EFFORTE –
'Efficient forestry by precision planning and management for sustainable environment and cost-competitive bio-based industry'

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R	Report	R
P	Prototype	
D	Demonstrator	
O	Other	

Big Data bases and applications

Pilot software for improved silviculture operations – Plant order

28 February 2019

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1. EFFORTE project objectives

EFFORTE is a research and innovation project providing the European forestry sector with new knowledge and knowhow that will significantly improve the possibilities of forest enterprises to assemble and adopt novel technologies and procedures.

The project aims at enhancing the efficiency of silviculture and harvesting operations; increasing wood mobilization and annual forest growth; increasing forest operations' output while minimizing environmental impacts; and reducing fuel consumption in the forest harvesting process by at least 15%.

The project is based on three key elements of technology and knowhow:

1) Basic understanding of fundamentals of **soil mechanics and terrain trafficability** is a crucial starting point to avoid soil disturbances, accelerate machine mobility and assess persistence of soil compaction and rutting. The key findings and recommendations of trafficability related to EFFORTE can immediately be adapted in all European countries.

2) Due to decreasing Cost-competitiveness of manual work and maturity of technology it is now perfect time to realize the potential of **mechanization in silvicultural operations**. EFFORTE pursues for higher productivity and efficiency in silvicultural operations such as tree planting and young stand cleaning operations.

3) 'Big Data' (geospatial as well as data from forestry processes and common information e.g. weather data) provides a huge opportunity to increase the efficiency of forest operations. In addition it adds new possibilities to connect knowledge of basic conditions (e.g. trafficabillity), efficient silviculture and harvesting actions with demand and expectations from forest industries and the society. Accurate spatial information makes it possible for forestry to move from classic stand-wise management to precision forestry, i.e. micro stand level, grid cell level or tree-by-tree management. EFFORTE aims at achieving substantial influence to the **implementation and improved use of Big Data within Forestry** and through this increase Cost-efficiency and boost new business opportunities to small and medium size enterprises (SME) in the bioeconomy.

EFFORTE researchers will develop and pilot precision forestry applications that, according to the industrial project partners, show the greatest potential for getting implemented immediately after the project.

This document describes a pilot software tool, "Plant Order" for improved silviculture operations based on harvester production files where the results can be utilised in combination with other GIS data. It is based on the use of microcompartments also derived from harvester production files as described in the Efforte report D 3.7 "Harvester information for micro compartments". The software is based on utilization of detailed forest information extracted from felling head measurements, production control monitoring and navigation system in Cut-to-length harvesters data, according to the StanForD 2010 standard. The tool provides detailed information supporting silvicultural operations. This includes ecologically and economically based support on regeneration method, tree species and number of seedlings per area unit within each micro compartment. The validation of the tool is presented in the coming Efforte report D4.6: "Validation of cost-efficient and productive silviculture".

2. Introduction

Forest owners are obliged by legislation to manage their forest in accordance with certain practices, regeneration being one of the most long-term investment. Currently, the regeneration planning is based partly on tradition and partly on the planner's visual impression of the forest characteristics. Regeneration is most usually planned for relatively large areas at a time and the planning takes place at the same site visit as harvest planning. This practice implies a risk of regeneration planning becoming somewhat arbitrary. There are, however, sources to immensely more detailed information about the variation of production potential in the forest.

Forest harvesters are programmed to optimize the product quality and timber volumes by cutting the harvested logs in optimal lengths. Parallel to this optimization the harvester continuously collects information about its action and about the timber products they process in order to log and categorize every activity. Since 1988 this data has been standardized to a certain format, StanForD, to make communication possible among various machines, and that standard is now implemented worldwide. The name is an abbreviation of Standard for Forest machine Data and Communication. The main reason for collecting this data was originally to be able to quantify the work performed by the harvester as indisputable background for statistics and for timber distribution control.

The rapid development of digitalization software and hardware made way for a significant update of StanForD in 2010. This latest version collects more data than earlier and has a new file formatting system applicable in a wider range of subsequent processing software. In addition to facilitating the administration of machinery costs, the collected data has also been found useful for other purposes. StanForD2010 is now the backbone for various tools for planning and evaluation in forestry. This document describes the use of selected data collected at final felling in the planning software tool *Plant Order*, written to create the optimal replantation regarding species and spacing for each individual subarea after harvest.

Plant Order consists of several algorithms that determines the optimal tree species and the optimal number of plants for different subareas of a felling site. The algorithms are based entirely on data collected automatically and manually by the harvester and is stored at a database central for the entire Swedish forestry. In the Plant Order software interphase all sites are displayed and can be chosen for planning with the tool.

3. Material and methods

Harvester information

A wide range of data including measurement, navigation and production monitoring is collected in the harvester, including e.g.:

- Location (automatically logged GIS-coordinates in the SWEREF system)
- Tree species (logged by operator)
- Root rot (indirectly logged by operator)
- Log diameter information at each cutting section (logged automatically)
- Log length as distance between each cut from base to final cut below canopy (logged automatically)

The above data is logged for each individual tree. However, the location logged is that of the harvest machine and not of the individual tree, since the felling head does not itself contain a GPS-device nor is its location relative to the harvester recorded. The harvester arm/lever reaches 7-9 meters from the location of the gps-logger, depending on individual machine dimensions. Accordingly, the resolution of spatial information corresponds to the operational reach of the harvester arm.

Hpr-file processing

An hpr-file is created for each tree felled. When the file is to be stored in the data base it is interpreted and processed and additional data is added to the file about estimated tree height and root rot occurrence.

Dominant height

The dominant height is a necessary component in subsequent calculation of site index (SI). Total tree heights are not measured during felling but can be estimated for each individual tree rather accurately from known relationships between dimensions at each cutting point along the stem and total stem height (see figure 1 below). When the height of each single tree has been estimated, the trees are aggregated in micro compartments, grid cells, of crane length. The sub-areas are then aggregated into homogenous calculation areas with at least 100 trees in each. The dominating tree species is determined, and the dominant height is determined as the 90th percentile to avoid unrealistic values. These calculation areas usually comprise ca 0.5 to 2 hectares each. These calculations are further elaborated in Efforte D3.7.

Root rot occurrence

Root rot in spruce is caused by a fungus in the forest soil that strongly disintegrates the biomass quality and affects spruce. At harvest each tree is first cut at its base in order to optimize the outcome of timber volume. But the harvester operator continually keeps an eye on root rot occurrence at the base cut. If a tree is found to be rotting at its base, the operator will discard as much of the lowest part of the log as necessary in order to only collect fresh timber. This manually directed cut is detected and logged in the harvester file, and during the file processing it is interpreted as occurrence of a rotting stem base. If there are any manual cuts on the first log on spruces felt it is considered to be root rot.

The interpretation of tree height and root rot (decay) occurrence is visualized in figure 1, which also clarifies the estimation of volume for each cut product.

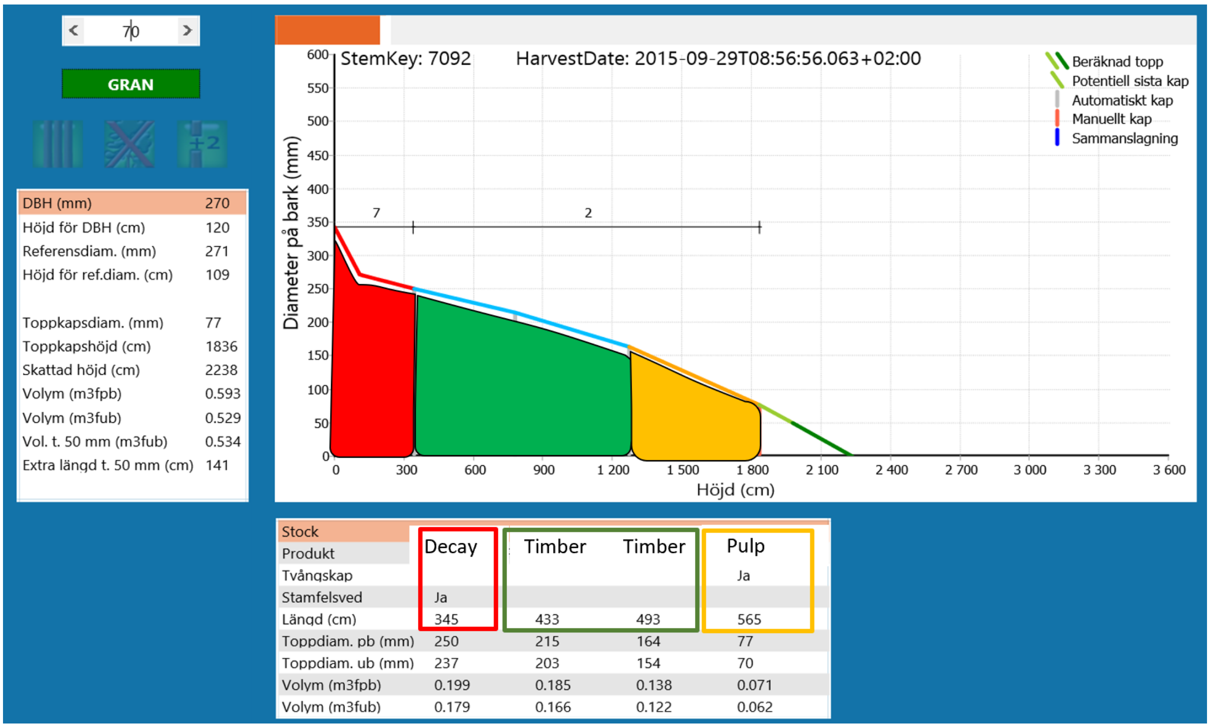

Figure 1. Visualization plot of the harvester data, hpr. Stem diameter on y-axis [mm] and stem length on x-axis [cm]. Stem diameter is interpolated between each cutting point as well as at breast height (120 cm above stump) and at reference height (109 cm). Total tree height is extrapolated from the last two cuts. In this particular case a cut was inserted at 345 cm which is interpolated as root rot. After that two cuts were made for timer lengths of 433 cm and 493, and the final cut gave rise to a 565 cm piece classified to be used for pulp. Volume of each product is calculated by integrating the curve at each section.

Plant Order software - processing sequence

The data collected during harvest represent a detailed model of all trees in the stand prior to felling. Together with temporal details harvest production files (hpr-files) contain data about every single stem and log in high detail and labeled with individual geopositions.

In order to benefit from the hpr-data, it is, however, necessary to interpret all collected data by statistics and various algorithms. This data processing is carried out both at individual tree level as well as in levels of aggregated trees into micro compartments.

The main objective of the Plant Order tool is to identify SI variation in the landscape and plan the regeneration accordingly. SI is estimated by combining tree height from the hpr-file with information about stand age.

The stand age can be provided by the land owner and added in the harvester manually and carried in the hrp-file to the Plant Order tool. That happens sometimes. When it doesn't the age information can be added in the Plant Order tool manually.

<u>*Site Index*</u>

The site index (SI) is defined as the maximum height of a given tree species at a certain age, 100 years being the prevailing index age. Having estimated tree height and knowing the stand age it is thus possible to deduct the SI_{100} for the specific sub-area by extrapolation along the known age/height curve (see figure 2), and this is where information about age is necessary.

This measure is species specific and can be transformed among tree species by known relationships.

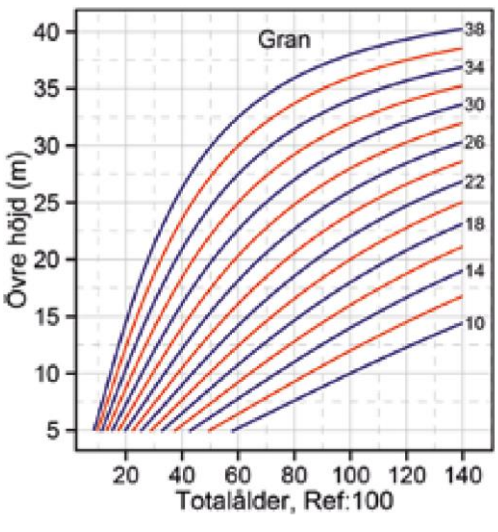

Figure 2. Example of relationships between age (Total ålder, yrs) and tree height (Övre höjd, m) for spruce (Gran). The numbers on the right-hand side of the diagram are the site indices for spruce at 100 years, SI_{100}. Translated from Johanssson et al. 2013.[1]

[1] Nya höjdutvecklingskurvor för bonitering (Ulf Johansson, Per Magnus Ekö, Björn Elfving, Tord Johansson, Urban Nilsson), FaktaSkog 14, 2013, Swedish University of Agricultural Science.

From SI and root rot occurrence the software produces a regeneration plan for the area of interest based on conditions determined in the software script.

Regeneration Plan

On a sub-area level, the frequency of rot will be accounted for when suggesting a regeneration plan for that particular stand.

In each calculation-area the software suggests planting the same species as was present prior to harvest except in two cases:

- For pine-SI_{100} higher than P28 the software suggests to plant spruce instead since it is considered to grow better on rich soils.
- High occurrence of root rot, over at certain threshold frequency, is handled by changing species in the smitten sub-area. Root rot occurrence above 30%: 30%-70% leads to mixed species; higher than 70% leads to changing species entirely.

The SI_{100} detected during harvest determines the suggested density of the new plants. Table 1 summarizers the conditions for change of species and planting density. These conditions may be changed depending on forest company specific requirements.

Table 1. Conditions for choice of species and plant density, 'P' representing pine and 'S' representing spruce.

SI-species	
>P28 → change to spruce, if at least 25% spruce at harvest	
SI detected	**Plant density (pl/ha)**
P25+	2300
P20-P24	2000
<P20	1700
S32+	2300
S24-S31	2000
<S24	1700
Decay Occurance when spruce is dominating species	
< 30 %, no change of species	
30–70 %, mixed species recommended	
> 70 %, change to species from spruce to pine	

A schematic view of the preprocessing and processing sequences are presented in figure 3.

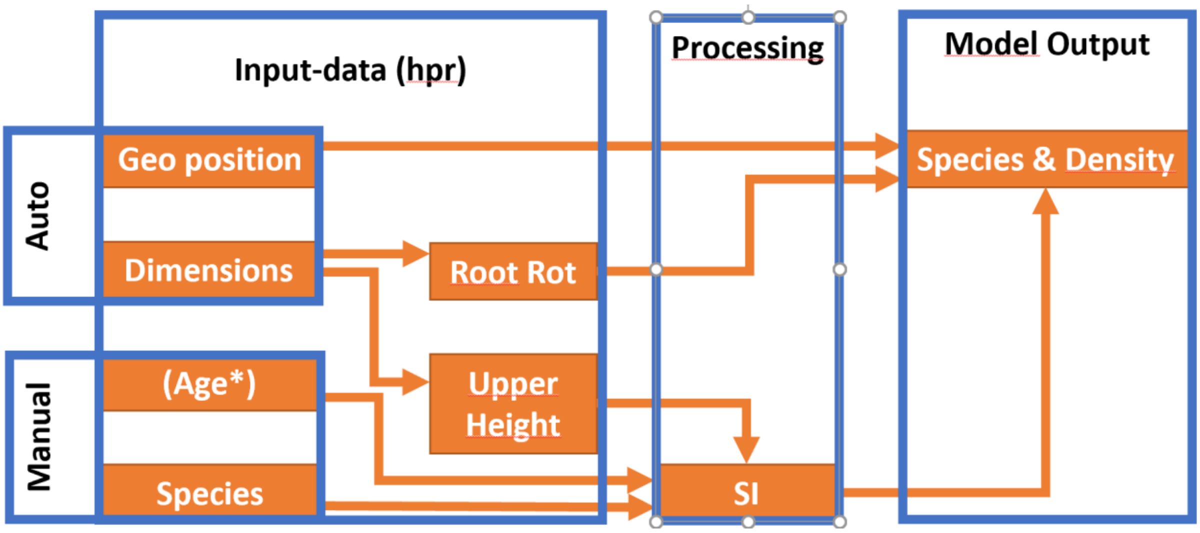

*Figure 3. Schematic view of the calculation processes that give rise to Plant Order model output. *Age is sometimes added manually to the Plant Order tool and sometimes along in the hpr-file.*

The Plant Order tool also displays a background map (WMS-service from Lantmäteriet, i.e. the Swedish Mapping and Land Surveying Authority) of the area for a better visual understanding of the output data.

User interface

Upon opening the software the user chooses location of interest from the harvester database either by entering the correct contract number (Virkesordernummer) or by choosing it on a zoomable map (figure 4). Skogforsk have set up a harvester database for R&D in co-operation with the forest companies involved in the Efforte project.

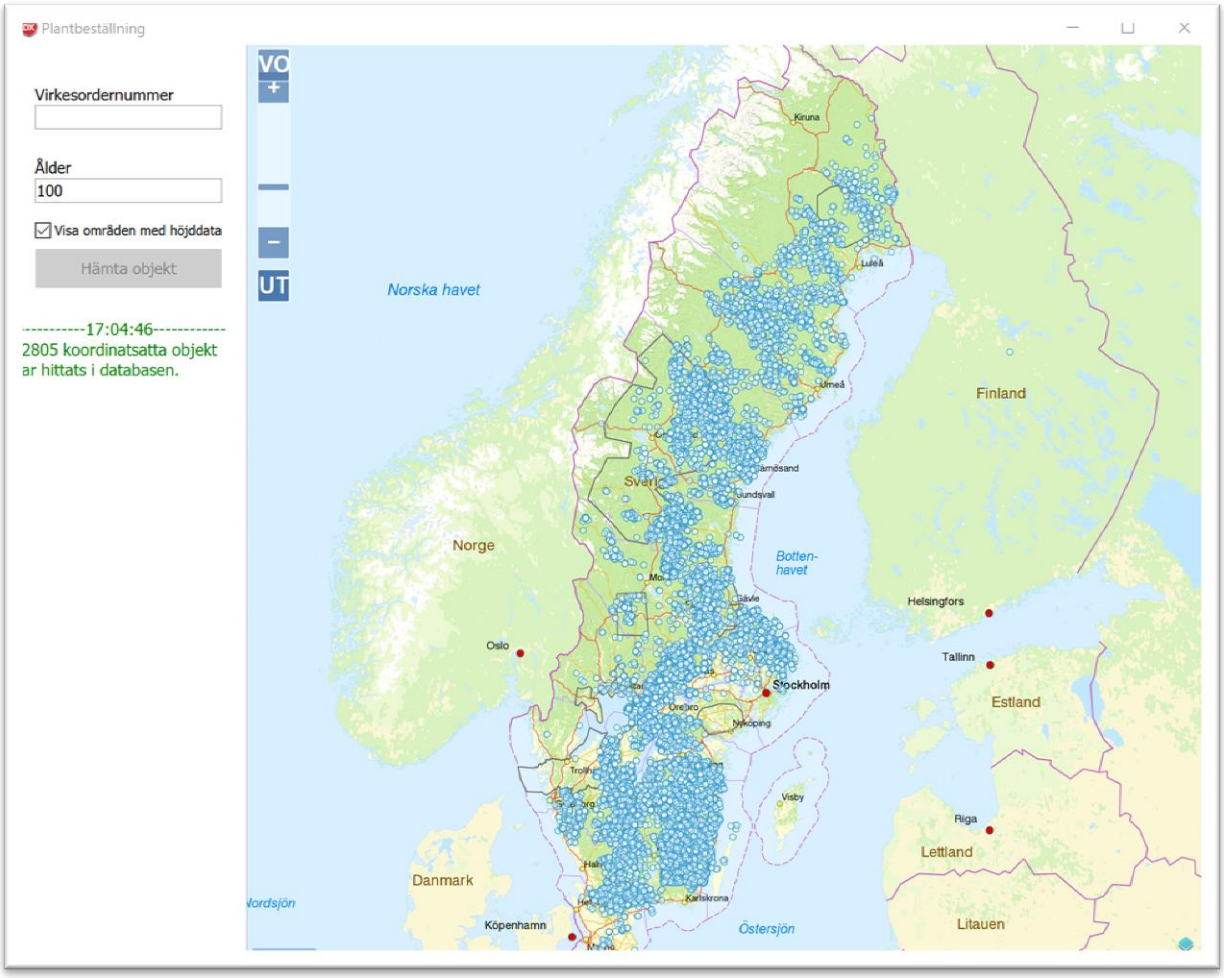

Figure 4. Plant Order (Plantbeställning) software interphase. User chooses an object by the map (blue dots) or by entering the identification number. This database only contains 2805 objects since it is a pilot test database.

4. Results

Decision support

Based on the entire sequences of preprocessing and processing as well as on the conditions for decay and SI_{100}, the software presents, as its main feature, the best solution for regeneration of the entire stand in question regarding tree species and density for each subarea as well as summarized for the entire stand. The output data is presented in a software interphase (figure 5) where several options are available for visualization.

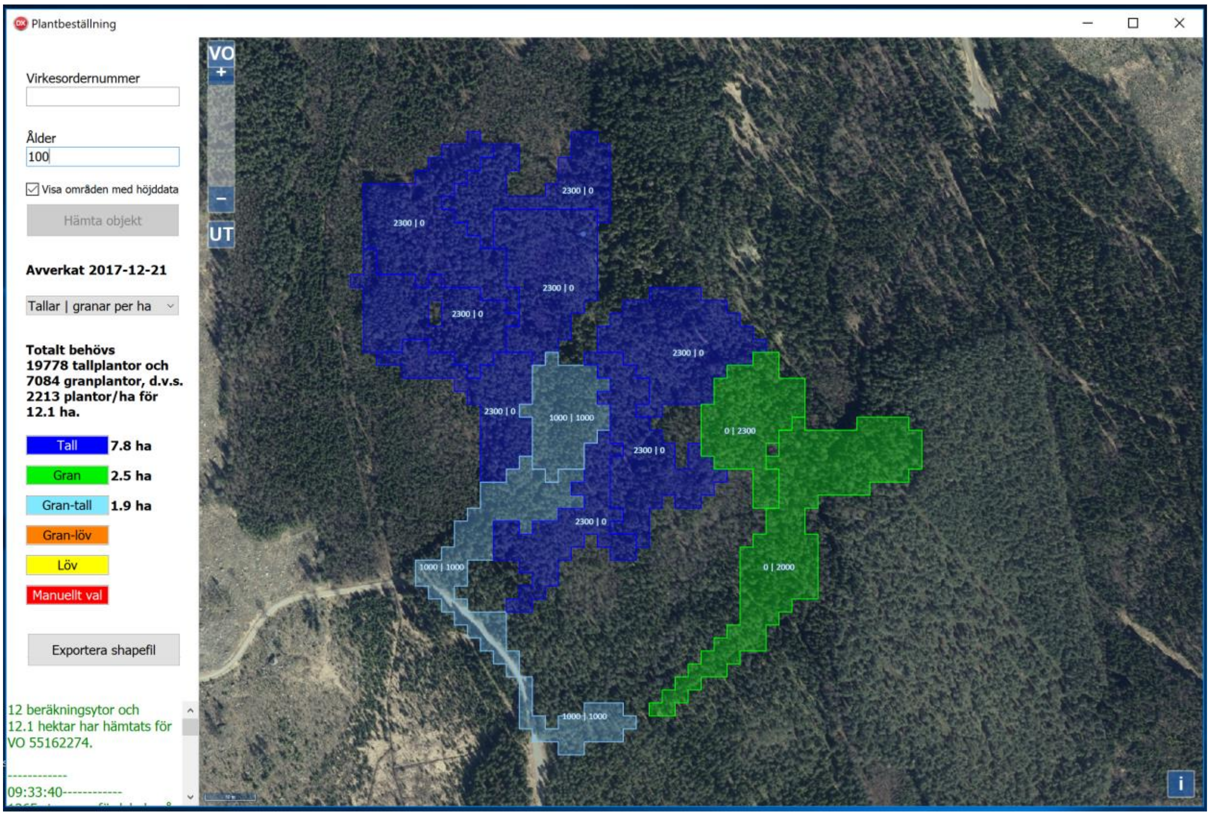

Figure 5. Data output from Plant Order software.

In the left pane is presented a summary of needed number of plants in total and per micro compartment/area unit. It also shows information about date of harvest as well as a legend to the adjacent map where different colors represent different tree species or mixtures of species. Next to the legend are numbers representing the sum of area for regeneration in each category. There is also a function that will export the results in a shape file.

Additionally, information generated by the sequences of data processing are presented for each subarea:

- SI_{100}
- decay occurrence at harvest
- previous distribution of pine, spruce and deciduous trees
- maximum tree height at harvest
- area size of each sub-area

Figures 6 show the four different visualizations of the data.

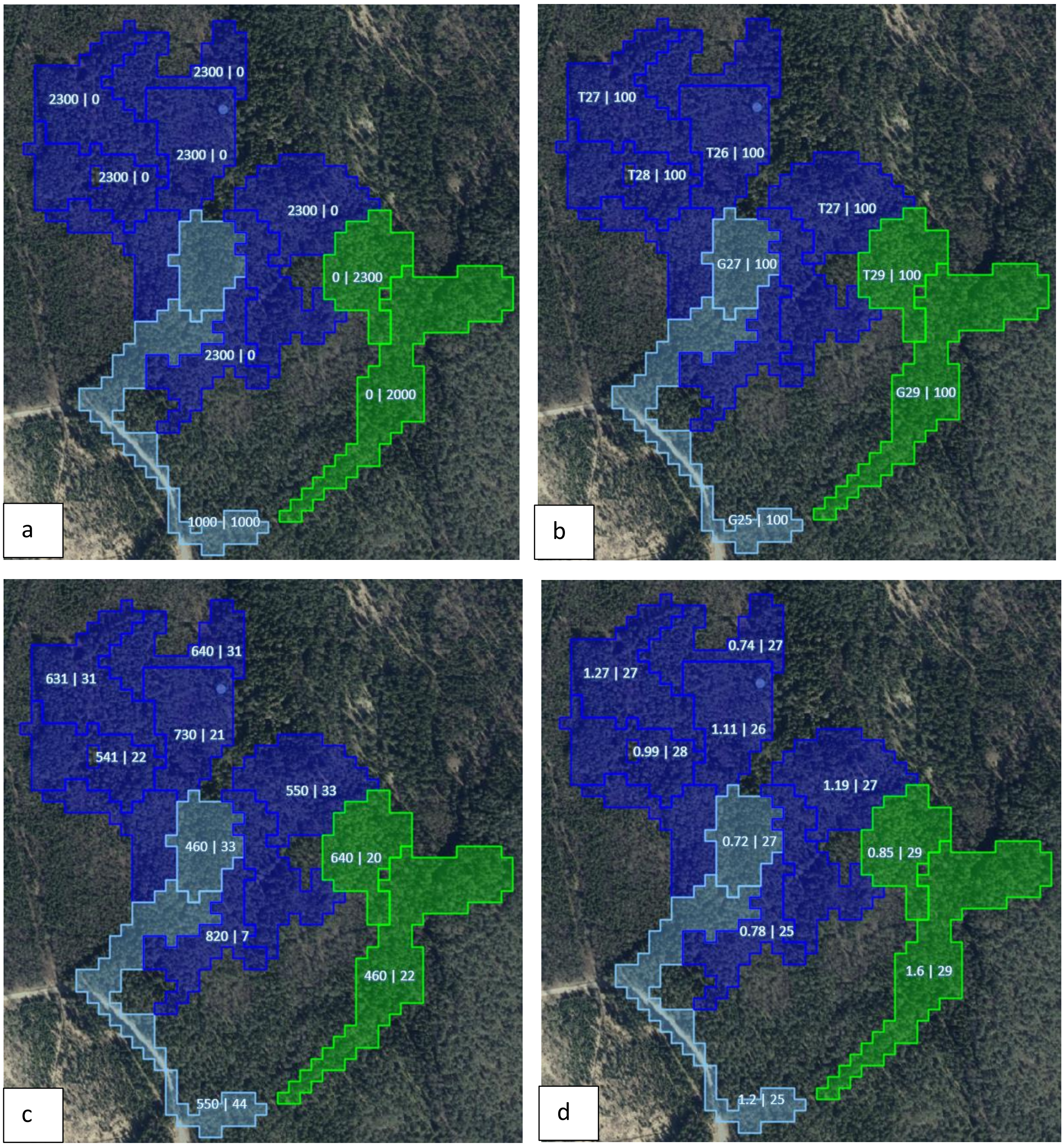

Figure 6. The four different visualizations of data in the Plant Order software; a) number of pine (blue) and spruce (green) plants per ha; b) SI and age; c) fractionation of pine, spruce and deciduous trees in 10th and proportion of root rot occurrence; d) area (ha) and dominant height.

Software architecture and design

The Plant Order software connects to a hpr-file database to load the location of all stands in the database, and when the user chooses a particular stand the software loads the hpr-data relevant for the site. Appropriate calculations are made before present them in the interphase. A map is shown in the background for the user to better benefit from the results. The map is provided by Lantmäteriet (the Swedish Mapping and Land Surveying

Authority) via WMS. When zooming in the map is replaced by an aerial photograph from the same provider.

The software is programmed in the Python language.

5. Discussion

Improving forest operations

Harvester data was initially collected in order to document the produced products, facilitating handling overview in the subsequent production chain. It turned out, however, that the gathered information provided a unique database of information about the forest, a database that had the potential to reveal the spatial variation in realized productivity also figuring possible potential throughout the forest, not only qualitatively but also quantitatively. Swedish forestry is already producing high amounts of timber and pulp, but the interpretation of hpr-data show that there is a potential to refine the regeneration process by paying attention to the site index variation in the forest landscape. The Plant Order software takes a leap in that direction by dividing the landscape into smaller units than what is feasible in conventional forestry, and tailor individual regeneration solutions for each unit with the aim of increasing the long-term biomass production.

Planting new forest is currently performed manually, i.e. each new tree is planted by hand. This process is very labor intensive and in the future it might be automated. Plantation machines are on the drawing board, but no prototype is ready yet. For the plantation machines to plant the correct species at the correct location and at correct density, the hpr-files will be of great assistance. This progress is a step towards modern, high-resolution, site index specific, forest management where higher volumes of biomass can be produces in harmony with the environmental prerequisites.

The software tool developed in Efforte may be used together with the PlantVal Optimal tool. It is developed outside Efforte, but when PlantOrder and PlantVal Optimal are combined they provide a significant improvement in sustainable regeneration and predicted future forest yield. By these tools, optimized distribution plans for the best fitting regeneration material (genetics and type) per micro compartment can be efficiently outlined concerning genetics (species and genetic improvement) and site fertility (soil and site conditions). PlantVal Optimal tool optimize the use of cultivated plants based on where the regeneration sites are located and the available stock of best fitting seedlings/seed. The Plant Order tool provide details about how many plants and what tree species to use and then PlantVal Optimal suggest the optimal plant material to the regeneration site.

A pilot study on PlantVal optimal was performed in 2018[2] to investigate and analyse the potential in developing a more automated way of working, and to improve and streamline the use and distribution of Norway spruce and Scots pine plant material for large forest holdings.

The project was run in collaboration with the Holmen forest company, using their 2015 regeneration sites of Norway spruce and Scots pine. Up to 1600 regeneration sites were used, approximately evenly distributed between Norway spruce and Scots pine, with information about available seed/plants for each available seed orchard. By performing a number of comparisons with different conditions in availability of plant material, from what was actually planted to unlimited availability, we obtained a broad representation of the improvement potential from optimising the use and distribution of plant material.

Key results for Scots pine can be summarised as follows:

- Optimising the use of the best plant material available to Holmen in 2015 increased forest production by 17.5-18.9% compared to using unimproved stand seed.
- The optimised use and distribution of plant material yielded a forest production increase more than twice the 8.5% Holmen achieved with their actual regenerations in 2015, compared to unimproved stand seed.

Key results for Norway spruce were as follows:

- If suitable provenances and/or foreign seed orchards are used to meet the shortage, forest production could be increased by 9-10% compared to unimproved stand seed, by optimising the use of the best plant material available to Holmen in 2015.
- The theoretically achievable forest production with unlimited access to all Swedish seed orchards is 3-4% higher compared to the optimised use and distribution of the seed orchards available to Holmen. This implies an additional potential increase in forest production by, e.g., improving seed production and seed/plant trade between plant producers and forest companies. This increase is larger than that for Scots pine.

Results from this pilot project imply that Holmen and probably several other large Swedish forest owners could substantially increase forest production by optimising the use and distribution of their available plant material. Results also suggest that PlantvalOptimal could be used as a platform for trade and exchange of improved seed between forest companies and lead to an overall gain in forest production.

We believe that the PlantvalOptimal system, possible in combination with Plant order tool, could replace manual labour with an automated way of working, increasing efficiency and reducing costs in various stages of planning.

[2] https://www.skogforsk.se/contentassets/9bda6244a9fb4dcf8bbd819414c09a18/arbetsrapport-996-2018.pdf