	Manual logging	U
2	Horse or mule	U
32	Small tracked vehicle with cable winch	U
4	Winch only used for pre-skidding the wood	N
5	Winch mounted on skidder, tractor	U
6	Skidder with forest equipment	Y
7	Special forestry skidder	Y
8	Forwarder	Y
9	Clamshell skidder	Y
10	Tower yarder	N
11	Long distance yarder	N
12	Trailer with crane	U
14	Sledges	U
15	Helicopter	U
16	Cableway	U
17	Ship	U
18	Railway	U
19	Others	U
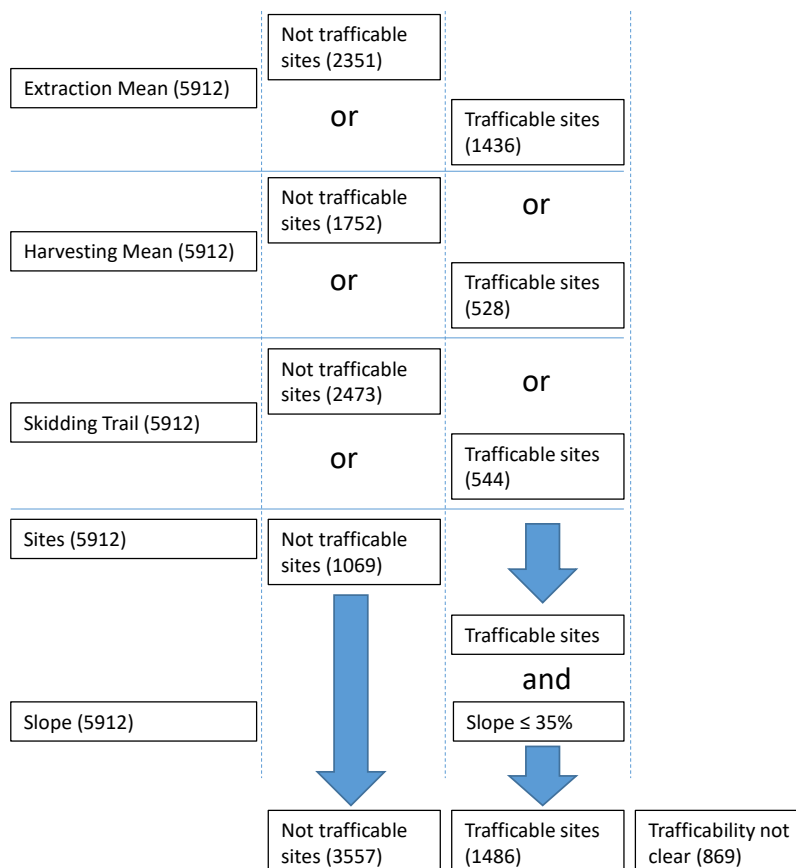
Figure 12: Principle of derivation of trafficable / non-trafficable samples. The numbers in brackets indicate the number of samples. Of 5912, 3557 were classified as not trafficable, 1486 as trafficable and 869 as undetermined.

Based on the surveys, it is not possible to say with absolute certainty for each sample whether it is trafficable or not. For example, if a forwarder was used, then the terrain can be considered as trafficable. But when a winch mounted on a skidder (#5 in

Table 2) was used, it is not clear whether it was used in trafficable terrain, or in non-trafficable terrain to pull timber from a steep part of the forest to the nearby forest road. The aim of the step 'sample cleansing' is therefore to identify those samples for which it can be said without any doubt whether they are trafficable or not. This was done according to the scheme visualized in Figure 12. Out of 5912 samples, 60% (3557) were classified as not trafficable, 25% (1486) as trafficable and 15% (869) as undetermined.

Predictors

The following soil and terrain attributes were modelled for the whole country in 25 m x 25 m resolution and were used as model predictors:

Table 3:Model predictors

Description	Abbreviation
Soil attributes	
soil organic carbon content	(corg_gehalt_final_5_15)
medium thoroughness	(mittlere_gruendigkeit_p)
PH value	(ph_cacl2_0_5)
skeleton content	(skelettgehalt_60_100)
clay / fine soil content (bulk density of the fine soil fraction <=2 mm) [g cm−3]	(trd_feinerde_final_0_5)
Terrain attributes	
A topographic index calculated with radii from 3-80 m and an increment of 25 m [index] (Zimmermann and Roberts 2001)	(ch_3_80_10)
Maximum height difference in a catchment area. Catchment are calculated with Rho 8 (this implementation adopted the original algorithm only for the flow routing and will give quite different results) (Fairfield and Leymarie 1991)	(zmax_rug_s4_25m)
A topographic position index calculated after a script of (Jenness 2006) using 3x3 kernel size	(tpi_1c_25m)
Slope given in percent (Wilson and Gallant 2000)	(slpM0_25m)
Maximum length of flow up to an interruption cell where the slope is considered to end (Wilson and Gallant 2000)	(slplength_s2_25m)
Valley bottoms identified using a slope classification constrained to convergent areas. (Gallant and Dowling 2003).	(MRVBF_25m)
Melton ruggedness index. Ratio of the upslope catchment height and catchment area based on the single flow direction (Marchi and Dalla Fontana 2005).	(melton_rug_s4_25m)
Maximal curvature in all directions (Shary et al. 2002)	(curv_maxM6_25m)
Ratio number of cells having positive curvature to the number of all cells within a circle with 6m radius (Iwahashi and Pike 2007)	(convexity_3_25m)
A topographic position index calculated after a script of (Jenness 2006) using 6x6 kernel.	(tpi0_6_s3 (5m resolution))

Statistical Methods

Random Forest

A Random Forest is a classification procedure that consists of several uncorrelated decision trees. All decision trees have grown under a certain kind of randomization during the learning process. For a

classification, each tree in the selected forest may make a decision and the class with the most votes decides the final classification (Breiman 2001).

The random forest algorithm was implemented using the statistical software R (R Core Team 2016) with the package "RandomForest" written by (Liaw and Wiener 2002). The algorithm was considering of the predictors of each split and was grown with 500 and 2000 trees.

Logistic Regression

The logistic regression (short: logit model) is an extremely robust and versatile classification method. It can explain a dependent binary variable and make a corresponding prediction of the probability of an event occurring or not. The logistic model was implemented using the R-package MASS (Venables and Ripley 2002). The final model was evaluated by performing variable selection based on the Akaike Information Criterion AIC(Akaike 2011).

The measures of the random forest model as well as the logistic model accuracy was defined as the leave one out cross validated root-mean-square error. For a 2-fold RMSE evaluation we have split our datasets into training (90%) and test (10%) datasets. However, to interpret the results only the leave one out cross validated root-mean-square error is relevant.

Results and discussion

Main predictors

The main predictors in the models are slope, skeletal content, permeability and watering of the soils and terrain roughness.

Overall Model accuracy

The output of the logistic regression model is the probability for trafficability located between 0 and 1. If the probability was below 0.5, we defined the target variable as not trafficable (value: 0), otherwise the value 1 (trafficable) was assigned. The accuracy was evaluated by comparing the modelled value with the real values. The 2-fold RMSE (logitmodel) showed an accuracy of 96%.

The error rate of the random forest model was 4%, with the following confusion matrix (Table 2):

	not_trafficable	trafficable	Classification error
not_trafficable	2533	74	0.02838512
trafficable	65	799	0.07523148

Table 4: Summary of the random forest model

Most misclassifications occured in the range around 30 to 35% percent slope inclination, which amounts to classification error of about 10% for this slope class (Figure 2).
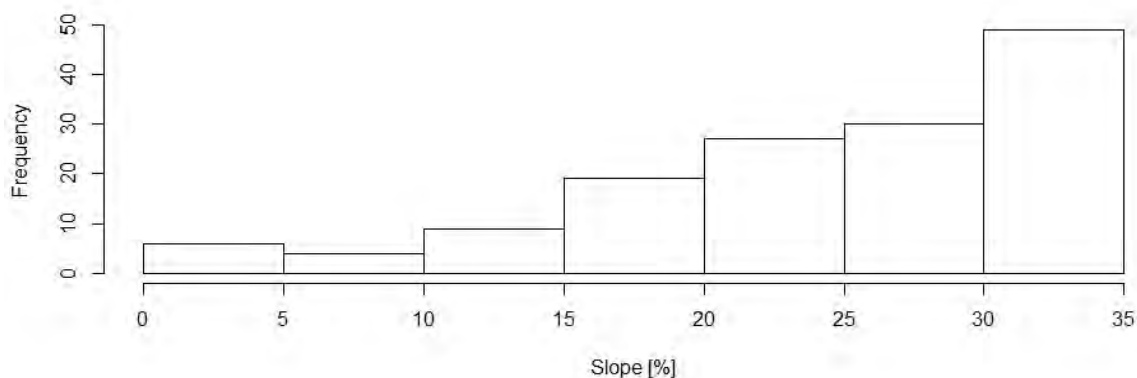
Figure 13: Frequency of misclassification depending on the slope

Conclusions

With this approach a country-wide (Switzerland) trafficability map can be derived that might be used for improved forest management planning. The results are promising, but the field verification is still ongoing. The accuracy is worst for areas between slopes of 25 to 35%. However, this does not mean that the model does not provide useful results for these areas. We rather think that the reason is that the field assessment of trafficability is a subjective one, especially at the borderline areas (similar plots could be once be assessed in the field as trafficable as well as not trafficable). This uncertainty is also reflected in the model. The method presented here could be assessed in other countries, too.

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Emission Reduction Measures in Timber Transportation in Finland

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Background

National goal of Finland is to reduce traffic greenhouse gas emissions by 50% (2005–2030). European Union (EU) and Finnish national objectives include also several other emission reduction goals for transport and cargo handling. These include increased use of alternative motive powers and bio fuels; increased share of rail and waterborne transportation; improvement of transport infrastructure; and new emission standards for vehicles and work machinery. Finnish timber transport produced in 2017 approximately 310 000 tonnes of CO_2eq emissions out of which 81% was produced by road transports; 10% by diesel trains; 7% by electric trains; and 2% by vessels and floatage.

Material and Methods

This study (Venäläinen et al. 2019) provides an overview of currently available and suggested new measures to reduce emissions that are caused by timber transports and handling in Finland. This study was carried out in the autumn 2019 and it is based on the available statistics, research reports, and policy papers.

Results and discussion

The study focuses on technological and operational measures to reduce emissions and excludes fiscal measures and subsidies. The measures are grouped in six categories: fuels, other motive powers, equipment, digitalisation, waterborne and rail transportation, and infrastructure. For each measure the following issues are concisely considered: The status of current use; targets and prospects for use volumes in the future; and impacts on emissions from (timber) transportation or handling.

Fuels. Recent legislation in Finland will raise gradually the share of distribution obligations of biofuel from 18% to 30% by the year 2029 and share of bio-based fuel oil up to 10% by 2028. Finland aims that in 2045 bio-based liquid fuels account for 100% of all domestic fuel use (Särkijärvi et al. 2018). The major challenge with biofuels is that they are restrictedly availability at the market. Renewable diesel is suitable for trucks, diesel locomotives, and (some) machinery at terminals and mills. It reduces greenhouse gas emissions even up-to 90% (Ministry of Transport and Communications 2017). In the long term (10–20 years), synthetic power-to-x (p2x) fuels provide an interesting option, as emission from production facilities, office air ventilation systems etc. may be utilised as CO_2 sources needed in the fuel production. Bioethanol reduces CO_2 emissions from heavy transportation even by 90% (Ministry of Transport and Communications 2017), but the availability of the fuel is very limited today.

Other motive powers. First hybrid timber trucks are now in use in Finland, but research results on their impacts on emissions are not yet available. Several manufactures of cargo handling machinery

provide hybrid options, but they are not yet used in timber handling in Finland. Feasibility of eHighways (roads with contact lines providing continuous electricity supply for vehicles) was recently estimated in Finland (Finnish Transport Infrastructure Agency 2020). 8% of the timber handling equipment at mills are fully electrified. For trucks, fully electric options are available only for low total weights. However, electric timber truck is being currently tested in Sweden (Skogforsk 2019). About 80 gas trucks are operating in Finland (Traficom 2019). Currently, gas trucks are more potential in by-product chip than timber transportation due to limitations in gas distribution network and total weights of gas trucks. Natural and bio gas are already used in some cargo vessels and locomotives. Finland aims to increase use of biogas (Huttunen 2017; Särkijärvi et al. 2018) and it has been estimated that domestically produced biogas could account for a half of the energy use of heavy road transport in Finland (Pääkkönen et al. 2019). Hydrogen and hybrid hydrogen trucks are available at the market, but not used in Finland. High setup costs of the distribution network for hydrogen reduces the potential of this motive power in the medium term.

Equipment. Besides alternative fuels and motive powers, emissions from trucks and cargo handling machinery may be reduced by various other means: more energy efficient motors, energy saving tyres, lower equipment's own weight, higher total weights (HCT trucks and LHT trains; Venäläinen & Poikela 2019, Venäläinen 2019), and improved aerodynamics (Löfroth & Gelin 2015). Estimation of impacts of these measures in timber transportation and handling needs further research in the future.

Digitalisation. Digitalisation as a measure to reduce emissions from transportation refers to fully or partly automated driving, route optimisation and backhauling, platooning, ecodriving, and Advanced Driver Assistance Systems (ADAS). Some of these measures are already widely in use, but more in-depth understanding of their impacts on fuel consumption in (timber) transportation is needed.

Rail and waterborne transportation. 23% of Finnish timber (39% of m^{3}km) is transported by rail and 2% (4% of m^{3}km) by vessels or floatage (Strandström 2018). New Stage III B standard (which concerns also locomotives), replacing old diesel locomotives, heavier and longer trains (LHT), and in the future hydrogen locomotives are means to reduce emissions and improve energy efficiency of train transportation of timber. Vessels utilised in domestic timber transportation are rather small and old. Due to the low transportation volumes, major development in vessels is not expected. However, there are other means (such as improved exchange of information in supply chains) to improve efficiency and thus competitiveness of waterborne transportation.

Infrastructure. Since ¾ of Finnish timber is transported by roads (and all train and waterborne transportation includes in average 50 km pre-transportation by trucks) (Strandström 2018), condition of road network (including winter maintenance) has great impacts on trucks' fuel consumption (Väylä 2019). Renovation of the network is needed both on public and private roads. 73% of Finnish timber transported on rails are carried by electric locomotives. Only 56% of Finland's rail network is electrified. Further, bottlenecks of the rail network restricts potential to increase rail transportation volumes. In waterborne transportation, infrastructure at some loading ports needs to be upgraded to allow larger transport volumes (for example construction of more berths and larger storage areas).

The study identified research needs for the future. These include cost impacts of emission reduction measures; life cycle impacts of measures (instead of emissions during use only); and in-depth research on impacts, especially in timber transportation and handling.

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Potential for improved energy efficiency and cost reduction through HCT vehicles for roundwood transportation in Sweden

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Keywords: HCT, high capacity transportation, efficiency

Introduction

As the Swedish road network is progressively opened up for high capacity transportation (HCT) vehicles with gross weights up to 74 metric tonnes, as opposed to the earlier limit of 64 tonnes, a burning question is what is the most cost and energy efficient vehicle combination. When the gross weight limit was increased from 60 to 64 tonnes in 2015, there was an immediate positive effect on both hauling costs and energy expenditure per tonne km. In addition, there was in many cases no need for investing in new equipment. Estimates indicated high potential in further increasing the gross weight limit, and initial tests with gross weights up to 90 tonnes were conducted in Sweden from 2009. Fears that the vehicles would be difficult to manoeuvre and suffer from long braking distance showed to be mainly unfounded. On the other hand, the increased weight limit was not reciprocated with a corresponding increase in vehicle length limit. Since the vehicles cannot be loaded higher, this imposes a constraint on the possible load volume that is in some cases the limiting factor, rather than the loaded weight. For roundwood transportation, this may occur for crooked stems, short assortments or seasonally occurring low density wood. The purpose of this work has been to investigate what efficiency can be expected for vehicles rated for different gross weights when transporting roundwood subject to the seasonal and other variations seen in Sweden. The goal is to give a quantitative estimate of efficiency both in terms of economy and energy use.

Materials and methods

The work is based on interviews with truck drivers, and truck and trailer retailers. The cost calculations have been made with a model developed by Skogforsk (Johansson & von Hofsten, 2017). Data regarding fuel consumption has been collected from trucks taking part in one of the initial HCT experiments (Brunberg & von Hofsten, 2018). The figures regarding load utilization have been computed from data on assortment distribution and raw volume weight collected for almost all delivered wood in Sweden during 2015-2018 (Asmoarp & von Hofsten, 2019).

Cost and energy analysis for vehicles of different gross weight

The life-cycle cost of roundwood vehicle types typical for Sweden and of different maximum gross weight has been analyzed. The analysis considers factors such as investment cost, fuel consumption, maintenance, salaries, load utilization and various other factors. Vehicle combinations of different gross weight require different engine specifications and number of axles. Retailer recommendations have been used to find appropriate technical specifications for the different vehicle alternatives along with investment costs. Table 1 presents data for a truck with detachable loader and trailer, common in mid-Sweden, and of three different rated gross weights. The gross weights are dictated by the chosen number of axles, the 74 tonnes limit and the maximum allowed axle group weights.

The figures for fuel consumption are the average values for driving loaded and unloaded (Brunberg & von Hofsten, 2018).

Table 1. Technical specification of three truck combinations with detachable loader and trailer.

Truck	Engine (hp)	Trailer, axles	Tare weight (t)	Max GWT (t)	Power ratio [kg/hp]	Axle group loads [tonnes]	Fuel consumption [l/100 km]
6x4	500 hp	4	18	64	128	9+19+18+18	54
6x4	580 hp	5	19	70	121	9+19+18+24	56
8x4*4	650 hp	5	20.5	74	114	9+23+18+24	58

Theoretical potential

If 100 % load utilization can be achieved, the trend is a decreasing cost per tonne kilometer as gross weight increases, as presented in Table 2. The difference between the 8-axle, 70-tonne combination and the 9-axle, 74-tonne combination is small, however. This is explained by the need for bigger and more powerful engines and heavier and more expensive equipment overall.

Table 2. Transportation cost and energy economy for roundwood transportation under ideal conditions (100 % load utilization).

Gross weight	Cost (SEK/t km)	Energy (ml dielsel/t km)
60 t, 7 axles	0.989	24.8
64 t, 7 axles	0.946	23.5
70 t, 8 axles	0.887	22
74 t, 9 axles	0.885	21.7

On the influence of raw volume weight on load weight

Practically achievable load weights can be calculated from data about raw volume weight variation over the year, log lengths of present roundwood assortments and available load volume. Fig. 1 shows how the different vehicle combinations are affected by raw volume weight variation over the year. The 64-ton combination is virtually unaffected, save from a decrease during the winter due to snow and ice build-up, since volume is not the limiting factor. The 70- and 74-tonne combinations are, on the contrary, hampered by the lighter wood during summertime.

Load weight variation over the year in mid-Sweden
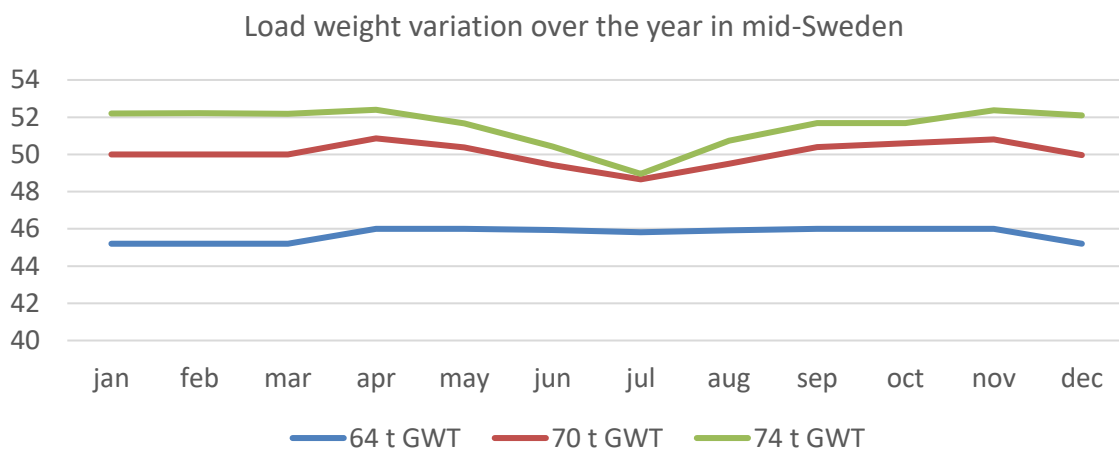
Figure 1. Load weight variation over the year for vehicles of three different maximum gross weights. Load utilization decreases during summer due to drier and lighter wood. Available load is also decreased during winter due to snow and ice build-up on the vehicle (Asmoarp & von Hofsten, 2019).

In terms of load utilization, the expected load weight variation over the year translates to an average of 100 % for the 64-tonne vehicle, 98 % for the 70-tonne vehicle, and 96 % for the 74-tonne vehicle.

Table 3. Transportation cost and energy economy for roundwood transportation under realistic conditions (varying load utilization).

Gross weight	Cost (SEK/t km)	Energy (ml diesel/t km)
60 t, 7 axles	0.989	24.8
64 t, 7 axles	0.946	23.5
70 t, 8 axles	0.903	22.3
74 t, 9 axles	0.914	22.4

Table 3 shows the expected transportation cost and energy efficiency under these more realistic conditions. There is an optimum for the 70-tonne, 8-axle combination both with respect to cost and energy. Although the figures about load utilization are based on calculations, they are largely confirmed by interviews with haulers and statistics from the initial HCT experiments. The experiments showed over-all a somewhat lower load utilization for all the studied vehicles, likely due to cautious loading stemming from uncertainty regarding loader scale accuracy.

Effect of a limited HCT road network

If the road network is only partially open to HCT, some transportations must be carried out with the gross weight limited to 64 tonnes. This reduces efficiency drastically, since the tare weight of a HCT vehicle is normally larger – and consequently the net load weight smaller - than for a 64-tonne vehicle. Table 4 presents the calculated costs and energy efficiency for partially loaded HCT vehicles.

Table 4. Transportation cost and energy economy for roundwood transportation when gross weight is limited to 64 t. A reduction in the fuel consumption for lighter loaded vehicles has been considered.

Vehicle combination	Cost (SEK/t km)	Energy (ml diesel/t km)
60 t, 7 axles	0.989	24.8
64 t, 7 axles	0.946	23.5
70 t, 8 axles	0.993	24.5
74 t, 9 axles	1.064	25.7

It is unavoidable that some transportations must be carried out under a 64-tonne restriction. If, for instance, a short section of a route is closed to HCT, the whole transport is affected. The break-even point when the 70-tonne vehicle is more profitable than the 64-tonne vehicle is when at least 50 % of the transportations can be carried out exploiting the full 70-tonne potential.

The presented figures refer to a vehicle combination typical for mid-Sweden. Vehicle that are common in other regions differ mainly in their loader arrangement, and hence the available load weight. Similar calculations as above for those vehicles give different figures for cost and energy use, but the general trends are the same; Both economical and cost efficiency attain a minimum for the 70-tonne combinations.

Discussion

Several factors influence the results of the presented analysis. The most uncertain parameter is probably the fuel consumption and its variation with load, which was taken from a follow-up of a comparatively small number (a dozen) of vehicles. The calculations of load weights have been carried out without regard to possibilities to more space efficient loading of the stacks through new log lengths, improved loading schemes etc. Depending on geography, vehicle fleet composition and other factors, it may be possible to increase marginally the load utilization of HCT vehicles through vehicle specific transportation planning and more efficient loading.

The technical specifications have been selected from retailer recommendations. Arguably, smaller and less expensive engines may be sufficient for the heaviest vehicle combinations in flat topographies, which would reduce the cost per tonne km. The weight-to-power ratio is slightly lower for the heaviest vehicle combinations, indicating some potential for such a reduction. It should however be borne in mind that engine displacement, rather than rated power, determines fuel consumption. Retarder efficiency and durability are also factors limiting the room for smaller engines.

Conclusion

It is essential that the road network open to HCT is large enough for the majority of transportation to be carried out taking advantage of the increased gross weight. Otherwise, investment in HCT vehicles is probably not motivated from an economical point of view. Economical and energy/environmental considerations do not always match, but the calculations indicate that also with respect to energy use, the 70-tonne, 8-axle vehicle is probably optimal under current length regulations. It is essential that reliable loader scales are available, minimizing the risk for over- or underloading the vehicle. For the future, altered length limitations are likely necessary for vehicles larger than 70 tonnes to be interesting.

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Assessing the relationship between depth-to-water mapping and rut formation, following fully mechanized harvesting operations in Norway

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The preservation of forest soils functionality is a key aspect in planning mechanized harvesting operations. Therefore, knowledge and information of the stand characteristics are vital within the planning process. In order to provide an additional basis for the decision-making process, maps have been calculated, predicting the depth-to-water (DTW) level by using digital terrain models.

To test the applicability and importance of these DTW-maps, the ground surface condition of 20 clear-cut harvesting sites was recorded post harvesting, using a drone (UAV) equipped with an RGB camera. Based on the created orthomosaics, 80km of tracks were categorized by the severity of occurring rut-formations. By adding the calculated DTW-information it was investigated if: i) operators avoid areas with low DTW-level by default, ii) a correlation between decreasing DTW-level and increasing rut severity exists, iii) DTW-maps can serve as reliable decision-making tool minimizing the environmental effects of big machinery deployment. In order to cover a larger entity of seasonal weather conditions, five different DTW-map scenarios were calculated ranging from very wet to very dry.

Initial results suggest that the frequency of harvester and forwarder tracks outside and inside of the low DTW-areas do not differ significantly. While the machine operators did not have access to the DTW maps during the operations, they did not show evidence of actively trying to avoid these areas based on their own judgement. However, a trend towards a higher frequency of severe rutting within areas of very low DTW-level was proven.

Keywords: *fully mechanized harvesting operations, soil trafficability, depth-to-water mapping, rut severity, drone imaging, UAV*

Developed collaboration in contractor forestry – an intervention in relational development

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This paper describes how a training effort in relational development is implemented at two forest companies in Sweden. The training focuses on professional feedback on prerequisites for work as well as quality of work performed. Openness and trust is expected to allow forestry contractors and their customer to operate more effectively within the system, thus gaining benefits both economically and on working conditions.

Qualitative approaches were used to describe the training process and investigate how the efforts affect effectiveness and collaboration between the parties.

One of the forest companies included both officials and contractors in the training effort. Participants of this intervention all agree that openness and understanding of the processes in the supply chain have increased. However, systematic feedback has not yet been achieved; there is uncertainty about what to give feedback on and who is responsible for ensuring that feedback actually takes place.

The other company chose to implement the training effort with only forestry officials present. In this case, the contractors acted as a reference group to evaluate if and how relations between officials and contractors developed during the period studied. Most of the officials believe that their commitment and the effect on communication would have been better if the contractors had been involved. Halfway through the project, focus changed and was directed more towards the officials themselves. During the meetings the colleagues got to know each other better and got an opportunity to reflect on and discuss issues that they usually not have time for and this was perceived as positive.

Keywords: feedback, forestry contractor, relational development, training

When does a logging or transportation company need a foreman?

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In Finland, harvesting and transportation companies have traditionally been small companies with a few forest machine fleets or logging trucks, where the company's named manager has also participated on practical work tasks. However, there has been a trend in contracting towards larger company sizes, e.g. through extensive regional contracting. Extensive regional contracting refers to the practice where a forestry company enters into a contract with only one main harvesting or transportation contractor on a certain region, which in turn enters into own contracts with subcontractors. This causes a change in operations where at least a full-time foreman is needed for the main company to planning tasks. This is also a common situation when an individual small company expands its operations, the need for pure work planning and management increases.

The aim of this study was to find out the correlation between the company manager's job description and the size of the company and to try to find out the size of company when the company's manager moves from partially practical work tasks purely to the planning and management tasks of the company. The results indicated that the majority of forest machine contractors job descriptions move to typical manager tasks when there are more than six forest machines (3 or 4 machine fleets) in the harvesting company. The job description of a transportation contractor becomes a manager when the company has an average of four logging trucks or more. In both logging and transport companies, these numbers of forest machines or trucks mean about ten employees. The boundaries are not always so unambiguous and shifts in both directions occur.

Keywords: *logging contractor, transport contractor, contracting, logging truck, forest machine*

SESSION 4 – WOOD USE

New opportunities in the forest value chain based on digital declarations of wood and fiber properties

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One challenge when using forest raw material in industrial production is its heterogeneous nature. Wood and fibre properties like wood density, size and distance of knots, heartwood content and fibre dimensions vary with factors like tree species, stem dimensions, tree age and geographical growth place and are highly impacting processability and suitability for different wood and fibre products. Variation is significant both between trees in a stand and on average between different stands. Therefore, information about wood and fibre properties should represent a significant potential to improve operations through better planning and selection of raw material to final products. Today however, only very limited information on wood and fibre properties of the forest raw material is available to the forest industry. At the same time, a lot of detailed digital data about harvesting operations and measurement technology like x-ray in sawmills provide opportunities to link forest and forest industries together. In this project, we have developed a concept of digital declarations of wood and fibre properties based on models and data from harvesters and forest registers. The calculated properties could then be evaluated based on measurements from industry. The concept has been developed and tested with positive results in cooperation with forest companies Holmen, SCA and Sveaskog and the common IT company of the Swedish forest sector, Biometria within the framework of the strategic innovations program PiiA (Process Industry IT and Automation).

Keywords: *Wood properties, fibre properties, digitalization.*

GreenLane IBM - integrating Insect, Blue stain and Moisture content prediction Models for value tracking in supply chain simulation

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Introduction

Intensified forest disturbances across the globe (Dobor et al. 2019, Zimova et al. 2020) challenge the forest sector. In 2019, salvage cut volume reached 62 % of the annual cut in Austria (BNT, 2020). Although it is unclear if increased forest management activities by harvesting bark beetle infestet trees as soon as possible can prevent further damage (Dobor et al. 2019), this will be the usual and in many countries legally required forest management response in production forests (Hoch et al. 2020) leading to an oversupply on the timber markets. As a decoupling strategy in the wood supply chain, the storage of roundwood (within bark) is necessary to achieve effective supply operations (Jonsson 2012). Wood quality loss can start immediately after the trees have been felled. This involves drying, discoloration, insect infestation and decay. Therefore, the forest-based sector tries to process the wood within reasonable time in relation to wood quality dynamics, which is especially challenging if forests are damaged by natural hazards (Riguelle et al. 2017).

Decay of wood is also influenced by the storage conditions and various studies of stored storm-damaged wood have been conducted to determine how wood properties change over time (Jonsson 2007, 2008, 2012, Blom and Thörnqvist 2014, Riguelle et al. 2017). However, most studies focus on long-term artificial wet storage whereas more versatile prediction models have rarely been developed.

To better cope with risks and unforeseen events and to decrease value losses in the timber supply chain proven managerial responses may support decision makers. A wood value estimation module as part of a virtual supply lab enables users to quantify effects on net value delivered to mill based on decisions taken (Westlund et al. 2019).

Therefore, the goal of the present study is to develop an integrated weather-driven framework for wood quality prediction or more precisely for the main drivers Insects (I), Blue stain (B) and Moisture content (M). The IBM model will enable value-tracking within a virtual supply chain laboratory environment. The focus is on finding appropriate models, implementing them in a general concept and validation of existing models for insects, blue stain and moisture content (freshness).

In case of blue stain development during storage of logs, limited knowledge exists. Representatively for the IBM model, the current prototype of the blue stain (b) model, and the underlying study and analysis concept will be presented.

Materials and Methods

IBM model concept

A survey of the Norwegian, Swedish and Austrian sorting rules and criteria for timber of Norway spruce (Picea abies), the main commercial timber species in the three countries, shows that the quality criteria that influence the storage include insect infestation, bluestain or sapstain occurrence and moisture content change (Holzfeind et al. 2019). Based on these findings, wood value paths help to understand the logic behind criteria changes induced by the before mentioned biotic and abiotic factors (Figure 14). To predict the behavior of all three factors, prognosis models were identified where available. For insects, specifically the eight-spined European spruce bark beetle (Ips typographus), PHENIPS presented by Baier

et al. (2007), will be used and tested to predict time of swarming of bark beetles, their subsequent breeding development and the numbers of generations. Persson et al. (2003) developed a model (TorkCalc) to predict the moisture losses during storage of pulpwood. This model shows that the drying rate is depending on temperature, relative air humidity and exposure of the piles to wind and sun. Friedl et al. (2004) proposed an approach to predict discoloration of the sapwood due to blue stain over time. All three mentioned prognosis models require weather data such as temperature, humidity and solar radiation as input data. While models for (I) and (M) have been presented in detail and tested insensitive over time, the functions proposed by Friedl et al. (2004) have not undergone further investigation. Therefore, in the following sections the focus is on blue stain modeling by describing the background and additional modelling.
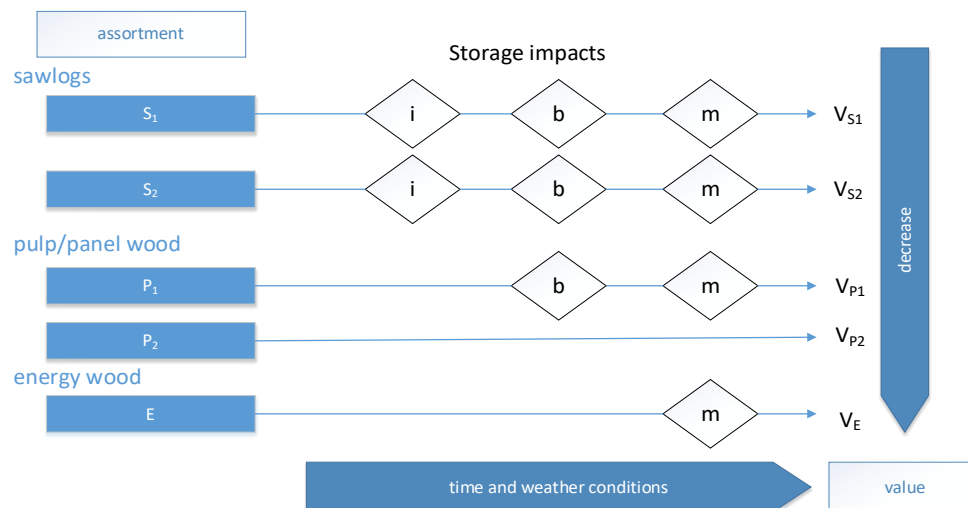
Figure 14. Basic framework illustrating the storage impacts which reduce wood value during dry storage of harvested timber.

The B-model - modelling of blue stain development

Friedl et al. (2004) carried out field trials at four different locations in Austria with four different variants (bark beetle summer/winter and air summer/winter). The four variants accounted for two major factors influencing blue stain development, that is time of felling and mode of fungal infection (either by spores disseminated by air or fungal dissemination by bark beetles, particularly Ips typographus). The variants 'winter' were setup in March before swarming of bark beetles. The variants 'summer' were setup in June. Additionally, the variant 'air winter harvester', consisting of harvester-felled logs with higher levels of stripped off bark, was setup at one location, but for the development of new blue stain models this variant was excluded.

At each location 30 logs with a mid-diameter between 25 and 30 cm and a length of two meters were laid out at the 'winter' as well as at the 'summer' variants. To prevent bark beetle attack 'air' variants were treated with the pyrethroid 'Ripcord 40'. A data logger recorded the air temperature at the storage sites every hour. Tracking of blue stain development took place with a fixed sampling interval of approximately every two weeks. At each sample date five logs were processed according to a fixed cutting scheme to obtain cross sections for various measurements and evaluations. The cutting scheme differed between the variants 'bark beetle' and 'air', taking into account that in the 'air' variants blue stain was expected to develop mainly from log ends. On the stem discs selected for blue stain quantification, heartwood, blue stained sapwood and unstained sapwood were delineated manually (Figure 2a). Stem discs were subsequently digitized with a digital camera mounted on a tripod. A metal frame with scale bars served as a reference (Figure 15a). As the contrast of the different areas would not allow automated detection of discoloration by image lab analysis software, manually coloring of the different areas using image processing software was required. With the support of image lab software, the different coloured areas (sapwood, heartwood, discoloured wood) were determined for each cross section (Figure 15b). For each

stem disc, the percentage of blue stained sapwood was calculated, which was used as parameter in the analysis.

(a)   (b)
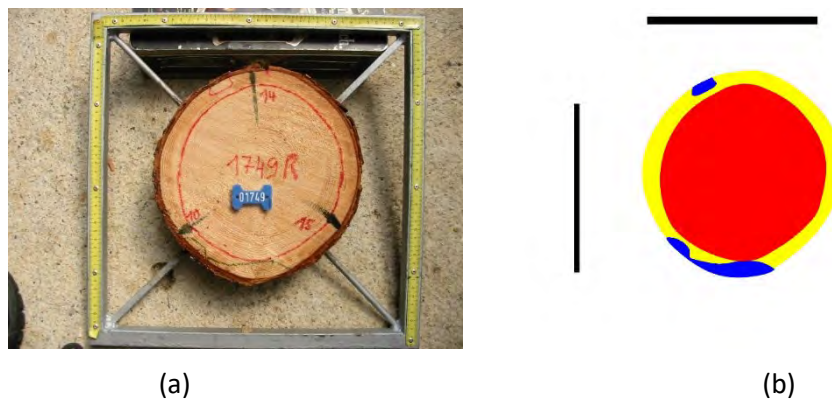
Figure 15: Cross section (1749R) cut from location (a) and the digital colored areas for unstained sapwood (yellow), heartwood (red) and blue stained sapwood (blue) (b). Additionally, scale bars on top and the left side were added as reference for quantification of the respective areas with image lab software. On this stem disc 16.2% of the sapwood area was calculated as blue stained (Friedl et al. 2004).

Results and Discussion

First decriptive plots indicate that at each location and for each variant, the percentage of blue-stained sapwood (%BSA) increased with later sampling dates (T1 - T6, Figure 16). At the air variants blue stain development was faster at the outer log crosssections (L and U) than at the inner ones (O and R) (Figure 17). This reflects the major entrance courts of fungi from cut surfaces of log ends.
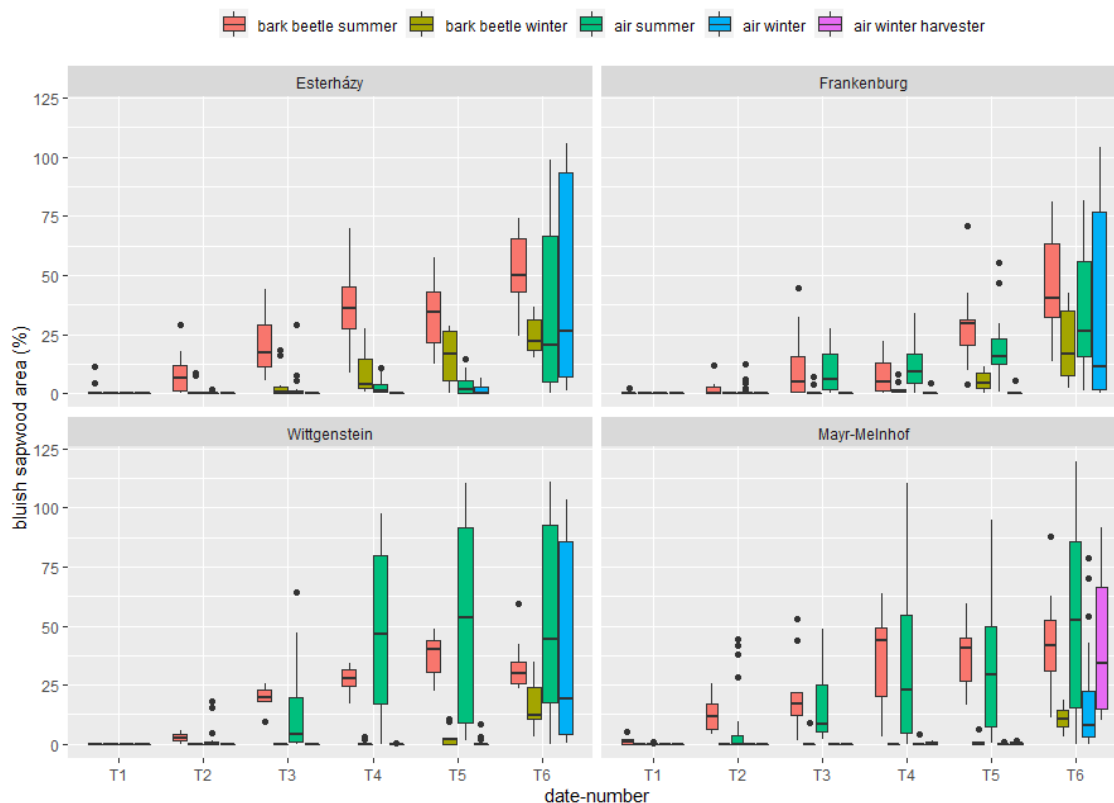
Figure 16: Boxplot of percentage of blue stained sapwood depending on date-number, variant, and location. Each boxplot represents mean values from five logs.
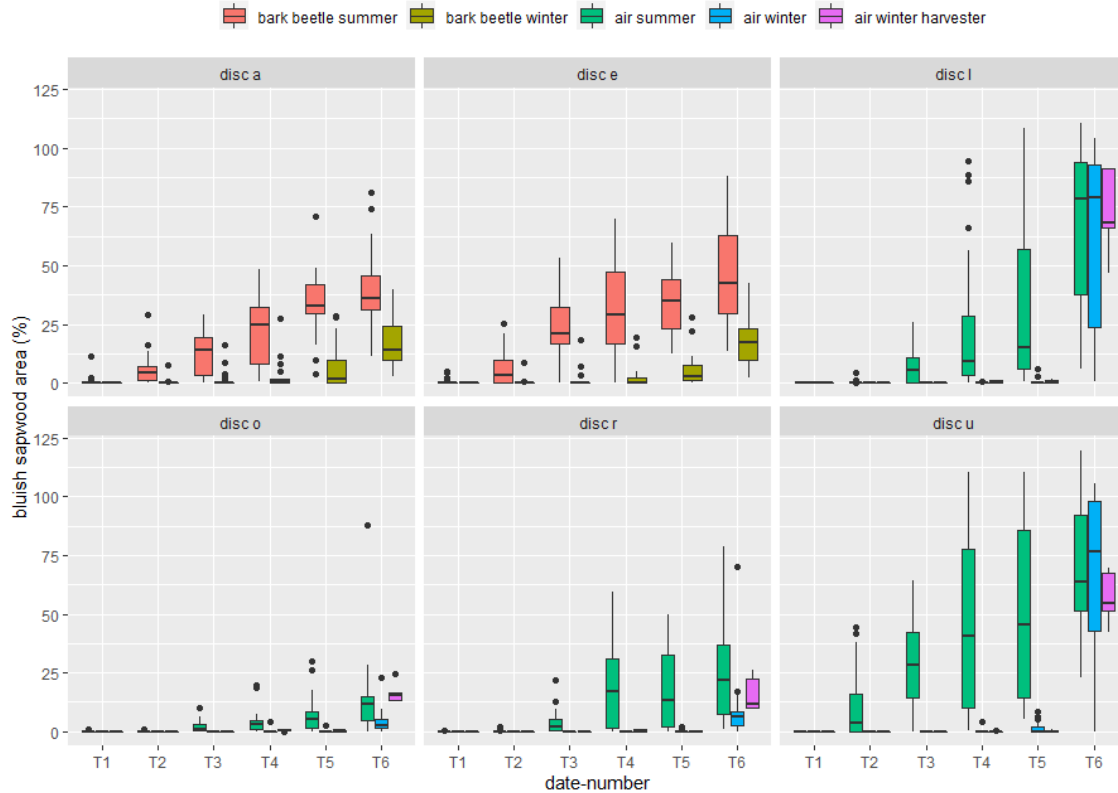
Figure 17: Boxplot of percentage of blue stained sapwood area in relation to date number, variant and stem disc. Each boxplot represents mean values from five logs.

The data from the different locations were aggregated for the four set-ups. For the model development, the crosssection with the maximum %BSA per variant and date was taken as dependent variable and the sum of mean daily temperature above 0°C from the start of the storage trial until the respective sampling date as independent variable. For each of the four variants the mean daily temperature sum above 0°C showed a significant influence on %BSA. A non-linear regression analysis according to formula (1) was carried out for each variant (Table 4). In addition, the confidential interval for each of the four variants was calculated.

$$BS = a * e^{\left(\frac{b}{tempsum}\right)} \tag{1}$$

Table 5: Description of the variables for estimating the percentage of blue stained sapwood.

Variable	Description	Unit
%BSA	Ratio of blue stained sapwood area to total sapwood area * 100	%
tempsum	Temperature sum of the daily mean temperature (only for days with a mean temperature above 0°C)	°C
a	Regression coefficient	-
b	Regression coefficient	-

%BSA developed much faster in the summer variants, where significant blue stain begins to occur at a temperature sum of approx. 250-300°C (Figure 18). Contrary, in the winter variants blue stain development increased later, at a temperature sum of approx. 700-750°C (Figure 19). This could indicate that it is not feasible to use the temperature sum above 0°C. Maybe blue stain growth starts at a higher threshold. However, this and the influence of other factors will be investigated by literature research and by analyzing the data again. Examples of factors that could cause variation in blue stain development are

the spectrum of insects, particularly bark beetles, infesting logs at various locations and geographically varying assemblages of blue stain fungi.
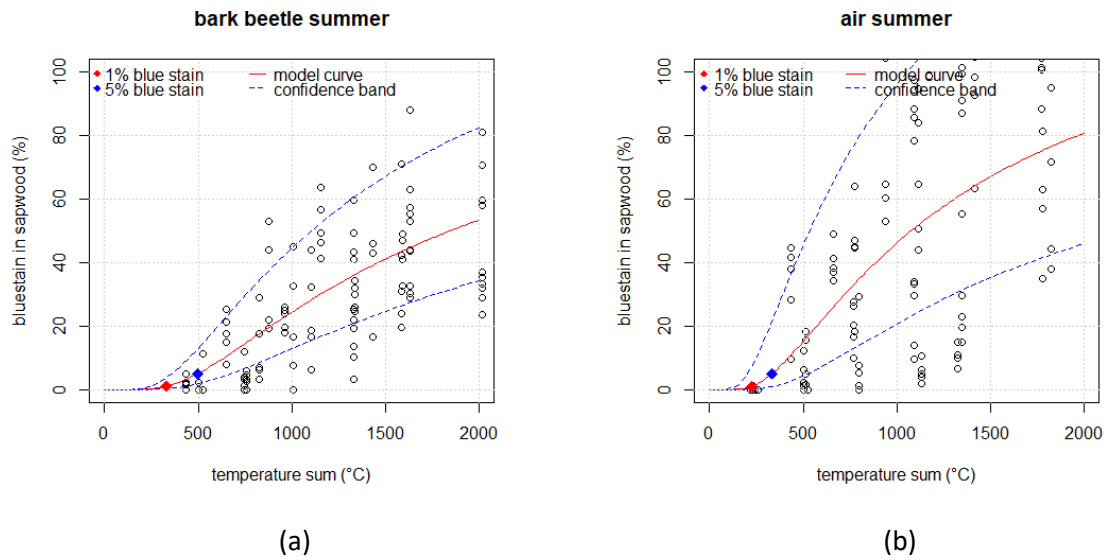
Figure 18: Percentage of blue stained sapwood in relation to mean daily temperature sum for the variants 'bark beetle summer' (a) and 'air summer' (b).
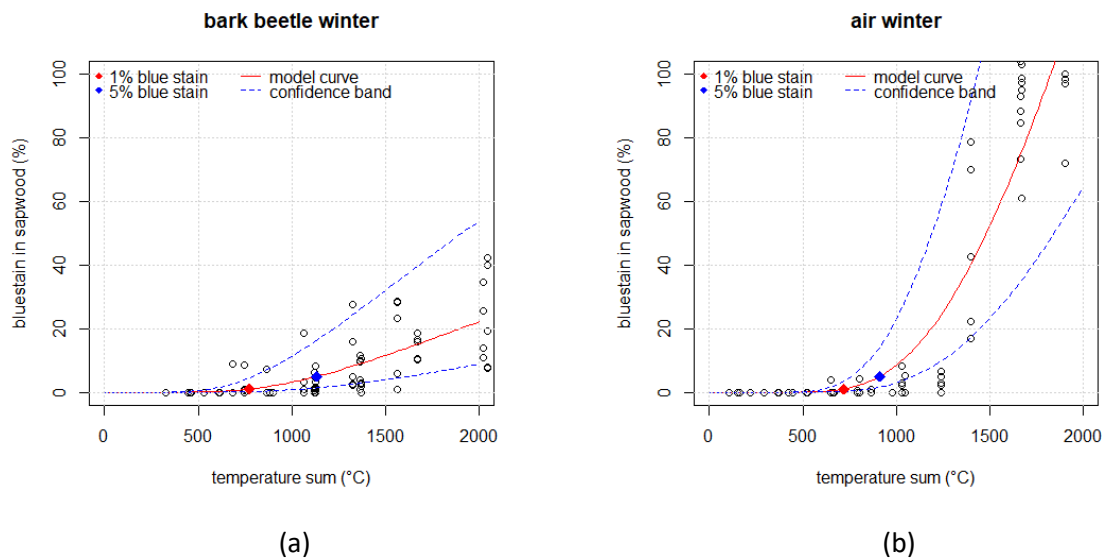
Figure 19: Bluish sapwood area depending on temperature sum for the variant 'bark beetle winter' (a) and 'air winter' (b).

Table 6: Coefficients of the different models for estimating the amount of blue stain in sapwood.

sub-model	a	b	$a_{upper\_conf\_int}$	$b_{upper\_conf\_int}$	$a_{lower\_conf\_int}$	$b_{lower\_conf\_int}$
bark beetle summer	117.2	-1572.4	153.0	-1235.2	91.4	-1968.7
bark beetle winter	156.0	-3903.5	256.3	-3117.7	99.8	-4851.8
air summer	141.4	-1119.4	204.6	-754.1	101.5	-1588.3
air winter	1995.8	-5464.9	2952.5	-4860.8	1394.4	-6140.3

The formula for the bluestain development (1) can be transformed to obtain the temperature sum until the sorting criteria threshold for %BSA is reached (2). Of course, also the coefficients for the lower and

upper confidential interval can be inserted into the formula to get the lower and upper confidential interval of the temperature sum.

$$tempsum = \frac{b}{\log\left(\frac{BS}{a}\right)}$$

(2)

With temperature data at a specific site, known harvesting date and the desired threshold for %BSA (e.g. 1%) the day the threshold is reached can be estimated. In addition, a table can be created, presenting the harvesting date and the date after which the %BSA threshold will be passed. Taking the coefficients of the lower and upper confidence interval, a worst-case and a best-case can be appraised (Table 7).

Table 7: Examples for harvesting date and date when critical blue stain levels occur for three different scenarios for the location 'Amstetten' in Lower Austria.

Harvesting date	Date until the logs have 1% bluestain (days from harvesting)		
	Mean	Worst case	Best case
01.01.2019	19.05.2019	27.04.2019	06.06.2019
30.01.2019	21.05.2019	30.04.2019	07.06.2019
28.02.2019	25.05.2019	06.05.2019	10.06.2019
30.03.2019	06.06.2019	24.05.2019	18.06.2019
30.04.2019	20.06.2019	10.06.2019	02.07.2019
30.05.2019	05.07.2019	25.06.2019	20.07.2019
30.06.2019	06.08.2019	27.07.2019	21.08.2019

Conclusions

Extended transport lead times due to increasing forest disturbances can lead to wood value losses resulting from attack by fungi and insects, and changes in mechanical/chemical properties and freshness. To guarantee that the wood harvested arrives at industry with the specified quality fulfilment, well-coordinated transport management is essential. Furthermore, it is necessary to understand how wood value develops over time under varying weather conditions, to take the right transport action.

Increasing availability of models, such as the one described here, digital data on felling time, storage location and grid weather values from service providers would allow the linkage and integration of predictions models into operational models for planning (Westlund et al. 2019). Current ICT-solutions provide the potential integration of quality prognosis for harvested timber during storage. Furthermore, for seasonal wood supply planning, the integration of such prognosis approaches into dynamic optimization models could greatly enhance the quality of the results.

Acknowledgements

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Where did the trees go?

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The modern forestry wood chain is data rich because of the measurements used to make the process more efficient at each step. It is also information poor because processing data that could feedback to forest management and operations are not linked. Linking forest data to processing data requires that we reliably trace individual logs from the point of harvest to the point of entry at the processing facility in a way that can be feasibly implemented at low cost for high-volume low-value softwood. The first step in the solution to tracking trees through the forestry wood chain needs to come by marking or biometrically identifying individual logs at the point of harvest, i.e. the stump, and reading this information at a processing facility. In this study we investigated the integration of several commercial log tracking solutions at the point of mechanised-harvest up to an X-ray CT scanner at a sawmill and have attempted to link the individual log measurements that contain physical properties, such as wood density and knot distribution, back through the harvester and via GPS to the original aerial survey resolved to the levels of individual trees. We have used a Norway spruce provenance trial as a case study and therefore we can consider that the acquired data are also relevant to the evaluation of forest experiments that are normally costly to measure, yet hold important information for optimising growth and product potential of future planted forests. We will present the results of this feasibility study in addition to the analysis that we are developing surrounding the use of such linked data.

Keywords: *Traceability, RFID, harvesting, CT scanning, remote sensing*

Catalytic fractionation of biomass

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Keywords: forest biomass, fractionation

The project "Catalytic biomass fractionation" aims to identify the most promising value chains for bio-based products based on catalytic fractionation of biomass and to assess the business cases for these value chains. The focus of the project has been on stem wood fractionation, but the techno-economic analysis of bark fractionation indicates that a bark process can also be profitable – or carry its own cost in case of a mixed stem wood-bark feedstock.

Descriptions and information on different tress species technical structure and properties and chemical composition have been gathered and mapped. Data on which inorganic materials are present in biomass, in different tree species and parts of the trees, and which are potentially harmful to the catalyst in the catalytic fractionation were mapped within the project. Since we do not know which catalyst will be used in a full-scale process, it is difficult to exactly say which substances will cause problems.

A preliminary techno-economic analysis of the identified promising value chains including the production of a high-quality dissolving cellulose pulp and lignin has been performed to assess if there is a potential viable business case present that merits further development.

Results and discussion

The main wood components are cellulose, hemicellulose, lignin and extractives, which mainly consist of carbon, oxygen and hydrogen. Wood is not a homogeneous material, but the chemical structure varies between sapwood and heartwood and between spring wood and summer wood. The hemicellulose content of deciduous trees is slightly higher than that of conifers. The lignin content, on the other hand, is usually significantly lower in deciduous trees.

The moisture content varies between different tree species, but also between the different parts of the trees. The moisture content of deciduous trees is on average about 10% lower than that of conifers. In deciduous trees bark and stem wood have approximately the same moisture content, while the branches of conifers usually have a significantly lower moisture content than stem wood.

The natural ash consists of minerals that the trees have taken up from the ground, and therefore to a large extent depends on where it grows. The minerals are mainly concentrated in the parts where the life functions are located, i.e. the bark, leaves and needles. These parts contain more than half of the amounts of calcium (Ca), phosphorus (P), potassium (K) and nitrogen (N). Other minerals found in trees are e.g. magnesium (Mg) and silicon (Si).

The fraction distribution is affected by the chipping equipment as well as by the moisture content, temperature, composition and coarseness of the material. Frozen logging residues give a higher proportion of fine fractions than unfrozen material during chipping. Chips of different origins can cause large variations in quality. Stem wood usually gives an even fraction size. Logging residues, tops and unbranched small trees can, on the other hand, give chips of greatly varying size. Logging residues give about 2-3 times greater proportion of fine fractions (<7 mm) than pure stem wood. Logging residues from conifers usually give a larger proportion of fine fractions than logging residues from deciduous trees.

The metals found in the tables below are known catalyst poisons from other systems and are considered to be more problematic trace elements in wood. In a coming project it will be relevant to assess how these trace elements affect downstream upgrade processes, but also the usability of the products.

The chemical composition and mineral content also depend to a large extent on the plant site and its rock composition and soils. Variations of minerals and heavy metals can therefore vary greatly.

Table 1. Deciduous trees. Average data regarding mineral concentration in dry biomass. Phosphorus, Potassium and Calcium are given in concentration (%), the others in concentration (ppm).

Variables	Stem wood	Branches	Bark	Whole trees
Phosphorus (P) (%)	0,02	0,06	0,09	0,05
Potassium (K) (%)	0,08	0,21	0,37	0,21
Calcium (Ca) (%)	0,08	0,41	0,85	0,25
Bor (B) (ppm)	2	7	12	6
Sulfur (S) (ppm)	90	218	341	212
Iron (Fe) (ppm)	20	47	191	27
Mangan (Mn) (ppm)	34	120	190	83
Zinc (Zn) (ppm)	16	52	131	39
Copper (Cu) (ppm)	2	4	13	5

Table 2. Average data regarding mineral concentration in dry biomass in conifers. Phosphorus, Potassium and Calcium are given in concentration (%), the others in concentration (ppm).

Variables	Stem wood	Branches	Bark/Needles	Whole trees
Phosphorus (P) (%)	0,01	0,04	0,08/0,016	0,03
Potassium (K) (%)	0,06	0,18	0,29/06	0,15
Calcium (Ca) (%)	0,12	0,34	0,85/0,5	0,28
Bor (B) (ppm)	3	7	12/9	6
Sulfur (S) (ppm)	116	203	343/673	236
Iron (Fe) (ppm)	41	101	60/94	85
Mangan (Mn) (ppm)	147	261	507/748	296
Zinc (Zn) (ppm)	13	44	75/75	30
Copper (Cu) (ppm)	2	4	13/10	5

Current technical knowledge indicates that high quality dissolving pulp and highly depolymerized lignin fraction are obtainable from stem wood catalytic fractionation. Production cost estimates for lignin and cellulose are favourable compared to for example an estimated medium-term dissolving pulp price of 825 €/t. The lignin fraction is more difficult to assign a value to but a tentative high-value application is PF resin at approximately 1700 €/t. The sensitivity of the production costs indicates a robustness in the analysis although the low TRL still means that there are very large uncertainties associated with the data presented.

It is important to note that the procedure within this project does not involve any profitability calculation as in a traditional investment assessment. The reason is the difficulty to assign a specific market value to the products, especially the lignin fraction, which precludes this approach. Instead, a production cost estimate has been made which can, in a more qualitative manner, be compared with ranges of market price estimates. The experimental data are approximate and not necessarily representative for commercial scale production.

Investment cost estimates do not include feedstock reception, feedstock pre-treatment or product storage. The current knowledge from experimental studies indicates that the process performance is not

very dependent on biomass particle size or moisture content, which means that feedstock pre-treatment may not need to be extensive, but debarking is an option for some process configuration.

The production cost is lower than the estimated medium-term value for dissolving pulp 825 €/BDt, which is the target product. Also compared to a lower cellulose value, 625 €/BDt for tissue pulp, the production costs are reasonable, especially considering that they also include the lignin fraction, which is more difficult to assign with a specific value.

The most important cost categories are feedstock procurement, toluene solvent make-up, process heat and capital cost. A sensitivity analysis of production cost with respect to the four important parameters clearly shows that the sensitivity to variations in the range studied is not excessive. Even with a 100% increased investment cost and 50% increased feedstock cost, which must be considered very pessimistic, the production cost increases not more than 35%. Likewise, decreased yields of cellulose and lignin with 20% and 10%, respectively, increases production cost by 20%.

There has not been any study of high value applications of bark components in the present study since focus was on stem wood fractionation to cellulose and lignin. A tentative "bulk" application of the bark products is upgrading to biofuels by co-processing with fossil feedstock in an oil refinery hydrotreatment process. Upgrading of the products from this bark fractionation process should be technically easier than for LignoBoost lignin but requires technical development from the commercial process used for production of drop-in HVO biofuels from fats and fatty acids today.

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Wood modification – a modern solution to meet the challenges of using wood in the outdoor built environment

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Introduction

Wood construction is surging in Europe, driven by the demand for sustainable buildings and the widespread adoption of new wood products. Using wood in the load-bearing structure is an easy way to reduce the climate footprint of buildings by substituting energy-intensive materials and lock-up the wood carbon in long-lasting construction products (Sathre and O'Connor 2010, Oliver et al. 2014, Hildebrandt et al. 2017).

Securing a long service life of wood products in outdoor environments is, however, challenging as the material is susceptible to fungal decay. Traditionally, this problem is solved by impregnating local wood species with biocides, or alternatively importing tropical wood species with high natural durability. While local wood species are preferred from a carbon footprint perspective, the leaching of biocides from impregnated wood is highly undesirable from an environmental perspective.

In addition, when using wood as façade material on high-rise buildings, the combustibility of the material needs to be considered. This is often circumvented by impregnation with fire retardant salts, however, leaching of these decreases the fire resistance over time.

Wood modification is the modern solution to meet the challenges of using wood with inadequate resistance to fungal decay and fire. Modification covers a range of technologies that alters the wood chemistry in a non-toxic way to change the properties of the material, e.g. resistance to fungal decomposition or fire. While modified wood products have been around for 100+ years, there is currently an increasing interest in the market. Moreover, the research field within wood modification is rapidly evolving in these years.

In this work, we highlight some of the latest research developments and discuss the future of modified wood products.

What is modified wood?

Wood modification is an umbrella term covering a variety of technologies that alter wood properties by changing the material chemistry in a non-toxic way. Thus, biocide impregnation is not considered a wood modification even though the overall chemical composition is changed. Wood modification was developed a century ago (Fuchs 1928, Tarkow and Stamm 1944), however, only since the development of the "ThermoWood" thermal modification process in the 1990s has modified wood been able to maintain a foothold on the commercial market. The last two decades has seen a steady increase in modified wood production and several more technologies have been introduced to the market. Today, the annual European production volume of modified wood totals about 0.7 million m3 and is dominated (73%) by thermally modified wood, see Table 1. This is, however, still significantly less than the annual European production of biocide impregnated wood of 6.5 million m3 (WEI-IEO 2020) and the 1.2 million m3 tropical sawn wood that is annually imported to Europe (ITTO 2020).

Table 8. European production volume of modified wood (incl. production under development in UK and Belgium). Data from (Jones et al. 2019).

Type of wood modification	Est. annual production (m³)	Relative share
Thermally modified wood	535,000	73%
Acetylated wood	120,000	16%
Furfurylated wood	45,000	6%
Other modifications	37,000	5%
TOTAL	737,000	100%

One of the barriers for more widespread adoption of modified wood is price. While thermally modified wood is sold for about twice the price of biocide impregnated wood, the other types of modified wood are typically even more expensive. It is therefore not surprising that thermally modified wood dominates the market for modified wood products. However, thermally modified wood is not suitable for more aggressive environments such as in-ground applications or marine environments (Welzbacher and Rapp 2007). Therefore, developing a cost-effective modification that effectively protects wood is a priority. A key challenge in doing so is the uncertainty as to which physical characteristics define an effective protection of wood.

Resistance to fungal decomposition

Wood is an element in the ecosystem carbon cycle, where organic matter is continuously formed and degraded. Therefore, wood materials are susceptible to decomposition by fungi, bacteria and insects. For wood structures, basidiomycetes fungi are the most widespread, economically important, and destructive organisms (Viitanen & Ritschkoff 1991, Duncan & Lombard 1965, Alfredsen et al. 2005, Schmidt 2007).

Moisture is an essential pre-requisite for fungal decomposition, so keeping wood dry is the most efficient strategy for maintaining a long service life of wood. This is why using wood for structures and products that are shielded from the outdoor environment is unproblematic. A lot of wood is, however, used in the outdoor built environment in the Nordic region, e.g. as façade cladding, staircases, decking, and fences. Keeping wood dry in this environment with regular occurrences of rain and high humidity is challenging. Direct rain exposure of outdoor wood surfaces can be limited by coatings or structural wood preservation, e.g. roof overhang, but these measures are not always possible or desirable from a design perspective. Instead, the protection of such outdoor exposed wood structures has traditionally been accomplished by using toxic preservative systems, i.e. biocides. These impregnations do, however, not lower the moisture content, but have a toxic mode of action. The wood is thus protected from degradation despite of it being wet. However, environmental concerns and restrictions of their use have increased the focus on non-toxic alternatives such as wood modification.

Although the mechanisms behind the protection against degradation may be different for different types of modified wood, it has been established that the lowered moisture content obtained by modification is an important factor (Thybring 2013). Unlike traditionally impregnated wood, modification of wood thus protects the wood by keeping the moisture content low. It is, however, not established how this reduced moisture content protects wood, i.e. what the underlying physical and chemical mechanisms are. However, recent insights from studies of ion transport in wood cell walls point towards a restricted mobility of decomposition agents in the solid cell walls when the moisture content is limited (Hunt et al. 2018; Jakes et al. 2019; Zelinka et al. 2015). Notwithstanding the lack of understanding of the underlying mechanisms behind effective wood protection, noticeable progress have been made in recent years both in terms of optimisation of existing modification technologies and development of new technologies. With regards to the previous, Liu et al. (2020) have reported a more efficient chemical route to furfurylation of wood, i.e. in-situ polymerisation of furfuryl alcohol. Instead of impregnating wood with furfuryl alcohol and a catalyst, only the latter is impregnated and furfurylation is achieved by exposure to furfuryl alcohol in vapour phase. The result is a remarkable reduction in moisture content achieved with relatively modest mass gains compared with the traditional furfurylation process. Overall, the results of Liu et al. (2020) suggest that effective wood protection by furfurylation could be produced at lower costs.

Another promising development towards cheaper wood modifications relates to the recent work done on the polyesterification of wood using sorbitol and citric acid (Beck 2020; Larnøy et al. 2018; Mubarok et al. 2020; Treu et al. 2020). This modification appears to yield superior performance against fungal decomposition, termites and marine borers by using cheap and commonly available chemical reagents. Further work is needed, but if these results are confirmed this new modification technology may be a game-changer in the market for sustainable, biocide-free wood protection for the outdoor built environment.

Fire protection

Wood is a combustible material. This gives wood an experienced disadvantage compared to other construction materials, even though building codes and design guidelines specify how fire safety can be achieved with combustible materials. Therefore, fire retardants are often added to improve the fire performance of wood products such as façade claddings or wood based insulation. This is not without disadvantages, since many fire retardants have adverse effects on the environment and/or work environment. Additionally, they are prone to leach out upon water exposure (such as rain), and the material therefore loses its resistance to fire, e.g. from long-term weather exposure.

Chemical modification offers a new route to improve the fire performance of wood without the downsides of traditional fire retardants. As described in the previous section, chemical modification has a long history of improving the resistance to fungal decomposition. However, it is only within the last decade attention has shifted towards fire protection by chemical modification. The chemical changes needed to improve fire performance differ from those imposing resistance to fungal decomposition. This can for instance be seen from the insufficient change in reaction to fire of acetylated wood (Mohebby et al. 2007).

Currently, research within chemical modification for fire protection is rapidly developing and a wide range of treatments have emerged from research laboratories and been documented in scientific literature. The list of treatments include a variety of bio-inspired mineralisation on the nano- and submicron scale (Guo et al. 2019; Merk et al. 2015), co-reaction with modifications for improving decay resistance (Kong et al. 2018), formation of zinc oxide nano-rods (Kong et al. 2017), clay impregnation into cell walls (Fu et al. 2017), and the list is getting longer each year.

One of the reasons chemical modification is advantageous compared with traditional fire retardants is related to leaching upon water exposure. Chemical modification entails chemical reactions within the wood of an added chemical which bonds covalently to the material (e.g. acetylation) or forms bulky, stable molecules (e.g. furfurylation), and both of these cases leaching is prevented. It is yet too early to single out the most effective modification in improving fire performance, given the rapid developments taking place within this topic. As with modification for improving the resistance to fungal decomposition, it is likely that a variety of modifications for fire protection is needed for different applications or material structures, e.g. fibre-based materials or solid wood products.

Trends and future outlook

Wood modification is an active and exciting research field that is currently undergoing a rapid development. In the societal transition towards a more sustainable way of living, wood modification holds great potential in supplying environmentally-friendly wood products for applications, where most locally available wood species have limited performance. In relation to the green transition of society, there are three important directions in the field of wood modification which we would like to highlight:

Improved circularity

Since wood modification improves the performance by non-toxic changes in the material chemistry, the modified material can be re-used and re-cycled (Heräjärvi et al. 2020). Thus, unlike traditional treatments like biocide impregnation, wood modification is not an obstacle for circular utilisation of resources. Moreover, wood modification can be applied to recycled wood material, e.g. turning reclaimed structural wood into outdoor exposed wood cladding or decking material.

Better utilisation of forest resources

The fundamental concept of wood modification is to improve an inadequate performance of wood for specific applications. Thus, wood modification offers a route to utilise local wood species that are otherwise not suitable for e.g. outdoor environments. Hereby, wood modification opens up a window of opportunities for European wood species that are currently under-utilised or mainly used for energy (Nemeth et al. 2020).

Broader application of wood products

A wide range of novel wood modifications are under development for a variety of applications of wood in society (Berglund and Burgert 2020). These include transparent wood for thermally insulating roof top windows (Mi et al. 2020), surface modifications for improved interaction with concrete for timber-concrete hybrid structures (Kostic et al. 2018), transparent UV-resistant modifications preventing weathering of wood surfaces (Guo et al. 2016), and many more. Although it is too early to judge whether these modifications will be commercialised, the current progress in the research field demonstrates the versatility of wood modification as a tool to alter the properties and provide new functionalities to the material.

Acknowledgments

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Estimating a height of decay column in severely rotten stems of Norway spruce (*Picea abies* (L.) Karst.) with log end face image features

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Background

Root and butt rot of Norway spruce (*Picea abies* (L.) Karst.) is caused by various fungal species that spread from tree roots to the stem while slowly decaying the wood. The decay causes a high economic loss to forest industries around the globe: e.g. at least 50 million euros is lost in annual stumpage price in Finland (Natural Resources Institute Finland, 2019). The value reduction is due to lower proportion of healthy sawlogs in clear-cuts, where the decayed stem part can only be used in secondary products or as energy wood.

A harvesting of a severely decayed stand is demanding for a harvester operator. In cut-to-length harvesting, the operator must decide a proper way to divide the decayed stem into logs that fulfil the quality requirements of an end-user. At the same time, the operator has to minimize the amount of healthy stem part allocating to pulpwood or energy wood. Currently, there are no devices to guide the bucking of decayed stems, thus, the outcome of bucking is driven by the expertise of the operator. Optimal bucking patterns for decayed stem part are mainly dependent on a diameter of decayed column on a first cross-cut (Kärhä et al., 2019).

After a felling cut, a cross-section of the stem is revealed. The cross-section reflects the general health of the tree and the severe decay can be seen by the operator. Previous studies indicate that the rot of the cross-section could be detected from an image, even from great distances (Ostovar et al., 2019). However, RBG-images has been rarely used to estimate decay inside the stem while other methods, such as acoustic tomography, ultrasonic or infrared imaging sensors, have received more attention (e.g. Fackler et al. (2010); Liu and Li (2018)).

Depending on the stem height the stage of decay is different. Near the stem base decay is more advanced than in the upper part of stem. Being a white-rot fungus, *Heterobasidion* sp. is able to degrade both the lignin and cellulose components of the wood, but the degradation of lignin occurs first in the early stage of decay (followed by cellulose degradation). Degradation of lignin results in a bleached appearance of the decayed wood and incipiently decayed wood is not readily distinguishable from sound wood (in the upper part of the stem). Typically, in the advanced stage *Heterobasidion* root rot has expanded also to sapwood (on stem base) but upper in the stem the more incipient infection is limited to heartwood (or part of them).

Moreover, *Heterobasidion* sp. is commonly associated with *Armillaria* sp. on Norway spruce causing together advanced (stringy, wet, dark brown) decay at stem base. *Armillaria* rot has limited extension usually less than 0.50 – 0.75 m above ground level, even after prolonged infection.

Predicting the length of the decay column in the stem would potentially increase the value recovery and overall productivity of the bucking by decreasing unprofitable offcuts. The aim of our study was to describe the longitudinal variation of a decay column inside a rotten stem based on the area, brightness and roundness of the decay on log end face, and finally estimate the remaining decay column height with a linear regression model.
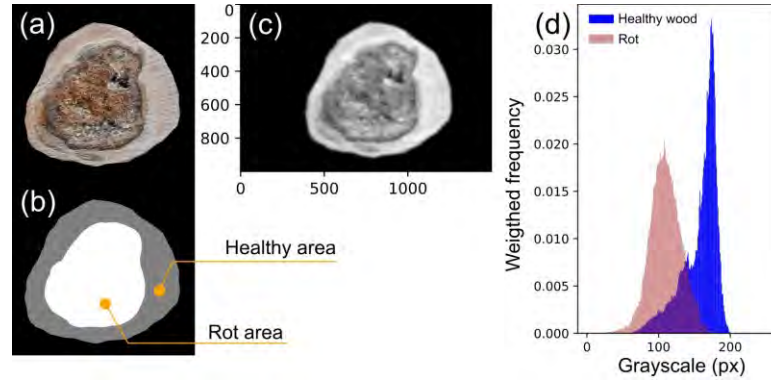
*Fig. 1 **(a)** A log end face image without background **(b)** manually segmented rot and healthy wood **(c)** a blurred grayscale image **(d)** grayscale value histograms of healthy and rotten wood segments.*

Material and methods

Severely rotten Norway spruce stems were selected from a clear-cut stand located in Pirkanmaa region in southern Finland. The root rot was widely spread on the stand and a proportion of decayed stems was generally higher than in other clear-cuts made in the region. The selected 11 trees were roughly from 70 to 100 years of age with decay proceeded at least a meter up to the stem. The stems were located close to each other and a type of rot was very similar within and between the stems.

The decayed part of the stem was divided into 50 cm (± 2 cm) long offcuts (total amount 139) with a harvester. The length of each offcut was measured manually, and each cross-section was imaged with a digital camera (Nikon D7200, Tokyo, Japan). The photographing took place approximately 30 minutes after the cutting, and due to wintertime, the cross-section surfaces were frozen. To measure the decay column height from each stem, the last top-end offcut was split lengthwise with a chainsaw.

Log end face images from the stem cross-cuts were processed in GIMP software (https://www.gimp.org) and analysed with scripts written in Python (v. 3.7) computing language (Fig. 1). The background of image was removed (Fig. 1a) and the decayed area was manually separated from the healthy wood surface (Fig 1b).

The analysis was performed with OpenCV (Bradski, 2000) and Scipy (Virtanen et al., 2020) image analysis libraries. An area of rotten wood was calculated from the image as square centimetres and as a relation to a total area of log end face in percentages. A scaling from pixels to square meters was made with a reference length from a measurement bar held in perpendicular to the log end face while photographing. To analyse the brightness difference between the rotten wood and healthy wood, grayscale histograms (Fig. 1d) were extracted from the segmented images (Fig. 1c). Relative brightness difference between healthy and rotten wood was calculated as

$$RB = \left(\frac{\left| HP_{avg} - RP_{avg} \right|}{HP_{avg}} \right) \cdot 100 \quad , \tag{1}$$

where HP_{avg} and RP_{avg} correspond to an average healthy and rotten wood pixel brightness.

$$RR = 4\pi \cdot \left(\frac{RA}{RP} \right) , \tag{2}$$

where RA and RP correspond to an area and perimeter of a rotten wood segment.

A remaining decay column height (DCH) above the log end face was predicted with rot area, brightness and roundness:

$$DCH_i = \beta_0 + \beta_1 RA_i + \beta_2 RB_i + \beta_3 RR_i + \epsilon_i , \tag{3}$$

where *DCHi* is the decay column height for log end face *i*, *β0*, *β1*, *β2* and *β3* were estimated parameters, and other parameters as described above.

A validation of DCH model was performed with a k-fold cross-validation where data was split into training stems and a test stem. In the cross-validation, each stem was set as the test stem once. A fit of the model to the data was evaluated with a $R2$, and with an average residual in the cross-validation.
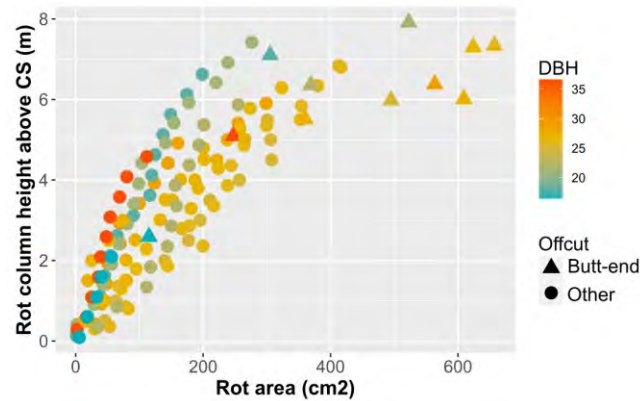
Fig. 2 A decay column height above a log end face against a corresponding rot area.
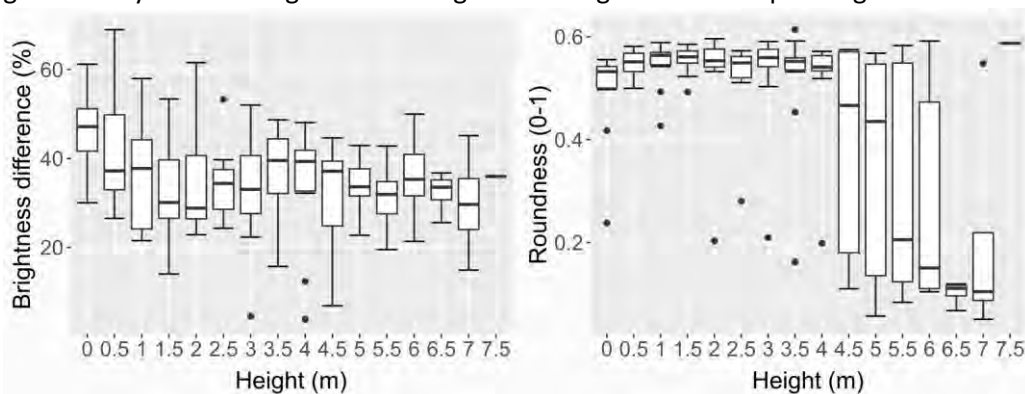
*Fig. 3 **(a)** Longitudinal variation in a brightness difference between rotten and healthy wood segments. Relative brightness difference was calculated by dividing the absolute difference between average rotten and healthy wood grayscale value by healthy wood average grayscale value. **(b)** Longitudinal variation in a roundness of rotten wood segment.*

Results and discussion

The height of the decay columns ranged from 2.6 to 7.9 meters with an average of 6.1 meters in the selected stems. The stems were in most cases highly decayed from the butt-end and an average ratio between the rotten and the log end face area was over 50% (442 cm2). The rot area ranged from 115 to 657 cm2 and the larger rot area on a cross-section increased the decay column height (Fig 2) which has also been found in an earlier study by Seifert (2007).

The difference in rotten and healthy wood color brightness slowly declined when progressing to upper stem parts (Fig. 3a). The brightness difference at different heights had a large deviation between the stems. Yet, when the rot slowly transformed into circular (Fig. 3b) at roughly 3-4 meters, the brightness difference between a ring-shaped rot area and healthy wood slightly increased for a short period. The circular rot slowly faded and turned into a healthy wood.

Rot area, brightness difference between rotten and healthy wood, and roundness explained 76% of the variation in estimated ending height of decay column in a model fitted dataset. Model parameters (Table 1) increased the estimated decay column height above the corresponding log end face.

Residuals of the fitted model indicate that the model overestimated DCH at the top-end of the column and accordingly underestimate DCH at the butt-end of the stem. After a first cross-cut, the residual error varied between -2 and 2 meters.

Table 1 Coefficients of the parameters in the linear model for a decay column height above a corresponding cross-section. SE is a standard error of the estimate.

Parameter	Estimate	SE	p-value
Intercept	-0.67	0.36	0.07
RA	0.01	< 0.00	< 0.001
RB	0.03	0.01	< 0.001
RR	2.78	0.55	< 0.001

The linear model estimating decay column height above the log end face was cross-validated with a k-fold re-sampling method where the linear regression model was fitted with the cross-sections of 10 stems and tested with one stem. An average cross-validated residual of decay column height was 0.82 m and among the estimates made for a first cross-cut, the error was 1.35 m.

Although the causal agents of decay were not identified in the present study decay progressing high up to the stem as well as the appearance of the decay suggest that decay was mainly caused by H. *parviporum* – the most common decay fungus in spruce stands in southern Finland. *Armillaria* sp. may coexist in the same stem with *Heterobasidion* sp. Because spruces infected by H. *parviporum* occurs generally in patches in a stand (due to vegetative spread of fungal mycelia), it is likely that H. *parviporum* (even the same genotype of H. *parviporum*) is present in all the analysed trees (maybe partly together with *Armillaria* sp.?).

The results suggest that more information from rot characteristics is required to achieve an accuracy for DCH that would be suitable for a practical wood harvesting. However, the rot area, brightness and roundness could be used to estimate the DCH in severely rotten stems and optimise trade-off for example between offcuts and 3-meter long energy wood log. Further studies are needed to apply algorithms to segment a rotten wood on a log end face or utilize deep learning in estimating the DCH directly from a raw, log end face image. The use of log end face holds a great potential to guide harvester operators in the bucking of decayed stems.

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Controlling pulp wood properties through integrated planning of bucking and transportation

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Keywords: *Bucking, Transportation, Wood properties, Wood supply chain management*

Introduction

The fact that pulpwood properties affect the quality of the produced pulp is well known. As pulp mills strive to increase the quality of their product, the demands on the delivered pulpwood are becoming more specific. Differentiation between pulpwood with different properties is often based on tree species and harvesting type. In some instances the differentiation has been formulated or tested along with optimizing approaches (Carlgren, Carlsson and Rönnqvist 2006).

There are existing models of wood properties that enable prediction of wood properties and would allow for product differentiation based on wood properties (Wilhelmsson et al. 2002; Ekenstedt et al. 2003). Prior research have mainly focused on controlling length and diameter, as these are most easily discernible and measured by the harvester (Andersson et al. 2016). Product differentiation based on internal wood properties has yet to be evaluated and implemented. Allowing internal wood properties to influence bucking and transportation decisions would increase the possibility to differentiate between pulpwood suitable for specific types of pulp. One of the greatest obstacles to implementing this kind of differentiation is the great amount of variation in the pulpwood, both between individual trees and between stands.

To manage and decrease the inherent variation bucking and transport must be highly coordinated. However, the two processes tend to be managed separately with slightly different goals. Where transportation is managed to minimize transport distance and the bucking is managed to maximize the value of the harvested wood. In some cases, this results in one goal being unfulfilled through customers receiving wood bucked for other mills or wood being transported long distances.

The aim of the study was to evaluate product differentiation of pulpwood based on internal wood properties and propose novel methods of sorting the pulpwood in practice. To achieve the aim an algorithm for integrated production and transport management, presented in Holappa Jonsson, Asmoarp, and Eriksson (2019), is combined with models for calculating wood and pulp properties.

Material and methods

The proposed algorithm maximizes the net profit, in terms of wood value and transportation costs while aiming to fulfill demand restrictions. This calculation is performed in several steps for each stand, as follows:

- The stems are bucked with all available product instructions to create alternative bucking patterns

- Transportation distances are calculated for each combination of receiving mill and harvesting site. The costs are derived using a cost function currently in use by the Swedish forestry.
- The value matrices of the bucked products are reduced with the transportation cost corresponding to the distance between harvesting site and receiving mill.

- The internal properties are calculated for each log and evaluated against the product qualifications. If the log does not fulfill the qualifications, that bucking alternative is eliminated.
- The most valuable bucking alternatives of the ones remaining are selected.
- If the demand requirements are not fulfilled, the value of that product is increased (with inversely progressive amounts) and the previous steps are repeated until the requirements were met.
- As a final step, products with a low amount bucked in a site (below 5 cbm/hectare) are eliminated if an alternative product is available. The previous steps are then repeated until no products with low amounts remain.

The algorithm is used in a case study representing southern Sweden. To identify properties of interest, interviews were held with specialists at the pulp mills. This establishes tensile strength index as the most valuable property possible to calculate for the pulpwood. The tensile strength index is calculated for each log according to a function described in Jonasson et al. (2001). The model is based on input from predicted latewood content according to Wilhelmsson et al. (2002) and predicted number of annual rings according to Wilhelmsson (2006).

Based on the algorithm and the sought-after property, two strategies for product differentiation are tested:

1. pulpwood differentiation by harvesting type (final felling or thinning)

2. pulpwood differentiation by number of growth rings and share of latewood (in each log).

The first strategy is based on the existing strategy and required no information about internal wood properties. Instead it relies on the harvesting type of the stand. To increase the reliability of the results, the second strategy is based on the number of growth rings and share of latewood rather than tensile strength index. These properties are also relatively simple to distinguish in practice, which makes sorting of individual logs feasible. The case study includes three pulp wood products, used as raw material for three different types of pulp at three separate pulp mills.

Results and discussion

The different scenarios resulted in slightly different supply patterns for the three mills (Figure 1).

The delivered quantities differed somewhat between the scenarios (Table 1). The transport costs (and distances) differed by approximately 7 % or 10 SEK (1 €) for the most desired product. This is probably due to strategy two being more limiting and precise and might

Figure 1. Map showing flows of pulpwood with the two strategies for product differentiation.

be countered by increased efficiency in the pulping process. If cost of production and handling were to be included in the algorithm the main effect would probably be that fewer products were bucked in each harvesting site. The effect on the pulpwood flows would probably be small unless the product differentiation is relaxed.

Table 1. Delivered volumes, wood values and transport costs for the most desired pulpwood product with the two strategies for product differentiation.

Product differentiation strategy	Total volume, cbm under bark	Value per cbm, SEK	Transport cost per cbm, SEK	Net Value per cbm, SEK
Strategy 2 - wood properties	2454,2	349,2	144,7	204,4
Strategy 1 - harvesting form	2289,1	352,9	134,1	218,8

There is a noticeable increase in the desired pulp properties associated with strategy two (Figure 2). The difference would be noticeable in an industrial setting, both in terms of difference in mean values and distribution. Some of the differences in properties are based on a combination of models, with inherent
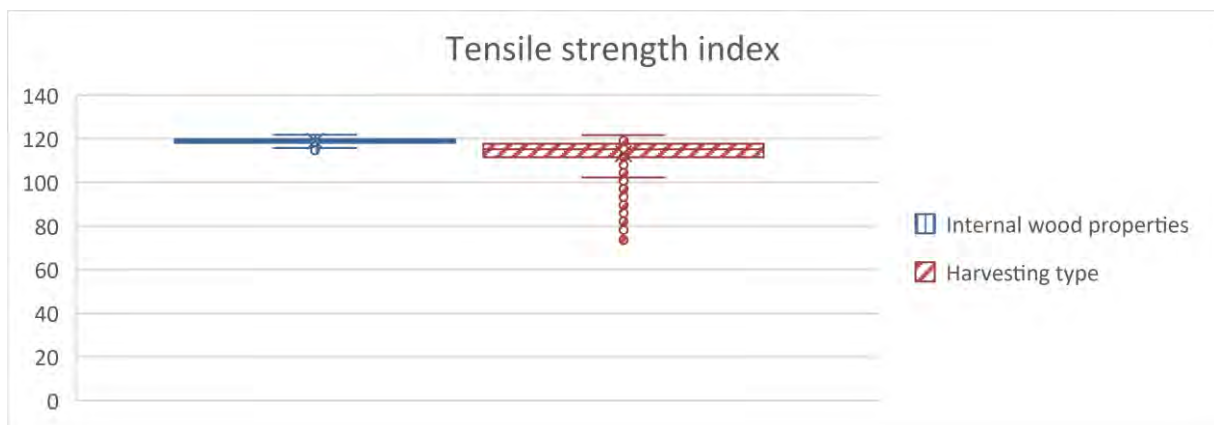
Figure 20. Tensile strength index for the most desired product, shown for the two strategies for product differentiation.

uncertainty, and the use of delimited and precise threshold values for demarcation between different products may not be optimal. This can be remedied through indexation of the decision parameters (i e share of latewood and number of growth rings). Such an approach will be evaluated in future studies. However, while the independent variables (input to the models) are unbiased, averages on site level are expected to be fairly accurate.

Whether to differentiate products on a log level (within sites) or on a site level is an open question. Differentiation within harvesting sites will probably result in increased handling costs (Arlinger et al. 2000). However, these costs might prove insignificant in relation to the increased value of the produced pulp. Additional research is clearly needed in this area.

Conclusions

Planning based on wood properties rather than harvesting type has potential to deliver a more suitable raw material. Furthermore, the integrated approach used in this project seems to be suitable for this and might prove to be an important part of increasing the quality of the delivered roundwood.

When the supply of pulpwood is limited, ordering a more specific product will reduce the available quantity, although this will probably be countered by an increased efficiency in the mill. Making a detailed analysis of benefits and costs will be central in managing the consideration between quality of pulpwood and costs of handling. Future studies include taking production and handling costs into account, as well as quantifying the benefits of more suitable pulpwood. Using the algorithm to investigate the potential for novel strategies in product differentiation for sawmills is also a future area of interest.

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Sieving of forest chips – a profitable operation?

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During recent years sieving of chipped forest fuels has become increasingly interesting as a method to reduce storage losses and thereby making it possible to increase the annual utilisation of chippers and chip trucks and the supply stability through an increased storage of chipped fuels. Advantages with sieving: The accept fraction

> A) has better storage properties and thus less likelihood of energy and dry matter losses as well as of spontaneous ignition during storage;

> B) can be priced higher due to better quality; and

> C) both accept and reject fractions are more homogeneous which makes combustion easier to control.

Disadvantages with sieving: Sieving is costly and there must be a market for the fines, which due to poor storage properties must be used shortly after the sieving operation. If the advantages outweigh the disadvantages, sieving operations can be used to increase the storage of chips and thereby the annual utilisation of chippers and chip trucks upstream in the supply chain, which should decrease supply costs. Four sieving operations have been studied, two involving vibrating screens and two involving star screens. On average the star screens were more productive than the vibrating screens. In all operations, the screen was limiting the productivity while the loader filling the machine with chips and removing the finished product was not fully utilised. Sieving costs ranged from 1,3 to 1,8 euro per MWh of chips, which may be possible to recover from higher values of and lower storage losses in the accept fraction. To enable profitable sieving operations, it will be crucial to secure a demand for the fine fraction at a price close to that of residue chips.

Keywords: *Forest fuel; biomass; Chipping operations*

SESSION 5 – SILVICULTURE

A forecast of silviculture regeneration technologies of the future in semi-natural plantation forests

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Keywords: *technology, mechanisation, Delphi research*

Introduction

Regeneration is an important component of any silvicultural system. In particular, the regeneration of semi-natural forest plantations is especially work-intensive and includes activities such as site preparation, planting and stand tending (Theron 2000). Since the mid 1900s, factors such as increasing labour costs, risk of labour shortages and the need to improve efficiency have driven the introduction of new technologies used to perform regeneration activities (Ersson 2014, Laine 2017) . Despite these innovations, very little is known about how these technologies are expected to evolve going into the future. The goal of this study was to identify the most promising such technologies that may become prevalent within the next 20 years and to forecast the date when each of them will account for 50% of the technology types adopted for performing a specific regeneration task.

Material and methods

A three-round Delphi was used to conduct the forecast. A dedicated questionnaire was administered to experts in the field of silviculture regeneration in semi-natural plantation forests. In total 31 regeneration experts from countries with semi natural forests were invited via e-mail to be part of the Delphi panel: 16 of them were willing to participate in the study. Within the context of this forecasting research, an expert was described as a person with in-depth knowledge and skill in the specific area of forest regeneration technology (Soanes 2002). The experts were identified through general industry contacts, literature, conferences and exhibitions and through referrals from other experts. When contacted, the experts were assured of anonymity and received an introduction to the Delphi process. The panel comprised of experts from countries that produce and use regeneration technology, namely the United States of America (USA) (47%), Finland (20%), Canada (20%), Sweden (7%) and Japan (7%). All the experts came from diverse forestry professions such as academia research (44%), forest machine technology development and sales (38%) and silviculture foresters (19%). The experts had experience ranging from a minimum of five years to over 30 years.

The 18 technologies included in the first-round questionnaire were divided into four broad categories as follows: machine-specific technical innovations (six technologies), material input innovations (three technologies), machine operator-specific innovation (four technologies) and computerized technology applications (five technologies) (Table 1). The experts were required to first evaluate which of these technologies actually held promise and then to forecast the dates when each of the selected technologies would represent 50% of the technologies adopted for the respective task. The following adoption prediction categories were used: 50% adoption by **2020**, by **2030**, by **2040** and beyond 2040.

Table 1: Description of regeneration technologies in Delphi questionnaire

Technology category	Specific technology	Description
Machine-specific innovations	Multifunctional machines	Integration of traditionally separate regeneration activities into one or two pass practicable operations on a machine
	Machine terrain handling enhancements	Technologies to enable regeneration equipment to handle poor soil conditions, rougher ground conditions and steeper slopes e.g. levelling machines
	Machine automation and robotics	Machine's ability to perform certain regeneration tasks with minimal human assistance
	Application of drones to monitor and conduct some regeneration activities	Drones with hyper-spectral, multispectral, or thermal sensors that can monitor the health and density of forest stands. Drones to perform regeneration activities e.g. chemical spraying
	Machine self-diagnosis and maintenance	Remote monitoring, data collection and self-diagnosis which encompasses reconfiguration, troubleshooting and self-maintenance with very little human input.
	-Ultra low emission engines - Hybrid electric power systems	Tier 5 diesel particulate engines for regeneration equipment and the development of hybrid drives over traditional hydraulic and mechanical ones
Material inputs innovation	Paper based plant pots	Containerised trays with degradable ellepot paper
	Advance chemical application	Optical and vision systems for weed sensing.
	Hydrogels/ superabsorbents	Hydrophilic / polymers used during planting to retain water for the plant and enhance survival during drier periods
Machine operator-specific innovations	Ergonomically friendly cabs	Operator cab with improved lighting, low vibration, temperature control options, better posture and enhanced range-of-motion and positioning
	Simulation training	Virtual reality, augmented reality, mix reality integrated with artificial intelligence to train the operator
	Artificial intelligence	Simulation of human thinking and decisions by regeneration equipment.
	Advance human-machine interfaces	Multi-touch enabled interfaces, gesture recognition, eye tracking and voice control. Machines controlled by using the mind/ muscular electrical activity.
Computerized technology applications	Real time machine monitoring	Telematics for tracking machines performing at a remote location e.g. machine productivity, fuel usage and chemical applied
	Real time stand assessment	LIDAR data to apply precise quantities of various inputs required during regeneration operations
	Operator behaviour and performance monitoring	Digital platforms on-board regeneration equipment to monitor key operator variables such as work performance for benchmarking and machine usage
	Processing and application of big data	Supportive technology for processing and application of historic big data (from GPS and on-board systems) to improve overall performance of machines
	Remote-control of operating machines	Radio controlled devices use to remotely operate machines

Delphi rounds and analysis

The Delphi followed an iterative process in which responses from each round were provided as feedback in a concise form to the experts. This feedback process allowed experts to reassess their

earlier forecast estimations, eventually confirming earlier predictions or readjusting them. The study underwent three iterations from August 2018 to January 2019. The overall response rate was good, with only three experts not proceeding to the final round. Delphi studies are not intended to produce statistically significant results because the views provided by the expert panel do not predict the views of the larger population (Gordon 1992).

Data from each round was summarized per item by producing frequency histograms which were circulated back amongst the experts as feedback in the second and third round. Central tendencies (mode) and percentage change in predictions between Delphi 1 and Delphi 3 iterations were estimated. The percentage change was calculated as a percentage of the earlier percentage predictions in order to balance for the different number of respondents. The qualitative data from the comments section was summarized for each round and used to substantiate the quantitative results.

Results and discussion

Before outlining the results, it is important to state the study limitations. The main such limitation was the relatively small number of experts who volunteered to join the study and their uneven regional distribution that did not allow to draw country-specific trends. Nevertheless, the number of experts was not smaller than found in other similar studies and the great care taken to produce and refine predictions makes it suitable for producing general guidelines on regeneration technology trends and adoption timeframes.
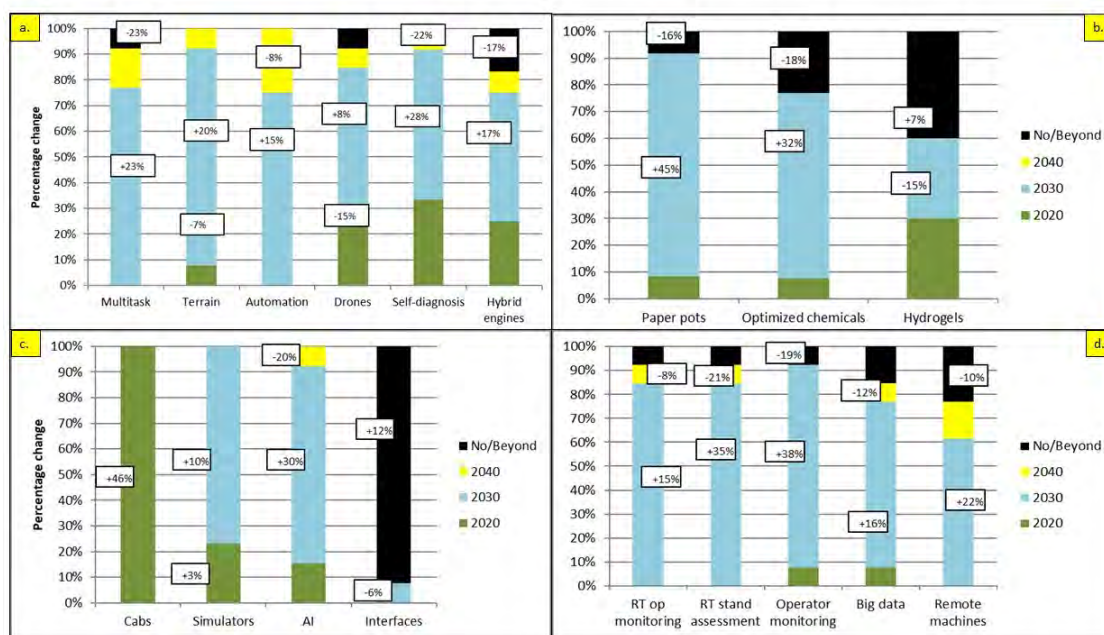
Figure 1: a. Delphi 3 Machine specific technical innovations b. Delphi 3 material innovation technologies c. Delphi 3 operator specific technologies d. Computerized technology applications

Machine-specific technical innovations

This specific category grouped technologies designed to improve the operational efficiency of regeneration equipment. In the final round 13 experts responded to the predictions for multitask and terrain handling technologies. For the four remaining technologies in this category 12 experts responded. The mode for 50% adoption of these technologies is 2030 (Figure 1a). The percentage changes between the first and third iterations of multi-tasking, automation, machine self-diagnosis and hybrid engine technologies indicate that as the discussions proceeded, predictions changed towards earlier adoption. The experts commented that machines which perform multiple tasks such

as mounding and planting (e.g. Bräcke and Risutec planting machines) already exist and that their adoption rate will increase over the years as teething problems are overcome and efficiency increases. The general view of the experts about terrain handling technologies (e.g. traction-aid winches and levelling machines) in regeneration equipment was that adoption of these technologies will be easier as these technologies are already widespread in harvesting equipment. Regarding the use of drones, one expert commented that "We constantly see robotics improvement in agricultural and especially in horticulture. I am confident that before 2025 we will see that technology justifying the initial investments in the forestry sector." The experts generally agreed that improved engines will be adopted in the future but the rate of adoption will be influenced by factors such as legislations and availability of alternative technologies.

Material inputs innovation

This specific category focused on future technologies that could be used with regeneration material inputs (e.g. plants, chemical and hydrogels). These material inputs can be used independent of, or in conjunction with, modernized equipment. In the final round 12, 13 and 10 experts responded to the predictions for paper pots, optimized chemicals and hydrogels respectively. The mode for 50% adoption of paper pots and optimised chemical technologies is 2030 and for hydrogels is in "future", intended as beyond 2040 (Figure 1b). The majority of the experts predicted that 50% adoption will be achieved in the same time span for paper pots and chemical technologies. The experts commented that it will be difficult to see large equipment manufacturers in silviculture, unless there is a standardization of the seedling rootplug. Some experts (50%) indicated that they do not see a future for the use of optimised chemical application technologies due to legislative restrictions and environmental pressures on the use of chemicals in agriculture and forestry. The other experts indicated that the expansion of artificial intelligence in agriculture could make the adoption of improve spraying technologies possible, but cost could be a limiting factor in forestry. The experts noted that due to the humid conditions in boreal/temperate forests the application of hydrogels would be limited, but as climate is changing and some areas are getting drier, this technology may be needed in the future (>2040) also in these regions.

Operator-specific technologies

This specific category focused on future technologies designed to improve operator efficiency and well-being, when using a machine to perform regeneration tasks. In the final round 13 experts responded to the predictions for all technologies. The mode for 50% adoption of ergonomically friendly cabs is "2020" (currently in place) and the mode for simulation training and machine learning is "2030" (Figure 1c). All the experts indicated that most mechanized regeneration work is conducted by using equipment with cabs well adapted for forestry conditions, hence this technology is already widely adopted. The experts described the use simulators to train operators in regeneration as an important part of technology adoption but they highlighted that the availability of this technology is very limited. The majority (92%) of the experts believe that advanced human interface technology will never be adopted in the future because of the availability and increase use of artificial intelligence, which is more efficient.

Computerized technology applications

This specific category focused on future technologies that would be dedicated to modernizing computer-based digital platforms used mainly for monitoring, management and remote accessibility. In the final round 13 experts responded to the predictions for all technologies. The mode for 50% adoption of all five technologies in this category is "2030" (Figure 1d). In the category there was a common trend that during the iterations the experts who forecasted earlier and later adoption dates changed their predictions and all converged to "2030". Regarding real time monitoring technologies, the experts agreed that such technologies were already available in the form of various telematics programs, but their further expansion was often limited by unreliable network coverage. One expert

commented that "most of the digital technology adoption rates will be dependent on the availability of network coverage in the forest areas which generally have poor connectivity." Even though two-thirds of the experts agreed that controlling machines remotely maybe adopted in future, they indicated that this will be a challenge because of the high cost of development and low volume of machines worldwide.

Conclusions

The study identified regeneration technologies which will become important in the next two decades and also forecasted the dates when 50% of these technologies will be adopted in new forest machinery. The Delphi findings showed that by "2030" there is a high probability that most technologies identified in this study will account for at least 50% of the technologies adopted for each respective regeneration task. Although one study based on a limited number of experts may not offer the strongest forecast, the research has exposed some key new and relevant technologies that forest owners need to be aware of when they plan for the future, and offers a first contribution to assess their potential.

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Forest operations in nature conservation management

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Introduction

Forests are the source for a variety of ecosystem services. Forest operations research traditionally has aimed for facilitating the extraction of one, biomass. Conservation biology often focus on another, biodiversity. A field less investigated is the crossing of the two, how can forest operations research be implemented when aiming to promote other ecosystem services, in nature conservation management (NCM)?

Swedish forest owners certified through either/or FSC and PEFC are required to voluntary set-aside a minimum of 5% of their forest land. From a forest management perspective, two different approaches are applied for voluntary set-aside areas in Sweden; stands left for free development (i.e. unmanaged) and stands in need of active management, i.e. NCM, to reach or maintain desired values. Apart from indications that NCM is being carried to a lesser extent than what would be desirable, there is a general lack of knowledge about areas intended for NCM, e.g. spatial distribution, conservation values, management strategies being implemented, and operations costs in management.

The overarching aim of this paper is to provide knowledge of forest operations in NCM. This is done by presenting and synthesizing four studies on this topic, referred to as study I-IV. These studies have the following, more specific aims:

- Give a comprehensive description of areas in Sweden intended for NCM at county, regional and national level (Study I).
- Describe current practices for NCM in voluntary set-aside areas in Sweden (Study II)
- Identify factors in current forestry affecting whether NCM in voluntary set-aside areas is carried out or not (Study II).
- Analyze time consumption for harvester and forwarder work in two examples of possible NCM treatments; (1) removing birch shelterwoods (Study III), and (2) patch cutting of an old mixed spruce and pine stand (Study IV).

Material and methods

Study I, Grönlund et al. (2019)

Five large forest companies (between them owners of about 8 million hectares, equal to 34 % of Swedish forest land) provided spatial data on 26,953 stands (136,672 ha) intended for NCM. The process of categorizing the spatial data started with an analysis of care demanding habitats presented by Andersson, Andersson, Blomquist, Forsberg, and Lundh (2016) describing care demanding habitats. The analysis resulted in a set of six NCM categories (Table 1). Each area category included criteria deemed identifiable given the available data and chosen so that there were no overlaps between area categories.

Table 1. Names, titles and a brief description of the criteria for identification of each category.

Category	Designation in text	Criteria
Areas with high degree of formal protection	Protected	Areas overlapping nature reserves, national parks or some other formally protected forest
Areas close to anthropogenic activity	Anthropogenic	Stands within 300 metres of residential buildings and stands overlapping areas or within 20 metres of lines and points identified as being sites with cultural heritage value
Areas close to water	Water	Stands within a 30-metre buffer zone of water surfaces
Areas with limited accessibility	Accessibility	Areas with limited accessibility due to low bearing capacity, high ground roughness, or steep slopes
Old coniferous forests	Coniferous	Stands where $\geq 70\%$ of standing volume is coniferous species and stand age ≥ 120 years
Old deciduous forests	Deciduous	Areas where $\geq 25\%$ of standing volume is deciduous species and stand age ≥ 60 years
Zero-category stands	Zero	Stands meeting none of the above criteria

The purpose of the categorization was to group and thereby attempt to explain the reasons why the forest companies chose to assign the analyzed stands/areas to NCM. Each category was identified applying the different criteria for each category on each polygon in the dataset. If a stand or parts of it met the criteria for a category, the entire stand was classified as being intended for NCM on these grounds.

Study II, Grönlund, Erlandsson, Djupström, Bergström, and Eliasson (2020)

Initially, a set of interviewee cohorts were defined (Table 2). Data was collected through 27 semi-structured interviews with professionals working with NCM in Sweden.

Table 2. Sampling matrix including the final number of interviews within each cohort of interviewee profession and climate region where she or he is operating.

	Operator	Forest manager	Nature conservation expert	Swedish Forest Agency officials	∑
Nemoral forests	4	5	2	5	**16**
Boreal forests	2	1	4	4	**11**
∑	**6**	**6**	**6**	**9**	**27**

The interview data on current practices was summarized on group cohorts. A thematic analysis was carried out of the slightly more complex data on key factors affecting decisions regarding NCM.

Study III, Grönlund and Eliasson (2019)

The study was carried out in stands with planted Norway spruce and even-aged spontaneous regeneration of birch, resulting in a two-layer canopy (Table 3). Time studies were done of harvester and forwarder in removal of the birch shelterwoods on 10 study plots (0.08-0.23 hectares). Unit of analysis was average time consumption per oven dry ton (odt) on plot level.

Table 3. Characteristics of study plots before harvest and harvest data for the study plots. Denotation d_a = arithmetic mean diameter and d_{ba} = basal area weighted mean diameter.

Characteristic	Unit	Observed min	Observed max
Birch prior to logging			
Trees*	n ha^{-1}	450	2,775
d_a	cm	7.1	10.5
d_{ba}	cm	6.9	12.7
Average height	m	8.9	12.6
Standing volume	m^3 ha^{-1}	17	133
Spruce prior to logging			
Trees*	n ha^{-1}	1,350	4,450
Average diameter	cm	4.1	8.9
Average height	m	4.2	8.8
Removal			
Trees harvested**	n ha^{-1}	1,735	5,126
Pulpwood removal	odt ha^{-1}	8.10	47.55
Energywood removal	odt ha^{-1}	9.20	19.49
Trees harvested per crane cycle	n	1.23	2.78
Gross revenues	€ ha^{-1}	595	4,314
Logging costs	€ ha^{-1}	1,282	3,586

* Diameter breast height ≥ 4 cm
** All diameters

Study IV, Eliasson, Grönlund, Lundström, and Sonesson (2020)

Harvester time consumption data was collected in the StanForD 2010-standard (Arlinger, 2020; Möller, Arlinger, & Nordström, 2013) through time-stamped hpr-files from 48 shifts. From these, 27 shifts (11,500 trees) were in normal final felling and 21 shifts (6,650 trees) in patch cutting. Patch cutting was made up of 10.8 hectares in 80 30x45 m patches, in a checkerboard pattern. Final felling was carried out on three sites (Table 4). Analyzes were based on shift level averages.

Table 4. Characteristics of the stands studied.

	Patch cutting	Final felling 1	Final felling 2	Final felling 3
Removal, m^3 ha^{-1} *	310	290	285	305
Average tree volume, m^3	0.49	0.30	0.52	0.36
Composition of species **	22/72/6	41/56/3	18/78/4	26/48/27

* In the area treated
** Percentage of trees (pine/spruce/deciduous)

Analysis of the terrain transport was carried out in three steps. Firstly, an analysis using the Skogforsk BestWay software (Friberg, Willén, Flisberg, & Frisk, 2017) was used to assess how the studied patch cutting affected the terrain transport distance compared to final felling of the same site. Secondly, there was a time study of forwarding in patch cutting and final felling. Thirdly, a theoretical analysis of total time consumption comparing the two treatments was carried out using the forwarder productivity norm by Brunberg (2004).

Results and discussion

Mapping of areas intended for NCM, Study I
From the area analyzed, 86 percent met the criteria of at least one NCM area category. The most common category was *old coniferous stand*, whose criteria were met in 43 percent of the stands (Table 5).

Table 5. Areas, number of stands and proportions of the analyzed dataset meeting the criteria of each category. Protected=Areas with high degree of formal protection, Anthropogenic=Close to anthropogenic activity, Water=Close to water, Accessibility=Areas with limited accessibility, Deciduous=Old deciduous forest, Coniferous=Old coniferous forest and Zero=Zero area categories applying.

Category	Area meeting criteria (ha)	Percentage of total area (%)*	Number of stands	Percentage of total number of stands (%)*
Protected	36 135	26	6 038	22
Anthropogenic	34 175	25	7 961	30
Water	33 116	24	6 104	23
Accessibility	19 358	14	4 247	16
Deciduous	22 537	16	6 322	23
Coniferous	58 553	43	8 168	30
Zero	19 163	14	4 569	17
Total	136 672		26 953	

* totals exceed 100% since stands could meet the criteria of several of the area categories simultaneously.

Old coniferous stands were strongly represented in the northern counties while all other area categories, except Accessibility, were more abundant in the southern part of the country.

Most commonly, stands met one or two area categories (41 and 32% of the area) while no stands met the criteria of all six area categories. NCM complexity, i.e. the number of area categories occurring within each stand, followed a south–north gradient with lower complexity being more common in northern Sweden; this area mostly comprised Coniferous stands.

Current practices for NCM in voluntary set-aside areas in Sweden, Study II
Although the terminology varied, all interviewees clearly distinguished between two types of NCM: restoration NCM and preservation NCM. Restoration NCM was described as taking place in areas that have needed NCM for a long time, and where the conservation values are suffering from lack of NCM. Preservation NCM, on the other hand, is carried out with such frequency that conservation values remain high.

When asked about what NCM operations are carried out, all interviewees described the same two, often concurrent, measures as making up by far the most NCM in Sweden: (1) creation of dead wood and (2) removal of Norway spruce to secure the survival of light-demanding species.

It was not clear whether the general and simplified task of removing spruce is a generalization applicable to all available NCM or if it was limited to the areas that were treated. It could be that the interviewees had slightly confounded the need for NCM with what is actually being carried out, which in many instances is the removal of spruce.

In mechanized NCM, i.e. operations involving harvesters and forwarders, the interviewees preferred the activities to be carried out in late summer, commonly August–September, and to some extent during winters when there are good ground conditions with little snow cover and frozen soil, mainly January–March. The reason for this short time-period is that there are many restrictions for when NCM is best carried out or even allowed.

Factors in affecting whether NCM in voluntary set-aside areas is carried out or not, Study II
The interview data helped identify several factors affecting whether NCM operations are implemented. When the factors were sorted into themes, and divided into barriers vs. incentives for NCM activities, there were substantially more barriers, and these were also mentioned more frequently. Incentives comprise requirements from certification standards and the dedication of individuals. Barriers can be attributed to the combination of four themes: (1) the short time span in each year suitable for the tasks, (2) the lack of incentives to invest the resources needed, (3) experienced or anticipated risk for costly operations and (4) experienced or anticipated criticism.

Time consumption for harvester and forwarder in two NCM treatments, Studies III and IV

Birch shelterwood removal
Average harvester time consumption was 1300 s odt^{-1} (2.77 odt E_0h^{-1}), at removal of 3000 stems ha^{-1} and 30 odt ha^{-1}. Harvester operators used multi-tree felling in 23–83% of the crane cycles, and the average number of trees per crane cycle in each study plot ranged from 1.23 to 2.78. Total harvesting time per odt was significantly affected by the covariates "harvested number of trees ha^{-1}" and "harvested biomass ha^{-1}" while there was no significant effect of removal method.

Of the 22 forwarder loads studied, 16 were pulpwood loads and six whole-tree energy wood loads. Time consumption for pulpwood loading was significantly affected by the parameter harvested biomass per 100 m of strip road, but not by the number of birch trees harvested ha^{-1} (p = 0.899) or removal method (p = 0.193). However, there was a significant correlation between removal method and number of birch trees ha^{-1} prior to logging (p = 0.0001).

With total cost ranging from 1282 to 3586 € ha^{-1} and revenues ranging from 595 to 4314 € ha^{-1}, only the largest removals per ha resulted in profitable operations. Harvester costs, on average, made up for 61% (ranging from 47 to 71%) of logging costs in pulpwood removal while in combined removals the corresponding number was 80% (ranging from 77 to 83%).

Patch cutting
Cutting treatment and average stem volume had significant effects on mean time per tree in patch cutting. There was also a weak tendency towards an operator effect and an operator by treatment interaction. The weak operator effect motivated use of the operator as a random factor in the mixed analysis, which showed a significant treatment effect corresponding to a 9.2 s per tree increase in the mean time per tree in patch cutting compared to final felling.

The observed difference in harvester productivity was 15-20% lower than in final felling, assuming equal tree size in both treatments. This was not unexpected, since harvester work is more restricted in the patch cutting treatment and productivity in even-aged thinnings are in the order of 30% lower than final felling of trees of equal size (Brunberg, 1997; Kuitto et al., 1994).

In forwarding, the BestWay GIS analysis of terrain transport distance found that patch cutting increased forwarding distance by 29%. Secondly, a time study found that loading and unloading times were 16% greater in patch cutting than in final felling. Thirdly, a theoretical analysis found that total forwarder time consumption was 16% higher in patch cuts than in final felling areas.

Synthesis

Forest operations in NCM present forest managers with new challenges compared to forestry intended for biomass production. Conventional forest operations strive for maximized long-term profitability

through silviculture aiming for high value biomass and forest technology aiming for low operation costs. Forest operations in NCM face other challenges. Initially, the task is to determine what the goal is, and how to measure and evaluate goal satisfaction. NCM also require collaboration between nature conservation and forest technology, two fields with different origin and traditions.

Both shelterwood removals and patch cutting result in higher costs than conventional forest management. It is, however, worth remembering that many areas need management, to avoid failing values (e.g. biodiversity or recreation). The most relevant point of reference is accordingly not to refrain from management.

Based on the findings in Study II, a set of managerial implications for NCM operations can be identified: (1) There must be incentives to carry out NCM operations if they are to be increased; (2) NCM operations that are not carried out in late summer will probably be deferred until a year later if they involve heavy machinery; (3) basic NCM operations are easily carried out, if adequate instructions are given; (4) NCM operations could be increased if there was a separate, not necessarily larger, budget for these tasks; and (5) identified key actors knowledgeable about NCM sharing their expertise with a relatively small group could contribute to a substantial increase in NCM operations.

The results in Study I identified a gradient of increasing conservation complexity along a north-south gradient, a trend supported also by previous investigations. Based on results from Study II, this increased complexity also result in higher operation costs. Adding to this, land values are higher in Southern Sweden. Accordingly, creating and managing preserves is more costly in Southern Sweden. Since more considerations need to made, successful operations also requires deeper understanding of the tasks. This highlight the need for efficient communication in these operations.

Even though the interviewees in Study II considered NCM operations as being a small part of Swedish forestry, no data were presented as to the actual extent of current NCM efforts. The best estimates are that altogether approximately ~1 million hectares in Sweden is intended for NCM. Based on rules of thumb presented by the interviewees, each stand intended for NCM need treatment, on average, every 20–30 years. Consequently, a conservative estimate is that NCM operations are needed on 30,000–35,000 ha in Sweden every year. As a point of reference, ~300,000 ha are commercially thinned and ~200,000 ha clearcut in Sweden every year.

Conclusions

There are several challenges regarding NCM in Swedish forestry, all contributing to the situation where NCM is not carried out to the extent needed to avoid failing conservation values. The studies presented herein provide; an initial mapping of areas intended for NCM and their conservation values, a description of NCM practices, a summary of factors influencing practitioners' decision whether NCM is carried out or not, and time consumption data from two examples of operations that may be carried out in NCM.

The conclusion is that; NCM areas can at an initial level be characterized using already available GIS-data, NCM operations are in most cases not complicated but operatives are disincentivized to perform NCM due to conflicting goals, and time consumption in NCM operations is higher than in conventional operations but applying adapted methods can reduce the difference from >30% to 10-20% without negative impact on other ecosystem services.

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Productivity of mechanized planting in spring, summer and fall in different forest sites

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Since the summer of 2020 A/S "Latvijas Valsts meži" is a purchasing mechanized planting service. Currently two mechanized planting machines are used in Latvia: RISUTEC TK-120 and Bracke P 11a. The productivity of mechanized planting was tested in three scientific research projects for one to two weeks. This time the productivity of mechanized planting is evaluated in real production conditions by chronometring files from a video recorder. Forest regeneration was evaluated in the Northern Courland region of Latvia in July – August of 2019 when rich herbaceous plant vegetation are, September – October 2019 when herbaceous plant vegetation decay and March – April of 2020 when herbaceous plant vegetation is yet starts to grow. Operations were timed for 10 stands each season where planting was done on mounds in drained and undrained mineral soils un drained peat soils. The same excavator and planting head was used in all recordings and operator was same.

Work productivity was calculated as time spent per one seedling planting as well as work operations. The best results were achieved in Oxalidosa turf. mel. stands in the fall with 13.58 seconds per seedling planting on average, the lowest productivity was recorded in Myrtilloso-sphagnosa stand in the summer with 18.74 seconds per planting. Time per planting varies most in Myrtilloso-sphagnosa stands with on average 13.84 seconds in the fall and 18.5 seconds per planting in the summer. In the spring 14.96 seconds were needed on average per plant. Less variation was observed in less fertile forest types – Myrtillosa mel. stands with an average of 15.63 seconds per planting in the spring, 15.86 in the summer and 15.81 in the fall.

In the research crane motion were determined to make up on average 31 – 35 % of total planting time with preparation of mounds making up on average 26 – 30 % of total planting time. Crane motion efficieny is directly connected to the amount of forest harvesting residue in the stand, the time needed for preparation of mounds depends on the composition of the spil and amount fo forest residue, since in the summer the amount and variety of vegetation is greater than in spring or fall. The greatest variation between fall and summer was recorded for time needed to clean up the mound spot with a difference of up to 275% with this stange of the planting process taking 2.5 times longer in the summer in comparison the fall. Nearly all stanges of operation took longer in the summer than in spring or fall, excpet for processes categorized as "other actions".

The amount of vegetation is so influencial on work productivity it is advisable to plan regeneration of stand with the most vegetation in the spring or fall and use the summer for planting in more fertile forest type stands.

Keywords: *mechanized planting, forest site, planting season, productivity*

Integrated in-stand debarking with harvester in cut-to-length operation

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Keywords: *debarking, harvester; fully mechanized harvesting, productivity*

Introduction

Norway spruce (Picea abies L. H. KARST) plays an important economic and ecological role among coniferous species in Europe. This goes hand in hand with its long tradition of cultivation and sourcing for raw material use. Changing climatic conditions, combined with natural hazards, have fostered one of the most destructive spruce pests—the Eurasian spruce bark beetle Ips typographus (L.) (Caudullo et al. 2016, Jansen et al. 2017, Michel et al. 2018). The amount of bark-beetle-damaged timber reached 4.38 million m³ under bark (23% of the annual cut in 2018)—a new record for Austria (BMNT 2018). One approach to control such bark beetle outbreaks is the debarking of harvested roundwood already at the harvesting site. Fully mechanized debarking of roundwood at the harvesting site with mobile machinery, also known as in-stand debarking, is well documented in relation to the supply of pulp and paper mills from plantations and continues to be in use (Watson et al. 1993, Hartsough and Cooper 1999; McEwan et al. 2017; Norihiro et al. 2018; McEwan et al. 2019).

Besides with the help of extra machinery, stems or logs can be debarked directly after felling during the processing by the harvester head itself. The harvester head is equipped with specially designed feed rollers that include trimmed machine settings for debarking. The felled tree is fed several times through the head until the bark is off, and the stem is cut into assortments. In-stand debarking in fully mechanized harvesting operations under European conditions was reported by Heppelmann et al. (2019). They analyzed harvesting performance figures during in-stand debarking using adapted conventional harvester heads from different manufacturers. The main aim of their study was to analyze the applicability of different modified harvester heads and their ecological potential by reducing the impact on nutrient loss due to timber extraction without bark. In addition, they included the quantifying of debarking quality with different modification and setups in their study (Heppelmann et al. 2019).

In-stand debarking is the result of optimizing and adapting roundwood logistics in terms of nutrient loss, transport cost or processing effort at the pulp and paper mill. Interim storage of debarked spruce logs close to the harvesting site may further improve roundwood logistics in terms of transport capacities and mill capabilities as it would automatically increase roundwood lead time without value loss due to blue stain.

Nevertheless, studies on the required additional effort for integrated debarking during harvesting in the stand with its effects on downstream processes are thin on the ground but would be essential for decision makers when planning harvesting activities. Therefore, the aim of this study was to analyze potential efficiency gaps in harvesting and forwarding by applying integrated in-stand debarking using a modified harvesting head with adjusted machine settings compared to conventional machine settings.

Material and methods

Layout and study site

The harvesting operation took place in the first week of June 2018 in the southern part of the province Lower Austria close to the village Säusenstein, which is owned by the Austrian Federal Forests (48°12′N,

15°08'E), 300m above sea level. The skid trails had a moderate slope with an average inclination of 10% and had no major obstacles. The stand was composed of coniferous (Picea abies L. H. KARST. and Larix decidua MILL) and single broadleaf (Quercus robur L., Fagus sylvatica L., Betula pendula ROTH) trees. Norway spruce (P. abies) dominated the stand with a share of 98.2% and were scheduled for the second thinning.

Machinery and debarking technique

The harvesting operation was carried out with a standard 8-wheeled harvester 1270G with a common harvester head H415, both of which were manufactured by John Deere Forestry Oy. The harvesting head was adapted for debarking by changing the conventional outer and inner feed rollers against specially designed feed rollers with twisting bars. The measuring wheel, as well as all the delimbing knives, were not changed or modified. Additionally, the hydraulic settings for controlling the delimbing knives and feed rollers were adjusted by technicians from John Deere Forestry Oy and the machine operator (Figure 1).

Figure 1. Adapted harvester head H415 with changed outer and inner feed rollers (left); inner feed rollers in detail (middle); outer feed roller in detail (right).

Unlike Heppelmann et al. (2019), the debarking process in this study was integrated, which means that the debarking of logs was done sequentially until the felled tree was processed and the top released. Debarking and delimbing was done repeatedly until the log was debarked, followed by the cross cut (Figure 2).
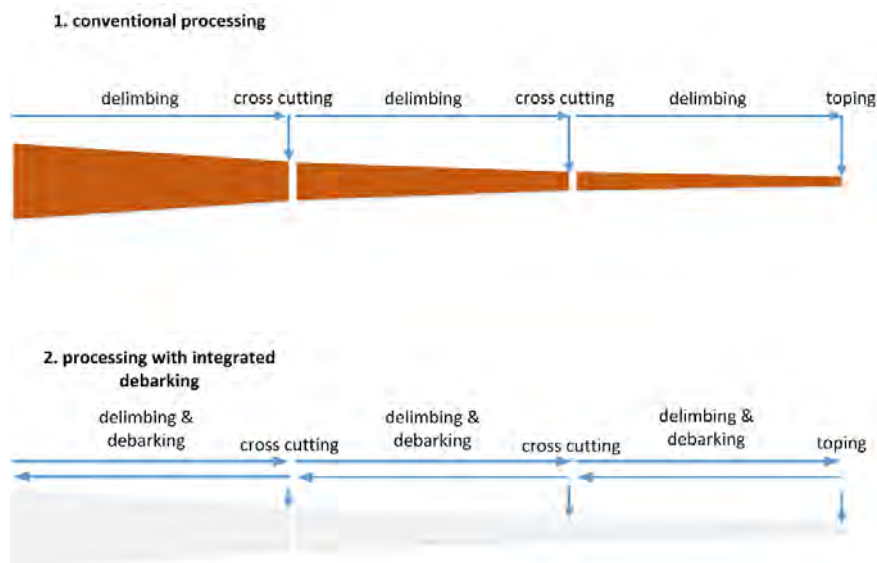
Figure 2. Schematic sequence of conventional processing (1); processing with integrated debarking (2).

Results and discussion

The average time consumption reached 0.89 minutes per tree, resulting in a mean efficiency of 2.69 min m^{-3} with a mean stem volume of 0.45 m^3 under bark. Based on the derived productivity model for the mean stem volume of 0.45 m^3 under bark, the harvesting productivity in this field trial decreased due to applied in-stand-debarking from 27.14 m^3 PMH$_{15}^{-1}$ down to 20.30 m^3 PMH$_{15}^{-1}$, which resulted in an average decrease of 25% (Figure 3).
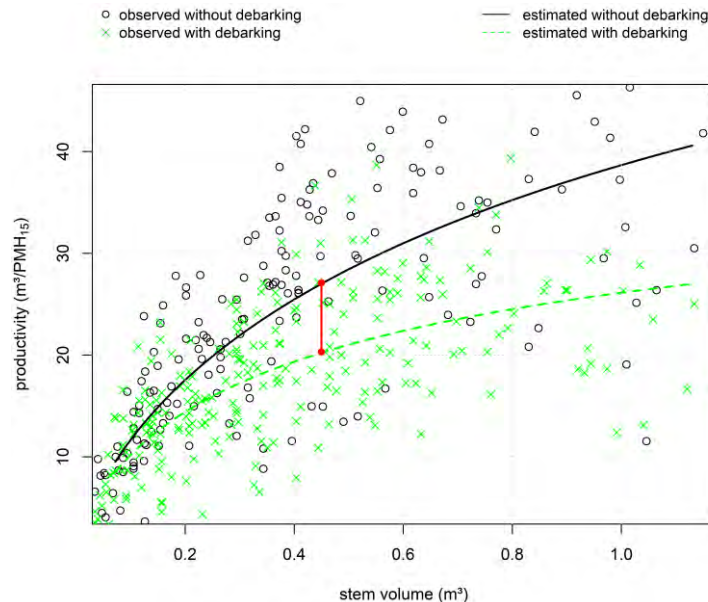
Figure 3. Productivity, depending on stem volume and whether integrated debarking was applied (green) or not (black), highlighting the difference in harvesting productivity at an average stem volume of 0.45 m³ (red)

The hourly costs of the harvester, including machine operator of 196.0 € PMH$_{15}^{-1}$ but without installed debarking technique, work out to 7.20 € m^{-3} at the derived mean productivity level of 27.14 m^3 PMH$_{15}^{-1}$. The modification of the harvester head is accounted to 7,750 €, which will increase hourly operating costs by 1.00 € and harvesting costs by 2.50 € m^{-3} (34.7%). This goes along with the findings of Magagnotti et al. (2011), who assessed the stump site debarking costs of logs from Eucalypt plantations with integrated in-stand debarking at the harvesting site by harvesters.

However, these are additional 15% within our study compared to the findings of Heppelmann et al. (2019), who reported 10% lower productivity due to debarking. It must be mentioned that the average processing time per stem increased by 48% with additional debarking during the study by Heppelmann et al. (2019) and these results are based on analyzing the machine's onboard computer data records.

Overall, harvester productivity in the presented study is within the range of the findings of Jiroušek et al. (2007) and Gerasimov et al. (2012), who reported productivity ranges for fully mechanized harvesting between 13.5 and 60.5 as 16.0 and 49.5 m^3 PMH$_0^{-1}$, respectively. These results are similar to the findings of Nurminen et al. (2006).

Conclusions

The present study was able to deliver important and detailed findings on productivity during in-stand debarking compared to conventional processing by applying this as an integrated but additional process during bucking and delimbing. The data will support decision makers along the whole supply chain of roundwood as debarking is expected to gain greater emphasis due to increasing changes in climatic conditions combined with natural hazards such as the European spruce bark beetle.

Acknowledgements

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Finding the best locations for furrows in soil berms of drainage ditches using LiDAR data

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Soil berms are typically built on the sides of ditches and are designed to purify water from agricultural fertilizers and to limit the transport of sediments to water bodies. However, for soils with fine particles, water filtration is limited and wet soil conditions can occur, which in turn reduces the soil's hydrologic conductivity capacity and hinders tree growth in the forest. The aim of the study is to develop a methodology for automatic modelling of the furrows in soil berms. Open source software QGIS and GRASS GIS is used in data processing. LiDAR data with minimum ground point density of 1.5 points per square meter were used in DEM creation. Local maximum analysis and further data filtration were used in determination of locations of soil berms. The results show that by making one furrow for every 185 m of ditches it is possible to reduce the area of the depressions by up to 91.8%.

Keywords: Depressions, wet areas, improved water regime.

Low cost prediction of time consumption for pre-commercial thinning

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1.Background

Pre-commercial thinning (PCT) is a release or spacing treatment in juvenile forest stands. The best individuals are chosen as crop trees, and site resources are made available by removing their closest competing trees, typically with a forest clearing saw by a forest worker. PCT is often needed in commercial wood production in many boreal forests. PCT has taken an increasingly larger share of the early rotation silvicultural costs, and the need to optimise PCT-procedures has become quite necessary.

The time consumption (TC) of pre-commercial thinning (PCT) varies greatly among sites, stands and forest workers. Silvicultural service providers need worksite difficulty and TC information of PCT in different stand and site conditions for payment and marketing purposes, it would be preferable to get this information before PCT is applied.

TC is typically estimated with removal based worksite classification (WSC) methods, which commonly account for density and size of the trees, but may also account some other factors. These methods have been used for several decades.

The estimation methods used for WSC are based on field measurements or visual observations of removal; they are rather expensive to implement with a precise outcome. Measuring a stand comprehensively and objectively can take 1.5–4.5 h ha^{-1} of work time. Thus, less time demanding methods are often used in practise, for example subjective visual observation and measuring only a few subjectively-selected plots. These are also less objective and less accurate methods, but still take some work time.

The costs of objective estimates of TC could be dramatically reduced by automating the process and predicting TC with the forest resources data (FRD) available from silvicultural service providers. For this purpose, we prepared a linear mixed model for the TC in PCT. Moreover, there are other factors which may affect the TC in PCT than the ones used in WSC, e.g. seasonal timing of PCT and variation among forest workers. Also these factors were included in the TC analyses.

2.Material and Methods

The modelling data included 11 848 and validation data included 3035 worksites with TC information recorded by forest workers within the period of 2008–2018. The TC was recorded from car to worksite and back. The worksites represented a range of site and stand conditions across a broad geographical area in Finland. The dataset and sites are described more thoroughly in tables 1 and 2.

Forest regeneration and management of young stands (including timing of PCT) were done according to the silvicultural prescriptions in Finland. According to the prescriptions, juvenile stand management was to be conducted in two phases; first removing undesired broadleaves (so-called early cleaning) and later spacing the crop trees. PCT may have been either of these operations. The need for and timing of the PCT were determined based on field visits and observations on the heights and densities of undesired and crop-trees.

The (fixed) effects of site and stand characteristics, as well as previous silvicultural management on the TC in PCT were modelled with mixed modelling by accounting for random year and forest worker effects. The accuracy of the model based on FRD was compared to the accuracy of a model based in WSC.

Table 9. Number of observations on different categories. Year and Month describe the time of application of PCT.

Year		Month		Site type [a]		Main tree species [b]		Soil preparation method	
2008	359	Dec–Mar	216	OMT	1316	*Pinus*	3936	Spot mounding	4637
2009	454	Apr	522	MT	6812	*Picea*	6184	Disc trenching	2689
2010	737	May	1625	VT	1869	*Betula pendula*	869	No preparation	45
2011	863	Jun	1618	CT or ClT	82	*Betula pubescens*	812	Inverting	68
2012	1120	Jul	1304	Rhtkg or Mtkg	1335	Other broadleaves	47	Excavator patching	1392
2013	995	Aug	1793	Ptkg	397			Continuous patching	1380
2014	1574	Sep	1489	Vtkg or Jätkg	37	**Establishment method**		Ditch mounding	1258
2015	1476	Oct	1967			Planting	9780	Not known	379
2016	1490	Nov	1314	**JSM [c]**		Direct seeding	1358		
2017	1533			Yes	1418	Natural	710		
2018	1247			No	10430				

[a] *Oxalis–Myrtillus* type (OMT), *Myrtillus* type (MT), *Vaccinium* type (VT), *Calluna* type (CT), and *Cladonia* type (ClT) on mineral soils, and the corresponding site types on peatlands herb-rich type (Rhtkg), *Myrtillus* type (Mtkg), *Vaccinium* type (Ptkg), dwarf shrub type (Vtkg) and *Cladonia* type (Jätkg).
[b] *Picea* includes also *Larix* and *Abies*, and *Pinus* includes both *P. sylvestris* and *P. contorta* as main tree species.
[c] Juvenile stand management (JSM) has been done earlier or not.

Table 2. Descriptive statistics of different variables in modelling data set.

	Min	Median	Mean		SD	Max
TC, h ha^{-1}	0.40	8.80	9.93	±	5.47	46.10
Worksite area, ha	0.03	1.34	1.89	±	1.75	27.73
Stand age, years	2	8	8.40	±	3.40	24
Establishment delay[a], years	0	1	0.58	±	0.59	9
Stand age in previous JSM[b], years	1	7	6.90	±	2.00	13
Birch in final harvest, m^3 ha^{-1}	0	5	13.78	±	0.24	233
Topographic wetness index	3891	6797	7263	±	1872	21846
Temperature sum, d.d.	935	1147	1161	±	98	1388
Latitude ETRS-TM35FIN	6699759		6930960			7331801
Longitude ETRS-TM35FIN	378536		596313			725856

[a] Time from the soil preparation to the artificial regeneration.
[b] Only worksites with previous juvenile stand management (JSM) (N = 1418).

3. Results and discussion

Site and stand characteristics and previous management logically explained the TC in PCT. The more fertile the site, the more working time was needed in PCT, e.g., stands on dry sites took only 55% of the time compared to the most fertile sites. Moreover, PCT in stands on mineral soils took less time than stands on peatlands on their corresponding site types.

On sites of medium fertility, TC in the initial PCT increased with stand age by 0.5 h ha^{-1} yr^{-1} (Fig 1). On stands, which had had earlier juvenile stand management operation, the increase of TC was a bit quicker with stand age.

The modelling revealed a significant and logical effect of the seasonal timing of PCT on TC (Fig 1). The TC in PCT was at its highest in summer when the flora is fully in leaf, and at its lowest in spring during the time period from snow melting until the full-grown leaves. In winter, snow cover presumably hindered the worker and PCT was more time-demanding. The effect of seasonal timing on TC could be utilized, for

example, by scheduling PCT of pure pine stands with good visibility in summer, and performing early cleanings (i.e. eliminating undesired broadleaves overtopping crop trees) in spring. Currently, silvicultural service providers try to schedule removals of broadleaves in summer, because the re-growth of the stump sprouts after removal is at its weakest at that time

Furthermore, site wetness increased the TC. Small areas were more time consuming to PCT per hectare than larger ones. Moreover, establishment method, delay in establishment, site preparation, and the main tree species of the stand affected TC.
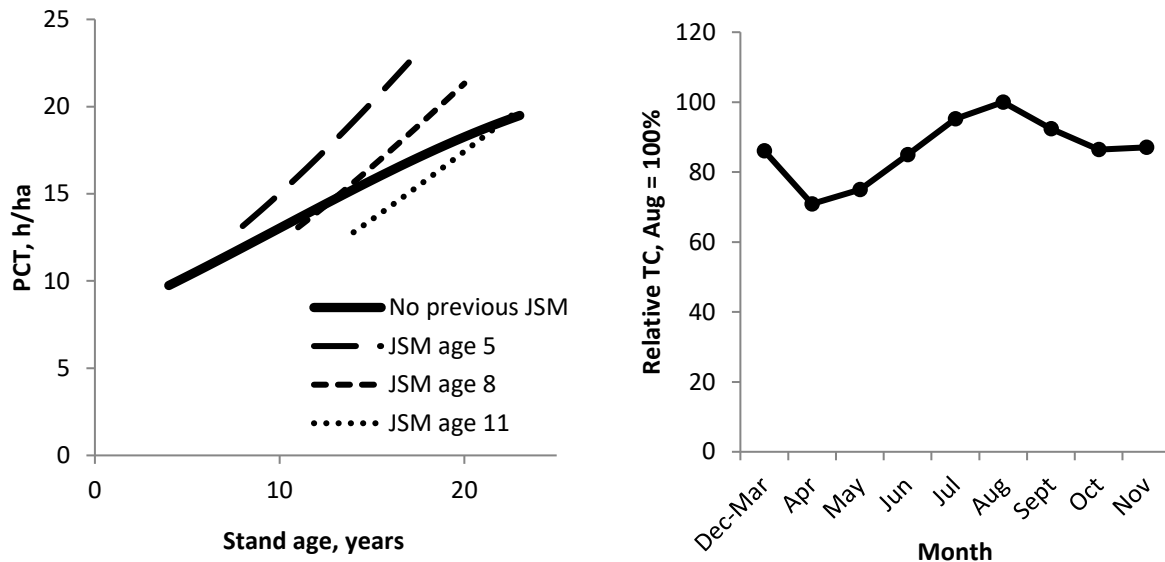

Figure 22. The effect of stand age (right) and application season of PCT (right) on time consumption of it.

Both FRD and WSC-variables used as predictors in different models explained significantly the variation in the TC in PCT. The proportion of the variance explained by fixed effects (R^2) was 20% in the FRD based TC model. Thus, the unexplained variation remains quite high in FRD based estimation. However, as much as 35% of the unexplained variation was found at the forest worker level, showing that the worker has high impact on time consumption of PCT. The coefficient of determination in validation data was 19.3%, RMSE 4.75 h ha^{-1} and bias −1.6%.

The field-assessed work difficulty factors were able to describe TC in PCT slightly more precisely than stand, site and management variables: RMSE 4.9 h ha^{-1} vs. 4.1 h ha^{-1} (52% vs. 43%). The proportion of the variance explained by fixed effects was somewhat higher in WSC-based model (R2 = 43.0%) than in FRD based. However, an advantage of using FRD based model is that it can be applied without field assessment prior to PCT. Field assessment requires a decent amount of extra efforts and is more expensive to apply in estimating the TC in PCT.

As a conclusion, time consumption (TC) in pre-commercial thinning (PCT) can be predicted with variables in forest resources data. Many site, stand and management variables described logically TC in PCT. The TC model could be connected to forest information systems where it would facilitate the predictions of the labour costs of PCT without field-assessing work difficulty factors. However, the TC FRD-model was slightly less precise than the one based on field-assessed WSC (removal quantity and type, and terrain difficulty).

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Harvester data as aid in trees species selection in forest regeneration

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Introduction

In current forest management practice forest stands are delineated and formed either on operational or biological basis. Typically, the size of forest stand varies between 1 to 10 hectares. However, stands comprise rather broad small-scale variation regarding soil properties, fertility, tree species mix etc. The term 'Precision forestry' is an emerging forest management concept based on observing, measuring and responding to the intrinsic variability within forest stands.

Based on modern techniques (e.g. airborne laser scanning and harvester data) it is possible to produce trustworthy, and in spatial scale, precise predictions on site quality indices, diameter-height distributions and micro-topography for a given point, grid cell or on micro stand level. Interlinking information of tree attributes and site index with topographical, cartographical and hydrological information provides a way forward to upgrade forestry efficiency. Further, precision forestry gives forest practitioners tools to adjust the unique features of the site by managing the forest more according to biological prerequisites.

Precision forestry philosophy – division of stand to smaller units and managing the stand at micro stand, grid cell or tree-by-tree level – provides a great possibility to increase the forest growth, forest stand structure and forest health. In regeneration phase by adjusting species selection, soil preparation, intensity of regeneration measures (planting density and material) and young stand treatment procedures according to precise information on soil properties (fertility, wetness, soil type) and micro-topography will inevitably lead to an increase in growth of the whole stand.

Case study

Description of study stands

The study material comprised six mature mixed Scots pine – Norway spruce forest stands on Finsilva Ltd forest property in Central Finland. All these stands were final felled in summer and autumn 2017. Area of chosen study stands varied from 1.3 to 23 ha. Site types according to Finnish site type classification varied in these study stands from quite unfertile Vaccinium type to fertile Myrtillus type (Cajander 1926). The main tree species was Norway spruce in 2 study stand and Scots pine in 4 study stands. All of these stands had some birch admixture (varying from 2 to 13% of stand volume). Average cutting volumes varied from 199 to 303 m3/ha.

Estimation of localized growth potential

While harvesting, most important tree characteristics were registered: geographic location of tree (=location of machine at the moment the tree had been felled), butt end and top end diameters of each log, length of each log and assortment of each log. After harvesting tree information was converted in hpr-format (Skogforsk 2018). Next, this hpr-file was interpreted and analysed with the HprAnalys software developed by Skogforsk. With this tool tree information was converted into ESRI

Shapefile-format. In the ArcGIS-tool, a new vector grid layout of 16 x 16 m was created and each tree was categorized to the one specific grid cell according to its location.

Tree height was based on harvester data and modelled top height. At first, height of each felled tree was estimated by aid of dbh, height of the last cut and diameter of the stem at the height of the last cut. Top height was estimated by model of Varjo (1995). Secondly, from each grid cell, three tallest trees were selected as the dominant trees. Thirdly, stand age was based on the forest stand data. Next, site index (i.e. H100=height of dominant trees at the age of 100 years) for each grid cell was estimated with the equations given by Gustavsen (1980). Finally, mean annual volume growth for each grid cell for the period of 100 years (m3/ha/year) was estimated for pine and spruce with the equations presented by Vuokila and Väliaho (1980). Greater value of these growths (pine or spruce) was selected to represent growth potential of the grid cell (Figure 1).

Figure 1. Maps of mean annual volume growth potential (m3/ha/a) in study stand 49 estimated by the past growth of spruce (left), pine (middle) and combined with maximum value of spruce or pine (right). The estimated growth potential (average of 9 neighbouring grid cells) varied from 3 to 14 m³/ha/a in the case stands.

Creation of micro stands

Delineation of micro stands was based on the growth potential (mean growth within 100 years, m3/ha/a) of each grid cell. In order to scale out variation in growth potential between adjacent grid cells the average value of nine grid cells (the center cell plus eight adjacent cells) was used as the growth potential value for the center cell. Micro stands were generated from adjacent cells within same growth potential category. The alternative threshold values for categories used in this case study were 6, 7 or 8 m3/ha/a. These values were used as threshold values for tree species change. First, the program segmented the given growth potential data and identified the continuous areas of different categories. An iterative process was run to segment the growth potential data to areas larger than the threshold value (nine grid cells; 0.23 ha). Areas smaller than nine grid cells were identified and their growth potential values were converted to the closest value in the neighbouring segments. The segmentation, area identification and cell value transformation were repeated until all the continuous areas were large enough (at least 0.23 ha).

Comparison of different micro stand solutions

Alternative micro stand solutions looked quite different in the same study stand (Figure 2). For instance in study stand 49 the one threshold solutions (alternatives A-C in figure 4) differ totally from each other and the double threshold solution seems to combine the features of one threshold solutions with solutions 6 and 8 m3/ha/a.

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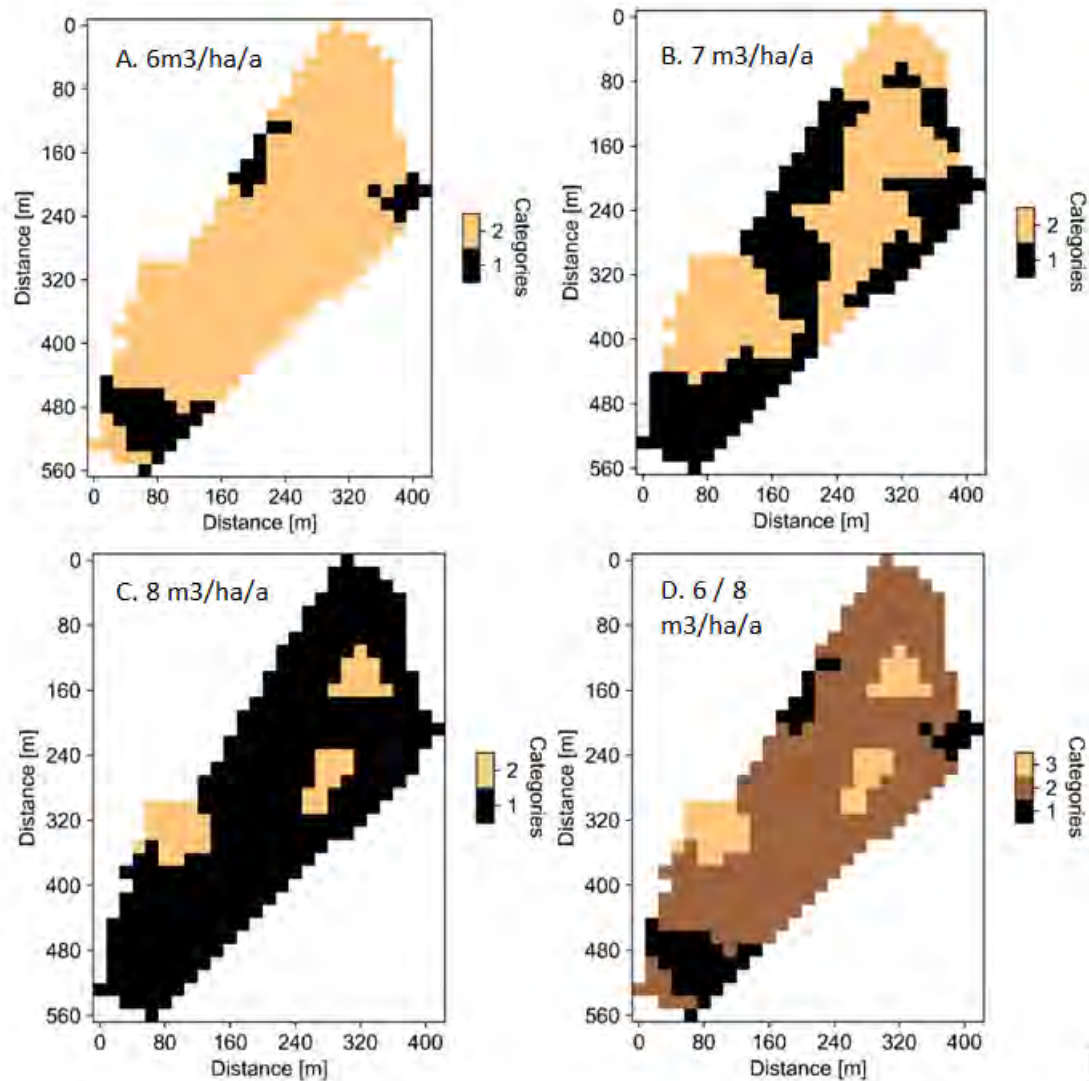
Figure 2. Visualization of micro compartments in study stand 49 categorized with single threshold values of 6 (A), 7 (B) and 8 m3/ha/a (C); and double threshold values of 6 and 8 m3/ha/a (D). A-C: Category 1= pine, 2= spruce, D: 1= pine, 2= pine or spruce and 3= spruce.

The number of micro stands varied from 1 to 13 in different solutions in study stands. In the smallest study stands delineation to micro stands did create only two micro compartments. This was obvious because the total area of these stands was less than two hectares. In larger study stands the number of micro compartments was clearly higher. In these larger study stands the average number of micro compartments in one threshold value solutions was six and in double threshold value solutions nine.

The average area of micro stands was 1.68 ha (excluding one micro stand solution in study stand 127). In larger study stands (stands 2 and 118 not included) the average micro stand area was more than two hectare. The minimum area of micro stand averaged 0.46 ha (excluding one micro stand solution in study stand 127) and in larger stands 0.27 ha correspondingly.

In two study stands the result was spruce dominated stock in every micro stand solution. Also options threshold value 6 m3/ha/a and double threshold value 6/8 m3/ha/a with spruce in middle category gave always a spruce dominated stand as result. Most often pine dominated stands were found when threshold value was 8 m3/ha/a, which was a quite obvious outcome.

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Stand simulations with different micro stand solutions

Further stand development for each micro stand was simulated with Motti software, which is developed at Natural Resources Institute Finland (Luke). Motti is a stand-level forest management and decision support tool that consists of stand-level models and distance-independent individual-tree models for predicting stand dynamics (regeneration, growth and mortality) and stand structure (Salminen et al. 2005, Siipilehto et al. 2014, Hynynen et al. 2015).The net present values (NPV, 3%) for the current rotation were compared between different micro stand solutions.

In all study stands NPV of pure spruce stand was clearly higher than that of pure pine stand (Figure 3). In four out of six cases the NPV of mixed stand (i.e. combinations of micro stands) was a little bit higher than the one of pure spruce stand. All these mixed stands were spruce dominated and they were treated following silvicultural guidelines of spruce dominated stands. In one study stand (study stand 118) the NPV(3%) was significantly higher with the option where stand was planted with two tree species (delineation with threshold value 8 m3/ha/a) than with one tree species. On the other hand in all study stands there exists a mixed stand solution or solutions which gave about the same NPV(3%) outcome as the pure spruce stand.
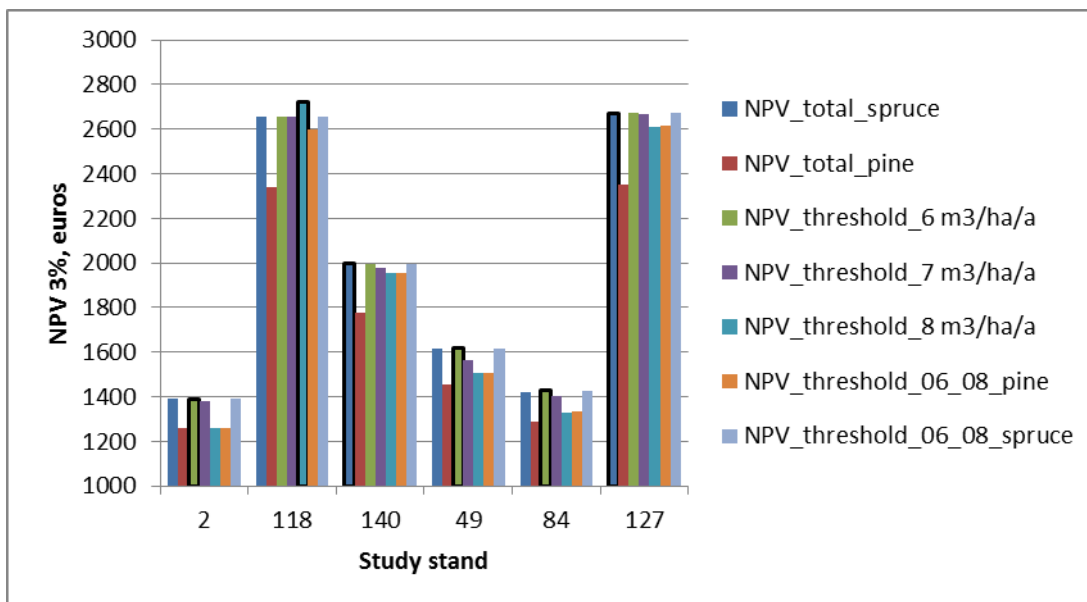
Figure 3. NPVs (3%) with seven different planting options in the study stands. The highest bar has bolded frames. Study stands were arranged in ascending order in area.

Discussion and conclusions

A method for creating micro compartments inside a large forest stand at regeneration phase was piloted in this study. Local site index was calculated for each grid cell using harvester data from final felling. Calculation was based on three biggest trees in harvester data for each grid cell. Study stands were thinned below in earlier cuttings so it could be assumed that the growth of dominant trees in final felling was a good estimate of local growth potential (site index). In our study we tried to measure the age of trees in field inventory, but it seemed that the age of stand in forest data was as good estimation as our field measurement. If the age of dominant trees could be detected automatically with some optical device during the felling operation it might give more precise estimate of local site index.

Site types in study stands were mostly classified as Myrtillus type in Finnish site type classification (Cajander 1926) which is quite suitable to regenerate both for spruce and pine. The estimate of local site index was used for delineation of micro compartments suitable for spruce or pine planting. The minimum micro compartment area was discussed with experts from practice and it seemed that the area of a micro compartment can be quite small without causing extra costs in site preparation or planting with varying tree species. In other silvicultural activities as well as cuttings the whole stand was treated with same operations and methods (e.g. timing of thinnings at same time). So the minimum compartment size was adjusted in this study to 0.23 ha. Practically this means for instance a 48 meters x 48 meters square. From biological point of view it is a possible solution that at least the middle parts of micro compartment do not get border effects from neighbouring micro compartments. This is especially important if neighbouring micro compartments are planted with tree species with strongly differing growth rates. In our study most of the best micro compartment solutions according to NPVs had several micro compartments and the smallest ones were usually less than 0.5 ha in area.

Our simulations pointed out that the "precision forestry" option where the forest stand may be planted with two different species is a very promising alternative to the current forest practices. The mixed forest stand structure never produced economically clearly inferior solution to the single species stand and in one case out of six it provided distinctly better solution in terms of NPV(3%) than the single tree option. Our case study showed that this kind of method could be used as a decision-making tool at regeneration phase.

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Decay fungus *Chondrostereum purpureum* in preventing sprouting of deciduous trees in young conifer stands

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Keywords: Sprout control, wood decay, commercial forests

Background

In Finnish young forests, there is a need for better sprout control methods than cutting only, since naturally grown deciduous species restrict the growth of more valuable conifers by forming thickets from re-sprouting stumps. Thus, these sites should be visited more than once in order to enable suitable conditions for conifer growth thus increasing costs of young stand management.

One new alternative to improve sprout control efficacy is the use of a decay fungus *Chondrostereum purpureum* (Pers. Ex Fr.) Pouzar in cutting operation. This method is based on the ability of the fungus to grow inside wood and decay it after fungal mycelia have been spread on freshly cut stump surfaces. When decay proceeds deeper it gradually prevents normal function within a stump and a tree dies.

A challenge in the use of fungal treatment is to spread the mycelia of *C. purpureum* efficiently to stump surfaces immediately after a sapling has been cut. A cost-efficient option is to utilize mechanized devices (cleaning heads with spreading systems) in cutting and spreading of fungal inoculum since forest regeneration areas include often high numbers of saplings to be cut thus making this work inefficient when performed manually.

Material and Methods

In 2007-2014, several experiments were established to investigate the efficacy of a decay fungus *Chondrostereum purpureum* in preventing sprouting of deciduous trees (Table 1). All sites located in southern Finland. In each study, saplings were cut with a clearing saw, and fungal mycelia were applied manually to cut stump surfaces using a plastic squirt bottle or a backpack sprayer within half an hour after cutting. Fungal strain R5 was used in each study, except for the rowan study performed in 2007 in which the strain P3 was used. Sample plots for the control were also established (cutting only). Stump mortality as a measure of the sprout control efficacy was investigated two to four growing seasons after the treatments in the field.

Table 10. Experiments performed in years 2007-2014, the number of saplings included in the studies, and the mean diameter and standard deviation (SD) of cut stumps investigated.

Target species	Scientific name	Year	Control	Fungal treatment	Stump diameter (mean ± SD, cm)
Birch	*Betula pendula* and *B. pubescens*	2011	80	80	1.1 ± 0.4
Aspen	*Populus tremula*	2011	70	76	1.2 ± 0.4
Alder	*Alnus incana*	2014	24	49	2.6 ± 1.0
Rowan	*Sorbus aucuparia*	2007	64	90	1.8 ± 0.7
		2013	239	235	1.3 ± 0.4

In 2012-2015, experiments were established to investigate the efficacy of clearing saws and mechanized devices in preventing sprouting of silver and downy birch (*Betula pendula* and *B. pubescens*, Table 2). All methods include both cutting of saplings and spreading of fungal inoculum from attached tanks immediately on freshly cut stumps. The results were compared to the control (cutting only, see above). The fungal strain R5 was used in each experiment, and the sprout control efficacy was investigated as above.

Table 2. Experiments performed with mechanized devices in years 2012-2015, the number of saplings included in the studies, and the mean diameter and standard deviation (SD) of cut stumps investigated.

Device	Year	Control	Fungal treatment	Stump diameter (mean ± SD, cm)
Clearing saw				
• nozzle at the stem of a clearing saw	2012	80	80	1.6 ± 0.9
• automatically functioning [a]	2012	80	80	1.7 ± 1.0
• nozzle at the side of a blade	2013	80	80	1.3 ± 0.4
• nozzle under the blade	2013	80	80	1.2 ± 0.4
Tehojätkä [b]	2014	529	907	1.3 ± <0.1
	2015	22	11	1.2 ± 0.6
Mense clearing head RP6L [c]	2015	22	38	1.2 ± 0.6

[a] Fungal inoculum is spread only when touched on the stem of a sapling
[b] A lightweight mini-harvester (Usewood Ltd., Finland) equipped with a boom-mounted UW40-cleaning head
[c] Attached to the harvester boom

Results and discussion

The fungal treatment utilizing a decay fungus, *Chondrostereum purpureum,* as a sprout control agent was efficient in preventing sprouting of different deciduous stumps (Figure 1). Ca. 78-92% of birch, aspen and alder stumps treated with a fungal inoculum were killed two to three growing seasons after the treatments indicating high sprout control efficacy of the treatment. In rowan, sprout control efficacy was lower, ca. 40-50%, verifying its ability to recover efficiently from disturbances (Hamberg et al., 2009). In the control (cutting only), stump mortality was lower as expected.
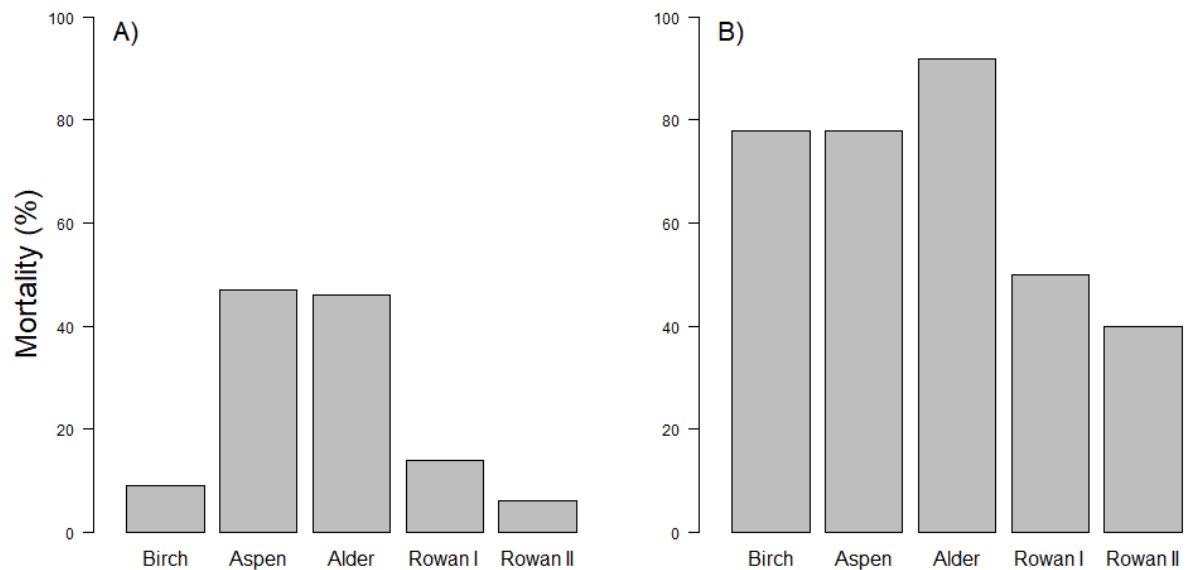
Figure 23. Mortality of silver and downy birch, aspen, alder and rowan saplings when they were A) cut only or B) cut and stumps treated with a decay fungus, Chondrostereum purpureum*. Mortality has been investigated two, three and four growing seasons after the treatments for alder, birch and aspen, and rowan, respectively.*

Four growing seasons after the treatments, the stump mortality of silver and downy birch was ca. 30-34% for the lightweight mini-harvester Tehojätkä and 42% for Mense clearing head whereas in the control, mortality was ca. 12-13%. The best clearing saw option having nozzle at the side of a blade, caused stump mortality 36% thus indicating promising sprout control efficacy corresponding to the mortalities of the manual treatments after two growing seasons. In the future, fully mechanized device able to carry the weight of inoculum and cut and spread fungal inoculum immediately to freshly cut stump surfaces is a desirable option. Before that more efficient spreading mechanisms should be developed to achieve better final sprout control efficacy. More information can be found in Hamberg et al. 2014, 2015, Hamberg and Hantula 2016, 2018, and Laine et al. 2019a, b and 2020.

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Boom-corridor thinning trials with an upgraded version of Bracke C16 in biomass dense first thinnings in Sweden, Finland and Slovenia – preliminary results from the Smallwood project

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There are large amounts of underutilized small-diameter trees in Europe which can be harvested for industrial processing to boost the growth of the bioeconomy. However, further developments of technology and working methods for harvesting and supply are needed to realize their sustainable potential at a competitive cost. The main aim of our study was to measure the productivity of a harvester equipped with an upgraded version of the accumulating felling head Bracke C16.c, during the first thinning of biomass-dense stands. Two working methods were compared: conventional selective thinning and novel boom-corridor thinning. The field trials were performed in Sweden, Finland and Slovenia during the Fall-Spring 2019/2020, using the same harvester and driver. Our hypothesis was that boom-corridor thinning would, on average, facilitate at least 15% higher harvester work productivity. Results from Sweden confirmed our hypothesis (15.7% higher productivity), yielding on average 6.2 and 5.4 dry tonnes per hour with the boom-corridor and selective thinning working methods, respectively. In Finland, the boom-corridor thinning yielded a 9.5% higher productivity than the conventional selective thinning (4.5 and 4.1 dry tonnes per hour for the boom-corridor and selective thinning, respectively). Removal of biomass averaged 45 and 36 dry tonnes per hectare in Sweden and Finland, respectively (corresponding to a removal of basal area of ca. 49% and 66%, respectively). Significant differences in time consumption of work elements such as felling and top bucking were found, with larger time consumption per harvested tree when performing a conventional, selective thinning.

Keywords: productivity; accumulating felling head; working methods; small-diameter trees; whole-tree harvest;

Disc trenching with rotatable discs on side slopes

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Mechanical soil preparation is a frequent operation in Swedish forestry. The most common method is disc trenching (it is performed on >50% of the yearly soil prepared area). Bracke Forest has recently developed an adaptable disc trencher with rotatable discs (Bracke T28.a).

The objective of this MSc thesis was to compare the quality of soil preparation on side-sloping terrain using a Bracke T28.a with the discs rotated in the same direction versus the discs rotated in separate directions (the latter set up imitates normal disc trenchers). The reason for studying the T28.a on side slopes was that the effect of the rotatable discs is more evident when machines work along the contours.

During autumn 2019, a field study was carried out in Västerbotten, Sweden. The soil preparation quality of the T28.a disc trencher on side-sloping terrain was observed and analyzed.

The T28.a disc trencher with both discs rotated in the same direction (downhill) produced 5% more acceptable planting spots than when the discs were rotated in different directions, and produced 12% more planting spots that contained inverted humus with mineral soil coverage. The difference between the two disc trencher versions increased with more challenging terrain characteristics.

The conclusions of this SLU study are that soil preparation on side-slopes is aided by disc trenchers with rotatable discs compared to normal disc trenchers. The results of this study opens up for an increased proportion of disc trenching on side sloping terrain, which can lead to economic and environmental benefits because both fuel consumption and risk of erosion decrease when trenching is performed along the contours.

Keywords: *Site preparation, scarification, microsite, silviculture, forest regeneration*

Load- and tool-carrying drones in silviculture

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Keywords: *Utility drones, silviculture*

Introduction

The use of drones in forestry is becoming widespread. So far, most applications have focused on operations dealing with collection of data, images etc. Today there is development going on to use high capacity drones for operational forest work, mainly in the field of silviculture. High capacity drones are characterized by high lifting capacity and in relation to that, long flight times. Furthermore, operational work can be carried out with high spatial precision and can with the use of advanced control system operate in swarms were tasks can be performed using several drones working synchronized and in sequence thereby increasing capacity, efficiency and productivity.

The current project

In Sweden, the first attempt to implement utility drones in silviculture focus on the potential to use high capacity drones for precision fertilization. Development is taking place in the startup company Nordluft. Their offer is a synchronized group of five multicopters, each carrying 30 kg, coupled with advanced control software and a vehicle mounted logistic base station. There are ongoing spreading tests using a full-scale drone and automatic area coverage using multiple drones has been verified. Spreading tests using multiple full-scale drones are planned.

The development of drone-based fertilization should be considered as a pilot project and a basis for development of other silviculture applications. Work in that direction is going on internationally. For example, in Canada attempts are made to regenerate forest using a combination of high capacity drones and seedpods. Other potential applications might include distribution of seedling during manual planting, ash recirculation, application of plant protection products, and early precommercial thinning.

Material and methods

The method used in the project is a step by step technology and commercial technology development process:

- One of the fundamental technical challenges is to construct a robust drone capable of carrying 30 kg of load. Nordluft has built and verified four different full-scale prototypes. Since the first version steps have been taken to improve:
    - Total weight (lower)
    - Weather resistance
    - Protection of sensitive electronics
    - Handleability (easier to assemble, lift and transport)
    - Size (more compact)
    - Battery design and performance

  Figure 1 shows the three first drone prototypes. The latest prototype is a slightly updated version of the third, the BF 2.1.

Figure 24. Drone development within Nordluft. From the left the first prototype BF 1, the second, BF 2 and to the right, the third prototype BF 2.1.

- Parallel to the development of the actual drone, an advanced control system is developed allowing several utility drones to work simultaneously and synchronized in so called drone swarms. This part of the system is critical in order to reach the targeted efficiency and capabilities. All drones used must be automatically controlled to finish the assigned task in a safe and efficient way. An operator monitors the work, but does not directly control each drone. Only in emergency situations can the operator choose to have direct control of a drone through a standard RC link. In the initial application of the drone system, the control system directs each drone so that the mission area is covered, e.g. for forest fertilizing. Emptying 30 kg takes only a short moment, why drones will frequently return to the base station for replenishment.
- In developing the control system, challenges have been
  - Connectivity, what technology should be chosen for the communication link between the drones and the base station.
  - Mission planning optimization. To reach to full potential of system efficiency, drone flights must be rigorously calculated. Flight distance must be minimized, queuing of drone shall not happen at the base station, and collisions between drones shall be avoided be planning.
  - Collision avoidance. Map data and active sensors are used to avoid collisions with the terrain. Collision avoidance between drones is integrated in the mission planning optimization.
  - Fail safe functions. The size and number of drones makes safety functions crucial. Nordluft is including different auto-commandos in the onboard autopilot, that will be activated if e.g. the drone loses its GPS or data link to the base station.
- For the application (high precision fertilization) a fertilizer system using granulated fertilizers is constructed and mounted on the drone. To the drone frame a fabric canister and a spreading mechanism are added. These parts have undergone development along with the drone prototypes. Weight of the spreading mechanism has been reduced significantly by using 3D printing technology. Sturdiness of the spreading plate has been increased using a carbon fiber structural layer together with sheet metal. Initially the sides of the canister did not have enough angle for the granules to pour out completely, this problem has been solved with a different design. Nordluft is currently testing a different spreading mechanism together with the latest drone prototype. This mechanism has dose function that instead of continues spreading over a swathe function, which gives small doses over point locations. The idea behind this function is to be able to provide precision fertilizing on a tree level. Partners is the project are the Department of Forest Ecology and Management together at SLU Umeå and Skogstekniska Klustret.

- In order to evaluate the practical potential for the concept the project plan will describe the commercial and legal aspects of the present and other future application for the use of high capacity drones in silviculture. Flying drones beyond visual line of sight (BLVOS) is the most important legal barrier in most regions, which in some cases is defined to 500 m. Authorities have these limitations to avoid collisions between drones and other aircrafts. There is intensive ongoing work in establishing standards and principles that would allow drones to operate at longer distances, see e.g. UTM and U space. Before such standards are in place drone utilization in silviculture is limited by flying withing visual line of sight and special permissions. If flight altitude above treetops can be strictly limited, this is a good argument for granting a special permission for BVLOS drone usage in silviculture, since no other aircrafts would fly within meters from treetops.

Results and Discussion

Nordluft has been working on this drone concept since 2017. Currently the company employs 5 engineers of which 3 are full time. The company has recently secured funding for building a full proof of concept, including a vehicle base station. Figure 2 illustrates the full system in operation.

Figure 25. A concept illusttration of the full drone system in operation with drone swarm, operator and base station.

Nordluft has secured a special permission from the Swedish Transport Agency for flying the company´s full scale drones for the purpose of development and demonstration (5C). When final drone design is chosen and the company has gained more test data from flying in different conditions, permission for widespread commercial operation will be applied for.

With the current full-scale drone design and control system, a number of tests/demonstration projects are planned within 12 months:

- Dose spreading of forest fertilizer with one drone – together with project partners Department of Forest Ecology and Management together at SLU Umeå and Skogstekniska Klustret.
- Verification of spreading performance and precision (forest fertilizer) with one drone - together with project partners Department of Forest Ecology and Management together at SLU Umeå and Skogstekniska Klustret.

- Verification of spreading performance and precision (forest fertilizer) using multiple drones and swarm control system - together with project partners Department of Forest Ecology and Management together at SLU Umeå and Skogstekniska Klustret.
- Demonstration of bio ash recirculation using 3 full scale drones and swarm control system - together with project partners Energiforsk/Askprogrammet, Fortum/Stockholm Exergi and Robotdalen.
- Full scale bio ash recirculation using the full 5 drone system including base station – together with project partners Energimyndigheten, RE:Source, Fortum/Stockholm Exergi and InnoEnergy.
- Seeding of coniferous trees in Canada – together with project partners Centre for Research & Innovation in the bioeconomy (CRIBE), Lakehead University and a major Canadian forest company.

To be able to succeed in the planned demonstration projects, the company needs to further verify the performance and reliability of its current drone design and swarm control system. The company plans to have 4 working drones of the current design available in early November 2020. First version of the logistic base station is planned to Q1 2021. When the main concept is proven to be functional and safe, Nordluft will invite partners to collaborations on alternative applications of the drone system.

Current development focus on the main mechanical capabilities of the system. However, the potential applications and benefits of the drone system can be significantly improved with the introduction of advanced sensors, AI and computer power. In the next phase, when further funding is secured, Nordluft plans to expand the development scope into these areas.

Precision agriculture is an interesting area for the drone system if equipped with advanced sensors. There is already early commercial use of precision spreading of plant protection products from drones, mostly in Asia. This technology has the potential if increasing yield while reducing the input of fertilizers and plant protection products. In its current form, it is however only applicable in special applications where normal farming machinery is problematic to use. With the capacity and efficiency in the system that Nordluft is developing, the benefits of precision agriculture can be introduced on a wider scale.

The PlantmaX continuously advancing tree planting machine: initial tests on Sveaskog sites in central and northern Sweden

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PlantmaX is a continuously advancing tree planting machine based on the Silva Nova concept from the 1980-1990s. Together with the constructor Plantma and the contractor Vallsta Skogsmaskiner, Sveaskog has performed extensive trials of a PlantmaX prototype during autumn 2019 and spring-summer 2020. The aim of the trials has been to evaluate the PlantmaX machine's planting quality, machine utilization, and productivity.

The machine has performed very well, considering it being a prototype, but it has not yet reached the predetermined goals. The planting quality is being measured according to Sveaskog's standard assessment procedure, and the latest assessment resulted in ~80 % acceptance rate. The machine utilization of PlantmaX has been ~70 % (averaging 49 productive hours out of 70 workplace hours per week). The goal regarding productivity was set to 2500 seedlings per hour, but this goal has not yet been reached during this initial test period.

The contractor has been trying different scarification methods (specifically single vs double trenches during a machine pass) to see how it affects production. Other factors affecting productivity that are being investigated are refueling strategies and how seedlings are loaded onto the machine.

Closing remarks

Rolf Björheden

The NB NORD2020 Forest Operations for the Future Conference

Most people would agree that your "first" often attach itself strongly to your memory. I, for one, have crisp memories of my first kiss, my first dog, my first car… …and now I feel certain that also this conference will belong to that very special category of "first" experiences, being the first web-based conference that I have arranged. Although I miss the informal, personal meetings with old friends and new colleagues, together, we created an efficient platform for information on the status and direction of our joint research interest: *improving future forest operations*!

This, third NB NORD Biennial Conference, 2020, will however also be remembered as a last. This is the last major achievement of this CAR. Originally scheduled to end in 2020 it has been "Corona-prolonged" by six months into 2021, and before the end we also aim to deliver:

- A white book on Climate effects of forestry in the Nordic Baltic region
- A joint Nordic-Baltic handbook of transport costing
- A brief on the possibility to increase the supply of sustainably produced forest biomass

We have also been approached by the *International Journal of Forest Engineering* who are proposing a thematic edition based on contributions to this conference. I hope we will make that happen!

Since I am now close to retirement, this conference will also be a last official contribution to Nordic-Baltic cooperation, to internationalization and networking within applied forestry sciences. It has been one of the most rewarding and meaningful activities of my career and I am going to miss it!

I therefore hope that the community we have built will continue to develop, joining forces in addressing the challenges facing forest operations as they appear and develop. The very close relationship that develops over the years builds trust, makes cooperation easier and improves quality and acting as a joint centre of excellence opens doors to funding that cannot easily be accessed by the individual research organization.

Therefore, it has been decided that we should approach SNS to investigate the possibilities of prolonged support for a forest operations R&D network also in the years to come. Gert Andersson, Skogforsk, has taken the lead in this process, together with the current Co-ordinating Committee.

Finally, I thank all participants and all contributors for three inspiring days, SNS and the Co-ordinating Committee for enabling this event, the Chairs for keeping us on the right time and track and, most of all, Ingeborg Callesen, Copenhagen University, for hosting a well-organized and smooth conference!

Conference Programme

Nordic Baltic Conference NB NORD2020

Forest Operations for the Future

September 22-24 2020, Konventum, Erling Jensens vej 1,
3000 Helsingør, https://www.konventum.dk.Helsinore, Denmark

UNIVERSITY OF COPENHAGEN

SNS
Nordic Forest Research

skogforsk

Tuesday, September 22
Opening

-12.30	Arrival, registration and accommodation at Konventum.
12.30-13.30	Lunch

Opening session Forest Operations for the Future (Chair Ingeborg Callesen)

13.30 -13.45	**Rolf Björheden and Ingeborg Callesen** *Welcome to NB NORD 2020!*
13.45-14.00	**Magnus Thor** *Forest operations for the future in Skogforsk's R&I strategy 2021-2024*
14.00-14.15	**Rolf Björheden** *Carbon balance of Nordic-Baltic forestry*
14.15-14.30	**Gert Andersson** *Future research and innovation needs within forest operations the coming four years – Swedish perspective*
14.30-14.45	**Håkan Lideskog** *Opportunities for forestry automation using a custom off-road machine*
14.45-15.00	**Ingeborg Callesen** *Wheel rutting: preliminary investigations of soil redox potential and automated monitoring of their presence using machine learning and high-resolution LiDAR data*
15.00-15.15	**Mikael Lundbäck** *Economic potential of tele-extraction of roundwood in the Nordic CTL system*
15.15 – 15.45	Coffee break

Session 1 - TRANSPORTS, ROADS AND LOGISTICS
(Chair Rolf Björheden)

15.45-16.00	**Victoria Forsmark** *Optimised positioning of landings and routing of terrain transportation*
16.00-16.15	**Perttu Anttila** *The effect of adhering snow on the load capacity of a timber truck*
16.15-16.30	**Franz Holzleitner** *Predicting forest road´s bearing capacity using smart sensing technology*
16.30-16.45	**Lone Ross Gobakken** *Seasonal variation in transport lead times and pulpwood freshness in a coastal geography*
16.45-17.00	**Kari Väätäinen** *Transport costing models – a common Nordic-Baltic framework*
17.00-17.15	**Dag Fjeld** *New bio-based industries – a Norwegian case study exploring roundwood supply, transport solutions and cost-competitiveness*
17.15-17.30	**Dag Fjeld** *Forest road availability – inferences from logging truck delivery messages*
18.30 – 20.00	Dinner
20.00 -	Group meetings etc. as planned by Focus areas …alternatively a healthy evening walk

Wednesday, September 23	
SESSION 2 – DATA AND SENSORS (Chair Magnus Thor)	
08.00-08.15	*Bruce Talbot* *Continuous surface assessments of wheel rutting compared to discrete point measurements – do the benefits justify the efforts?*
08.15-8.30	*Weria Khaksar* *Direct Multi-Tree Stem Detection and Analysis from terrestrial LiDar Dat*
08.30-08.45	*Helmer Belbo* *Methods for harvest site delineation based on machine positions in harvester stem reports*
08.45-09.00	*Morgan Rossander* *Automatic detection of work elements and disadvantageous work practices in mechanized forestry*
09.00-09.15	*Janis Ivanovs* *Comparison of ALS models for the estimation of forest height and wood volume*
09.15-09.30	*Hans-Ulrich Dietz* *Measuring Log Piles at Roadside with Photo-optical Mono Camera Systems*
09.30-09.45	*Helmer Belbo* *Stanfordclassicr: R-package parsing data hidden in StanForD classic forest machine reports to readable datasets*
09.45-10.00	*Mikael Andersson (cancelled presentation)* *Measurement of Boulder Fraction in Forest Land by Ground Penetrating Radar*
10.00-10.15	*Dan Bergström (cancelled presentation)* *Forest data acquisition with the application Arboreal Forest – measurement precision, accuracy and efficiency*
10.15 – 10.45	Coffee break
SESSION 3 – Impact and organization (Chair Ingeborg Callesen)	
10.45-11.00	*Leo Gallus Bont* *Mapping soil trafficability with statistical models and machine learning algorithms*
11.00-11.15	*Pirjo Venäläinen* *Emission Reduction Measures in Timber Transportation in Finland*
11.15-11.30	*Daniel Noreland* *Potential for improved energy efficiency and cost reduction through HCT vehicles for roundwood transportation in Sweden*
11.30-11.45	*Joachim Bernd Heppelmann* *Assessing the relationship between depth-to-water mapping and rut formation, following fully mechanized harvesting operations in Norway*
11.45-12.00	*Lotta Woxblom* *Developed collaboration in contractor forestry – an intervention in relational development*
12.00-12.15	*Heikki Ovaskainen* *When does a logging or transportation company need a foreman?*
12.15-13.30	Lunch

	SESSION 4 – Wood use (Chair Rolf Björheden)
13.30-13.45	*Maria Nordström* *New opportunities in the forest value chain based on digital declarations of wood and fibre properties*
13.45-14.00	*Christian Kanzian* *GreenLane IBM - integrating Insect, Blue stain and Moisture content prediction Models for value tracking in supply chain simulation*
14.00-14.15	*Paul McLean* *Where did the trees go?*
14.15-14.30	*Maria Iwarsson Wide* *Catalytic fractionation of biomass*
14.30-14.45	*Emil Engelund Thybring* *Wood modification – a modern solution to meet the challenges of using wood in the outdoor built environment*
14.45-15.00	*Antti Raatevaara* *Estimating a height of decay column in severely rotten stems of Norway spruce (Picea abies (L.) Karst.) with log end face image features*
15.00-15.15	*Oskar Gustavsson* *Controlling pulp wood properties through integrated planning of bucking and transportation*
15.15-15.30	*Lars Eliasson* *Sieving of forest chips – a profitable operation?*

Field trip/excursion
15.00 –   Excursion by bus

15.15 – 15.30 Boarding bus (sturdy shoes and, if needed umbrella and raincoat!)
- Current forest policies and operations of Danish forestry

19.00-	Conference dinner

Thursday,	September 24
	Session 5 Silviculture (Chair Lars-Göran Sundblad)
08.00-08.15	*Elof Winroth* *Load- and tool-carrying drones in silviculture*
08.15-08.30	*Örjan Grönlund* *Forest operations in nature conservation management*
08.30-08.45	*Dagnija Lazdina* *Productivity of mechanized planting in spring, summer and fall in different forest sites*
08.45-09.00	*Franz Holzleitner* *Integrated in-stand debarking with harvester in cut-to-length operation*
09.00-09.15	*Janis Ivanovs* *Finding the best locations for furrows in soil berms of drainage ditches using LiDAR data*
09.15-09.30	*Karri Uotila* *Low cost prediction of time consumption for pre-commercial thinning*
09.30-09.45	*Timo Saksa* *Harvester data as aid in trees species selection in forest regeneration*
09.45-10.00	*Leena Hamberg* *Decay fungus* Chondrostereum purpureum *in preventing sprouting of deciduous trees in young conifer stands*
10.00 -10.30	Coffee break
	Session 5 Silviculture, continued (Chair Lars-Göran Sundblad)
10.30-10.45	*Raul Fernandez Lacruz* *Boom-corridor thinning trials with an upgraded version of Bracke C16 in biomass dense first thinnings in Sweden, Finland and Slovenia – preliminary results from the Smallwood project*
10.45-11.00	*Gunnar Boglind (cancelled presentation)* *Disc trenching with rotatable discs on side slopes*
11.00-11.15	*Muedanyi Ramantswana* *A forecast of silviculture regeneration technologies of the future in semi-natural plantation forests*
11.15-11.30	*Stefan Ivarsson* *The PlantmaX continuously advancing tree planting machine: initial tests on Sveaskog sites in central and northern Sweden*

11.30-12.00 Plenary Closing session (Chair Rolf Björheden)

Summing up and looking forward. Continuation of NB NORD *Rolf Björheden*
Plenary discussion
Closing remarks *Rolf Björheden*

12.00—13.00	Lunch

Hopefully departing to meet again, in a new CAR for NB NORD 2022

| 13.00-16.00 | Focus area Coordinators are encouraged to host digital **Technical meetings** |