B4EST

Adaptive BREEDING for productive, sustainable and resilient FORESTs under climate change

Deliverable D4.8

Joint Nordic Planter's guide web-decision tool for Scots pine and Norway spruce

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1 Summary

This deliverable presents the Planter's guide software platform which features decision support tools for selecting improved FRM of Scots pine and Norway spruce in the Nordic region. The basic foundation of the platform existed before B4EST but it has been substantially improved during the project by introducing better climate data, new transfer effect models for both species valid in Nordic region and a commonly developed database of all currently productive seed orchards. The platform can be used for providing operational tools for forestry but also as test version when developing new functionality and design in dialogue with stakeholders and end-users. A main achievement has been the release of the operational joint Swedish-Finnish Planter's guide for Scots pine and the updated formal deployment regulations facilitating the use of Swedish seedlings in Finland and vice versa. However, the main objective in B4EST has been the development of the joint Nordic new versions of the Planter's guide tool for both species. They are now available as fully functional online test versions for evaluation from stakeholders and end-users. Some key new functionality includes: (i) the ability to select planting sites in the entire Nordic region; (ii) all suitable national improved FRM are ranked on a common scale; (iii) the introduction of different RCP-scenarios which affect the prediction of the FRM performance. Apart from the online tools, we have also developed software systems and methods to illustrate and address the variability in predicted performance arising from uncertainty about the degree of future global warming. The group of Nordic researchers/breeders, with the support of plant producers and forest owners, are committed to the continued development of the Planter's guide platform after the end of the B4EST project with the aim of releasing an operational joint Nordic decision support tool in the coming years.

2 Introduction

In the Nordic[1] countries the two most commercially important tree species are Norway spruce and Scots pine which are used in most artificial forest regenerations. The majority of seedlings used originate from seed orchards including phenotypically and/or genetically selected genotypes. The growth rhythm and adaptive properties of these species are strongly related to light and temperature conditions which in turn are linked to latitude and altitude. Thus, growing conditions vary substantially across the Nordic region and it is therefore divided into many different seed zones. When designing a seed orchard, its adaptive properties are selected to match a specific seed zone by selecting suitable origins of the genotypes as well as high performance of other desired traits (foremost increased growth). In the Nordic region there are numerous seed orchard (crops) available, each with a different combination of genetic gain in growth and adaptive profile. For example, in Sweden around 40 Norway spruce and 70 Scots pine productive seed orchards exist spanning from older 1g orchards, estimated to reach 10% increased growth, to the modern 1.5g orchards estimated to reach up to 25% increased growth.

[1] By Nordic we mean Sweden, Norway and Finland in this document.

Furthermore, by using knowledge about reaction patterns when transferring genotypes or provenances from Universal Response Functions it is possible to predict seed orchard crop performance at an arbitrarily selected new planting site. This makes it possible to construct deployment maps with predicted seed orchard crop performance without the static zonation. As climate change affects the temperature (and other characteristics) it alters the site conditions and thus changes the suitable deployment area where high performance is anticipated.

Consequently, there is a need for improved deployment guidelines and user-friendly tools to facilitate and improve decision making when selecting FRM in the Nordic region. By developing joint Nordic deployment recommendations and a Planter's guide platform we enable the common use of all national FRM in the entire Nordic region in the future.

3 The Planter's guide platform

The Planter's guide platform consists of several different components all necessary to develop joint Nordic climate adapted deployment recommendations leading up to web-tools (Figure 1).

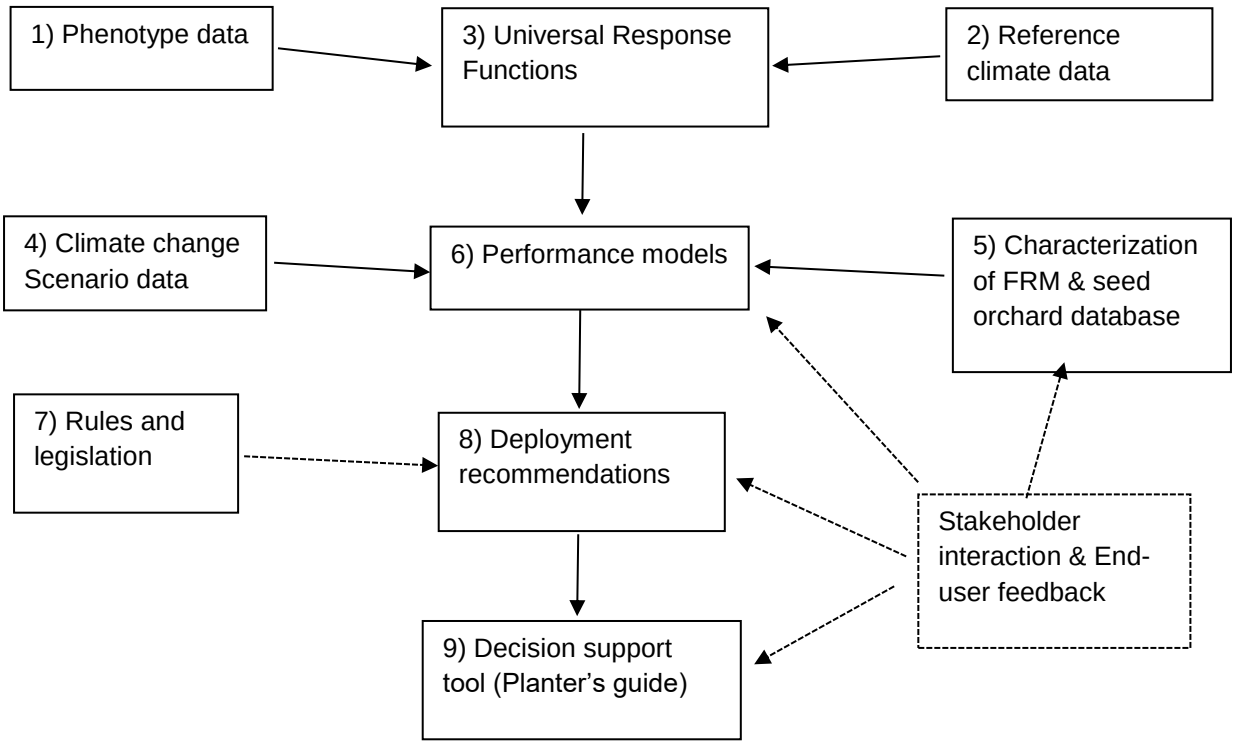

Figure 1: Schematic overview of the different components in the development of a joint Nordic decision support tool for Norway spruce.

The development of Universal Response Functions (URF) (3) requires both appropriate phenotypic data (1) and historic climate data (2). Phenotypic data should span a sufficient

range of growth conditions both regarding field trial sites and genetic entry origins to capture the transfer effects / reactions patterns. Climate data needs to fulfil certain requirements with regards to both spatial and temporal resolution and also contain tailored climatic indices that are known to be associated with desired properties of the species under study. URFs that include climate indices as independent variables can be used to predict reaction patterns in future climatic conditions if they fulfil the requirements above. The development of URFs for Scots pine and Norway spruce are described in the next section.

If several different traits are to be considered, performance models must be developed by combining these traits into a desired compound measure or performance (6). For both Scots pine and Norway spruce, performance is defined as per hectare volume production over a rotation and is described below.

The performance models must be able to predict performance of contemporary forest reproductive material (FRM). For Norway spruce in the Nordic countries, the major bulk of FRM are genetically improved seed orchards. This means that the seed orchard characteristics must be standardized and formalized into a structure that is compatible with the performance models (5) and common for all Nordic countries. This step and the resulting seed orchards data base is described further below.

In addition, the effects of climate change (4) must be introduced as performance needs to be predicted in future climatic conditions. However, climate change is a complex concept with an inherent variability induced by the uncertainty of the magnitude of the global warming. The reference and scenario climate data, the climate change signal variability and methods to address it is introduced in a section below.

Based on the performance models adapted to genetically improved FRM and calculated for a span of future climate conditions (4, 5, 6), joint Nordic deployment recommendations (8) can be developed. Here both biological (e.g. model validity ranges) and administrative (e.g. current legislations/regulations - 7) delimitations have to be taken into account.

All this information will be implemented in a programming platform where the main Graphical User Interface (GUI) is the web-based Planter's guide (PG), which is a decision support tool that ranks different seed sources for an arbitrarily selected planting site (9). A description of the design and functionality of the online beta version of the Norway spruce and Scots pine PG tools are described in a section below.

Figure 1 also stresses the key role, stakeholders and end-users will have to achieve operational deployment recommendations and decision support tools. Continued interaction with these actors will be vital to succeed in the implementation and use of the new research results.

3.1 URF's for Scots pine and Norway spruce

As a result of an earlier EU-project (Noveltree), joint Scots pine URF's of height growth and survival were jointly developed between Sweden and Finland (Berlin et al. 2016). However, these models were based on climatic data that was limited in geographical distribution to Sweden and Finland only, had a relatively coarse spatial resolution and was not directly compatible to new RCP/SSMP climate scenarios. Furthermore, the models were developed using only data from >60°N (excluding southern Sweden). In the B4EST project we re-developed the URF's based on state-of-the-art climatic data addressing (for details see the next section) all shortcomings of the previous dataset described above. Also, we tested new independent variables (including daylength described in the Norway spruce models below) and used all available/suitable from southern Sweden and central Norway. This will allow the URF

to be a joint Nordic model. The developed Nordic Scots pine URF contains annual temperature sum, latitude, daylength, altitude and interaction terms between these variables. Different models were found to be useful both for height growth at 15 years of age and survival at the timepoint where 1.5 m tree height was reached, respectively.

For Norway spruce a joint Nordic URF was developed using a very comprehensive (field) data set from all Nordic countries. The same state-of-the-art climatic data set used in the Scots pine modeling was used also here. A key feature was that the climate data set covered the entire European region which was necessary in Norway spruce due to widespread origins tested in the field data. In earlier models, latitude has been used as a proxy for light climate and that may be a fair (linear) approximation when studying only the Nordic region. However, already in the southernmost parts of the Nordic region and in continental Europe this (linear) approximation becomes very poor. To address this, the actual day length was introduced as an alternative proxy for light climate which proved to be a key variable when dealing with very long spans of transfer in the URF modeling. Although thoroughly analyzed, no model with substantial predictive performance was found for survival so only height growth models were developed. The developed joint Nordic Norway spruce URF contains reciprocal of trees age, annual temperature sum, precipitation in vegetation season and their interactions. Day length in a 205th Julian day of the year was used as a transfer variable and in interactions with climate variables.

3.2 Improved FRM Performance models

For both Scots pine and Norway spruce, per hectare volume production over a rotation (henceforth volume production) has been, and still is, the main objective trait to improve in seed orchard crops (and to communicate with forestry) and is consequently considered the measure of performance. Models to predict volume production by combining height growth and survival has been developed for Scots pine (Berlin et al. 2009a; Berlin et al. 2009b). Thus, for Scots pine the URFs for both height growth and survival are used to calculated predicted volume production. For Norway spruce, only URFs of height growth were possible to develop with reasonable predictive ability. The reasons for poor survival-URF-models are that survival is: (i) generally so high that it will not strongly affect volume production; and (ii) hard to predict and likely governed by many different factors (poor planting positions, vegetation competition, drought directly after planting, etc) making it difficult hard to find causality and powerful models (Liziniewicz et al. 2022). Thus, for Norway spruce height growth is used to approximate volume production.

There are several other traits in Scots pine and Norway spruce that have been improved in the selected genotypes included in seed orchards. For Scots pine, traits such as stem and branch form have been improved to some extent in the existing seed orchards and in a few seed orchards reduced susceptibility to Scots pine blister rust (*Cronartium flaccidum*) has been introduced by genetic thinning. For Norway spruce, phenology in an important complementary trait to growth in the southern parts of the Nordic region. For both species improvement in wood quality traits and reduced susceptibility to other biotic and abiotic factors are under development in the breeding programs but are only introduced in a few contemporary seed orchards. There are a number of factors making it difficult to directly introduce additional traits into a performance estimate on a common scale. Firstly, there is a lack of relevant data to develop URFs for other traits than growth and survival making it difficult to provide site and

provenance specific prediction in current and future climate. Secondly, is it difficult to combine volume production with the other traits on a common scale so that a single value of performance can be calculated. For the abovementioned traits, economic weights and indexes are considered preferred in forest tree breeding (e.g. Borralho et al. 1993; Greaves et al. 1997; Ivkovic et al. 2006) but it can be very difficult to assign those traits appropriate economic weights, especially in the Nordic context with long rotation forestry and multiple industrial uses (Berlin et al. 2012). Thus, such traits are currently not included in the performance models for any species and information of different levels of improvement of one or several of those traits have to be given separately as additional information if required.

Finally, the URFs for both species and traits are developed based on information from unimproved stand seed assumed to be autochthonous. However, URFs and performance models have to be able to predict volume production of improved FRM. Thus, for Scots pine progeny data was used to validate that the URFs have a good prediction ability also for selected and improved genotypes (Hayatgheibi et al. 2020). For Norway spruce such studies are currently lacking but we assume that the same results apply also here.

3.3 Climate data and uncertainty

3.3.1 Reference climate data

We obtained a reference climate dataset by downscaling the CRU-TS dataset (Harris et al. 2020) from ~50km to ~1 km (30-arc sec) using WorldClim v1.4 (Hijmans et al. 2005) For bias adjustments of future climate scenarios the normal period 1961-1990 was used as it is considered to be a stable and well established reference period frequently used for both scientific and implementational purposes. However, with respect to new developments of the Planter's guide a number of other reference periods were investigated: i) the period 1961-2007 because this is the baseline period used for the currently operative version of Planter's guide using the PTHBV/FINADAPT dataset (Bärring et al. 2016; Berlin et al. 2016); ii) the period 1971-2017 because it was used with another climate reference dataset (E-OBS) and was moreover also used as a descriptor of the current climate in deliverable 4.4 within B4EST; iii) the period 1991-2020 for being a brand new 30-year normal period which likely best reflects current climate conditions. Our downscaling technique used the delta method (Ramirez-Villegas and Jarvis 2010) a technique that accounts for topographic variation and improving the reliability and spatial resolution of coarser spatial datasets (Fréjaville and Benito Garzón 2018; Moreno and Hasenauer 2016).

3.3.2 Climate scenario data

To characterize the climate of the future, we aligned future climate scenarios from CMIP5 at 1km resolution (WorldClim v1.4. - Hijmans et al., 2005) to the normal period (1961-1990) of the previously downscaled CRU-TS climate data. The use of such a common baseline (WorldClim v1.4) used for present and future climatic conditions avoids statistical artefacts that

may occur when different data sources are combined. In order to compare different scenarios in terms of different levels of greenhouse gas emissions, future climate data predictions made for four different Representative Concentration Pathways were investigated (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5). The RCP 2.6 represents an increase in global temperatures below 2℃, whereas the intermediate RCP 4.5 is projected to cause temperatures to rise until 2040-50 after which reductions in GHG emissions forcing will occur. For RCP 6.0 emissions will peak in 2080 and then decline. For RCP 8.5 GHG emissions continue to rise throughout the 21st century leading to global warming of up to 4.8℃ by 2080.

Furthermore, for each of these four RCPs we also compared five different General Atmospheric-Ocean Circulation Models (GCMs) that have been developed and parametrized by different climatological institutes throughout the world for the Fifth Assessment Report of IPCC (IPCC 2014). The particular GCMs selected were: BCC-CSM1-1, HadGEM2-ES, MRI-CGCM3, MIROC-ESM-CHEM and NorESM1-M; based on the availability of the RCPs for the 2070s period. The raw global files of the downloaded GCMs are available at (). For these combinations of RCPs and GCMs, two future time-periods were available for implementation. The first period (2041-2060) was denoted the *2050s* and was used to describe the climate of the near-future mostly relevant for seedlings that are planted currently and are expected to be in their rapid growth phase during that time period. The second period (2061-2080) was denoted the *2070s* and was used to describe climate of the far-future, mostly with respect for seeds and seedlings produced in 30 years time by new seed orchards that are currently under establishment.

3.3.3 Tools and methods to handle climate variability

As mentioned previously, the predicted future climate varies not only depending on expected emissions of greenhouse gases but also because the different GCM have different climate sensitivity, i.e. they differ in how they respond to a certain greenhouse gas forcing. Some models are more sensitive and show a stronger warming while other models are less sensitive and show a more modest warming for the same greenhouse gas forcing. This means we have a substantial variation in the degree of warming both within and between RCPs and this in turn creates a variation in the the predicted performance of improved FRM. There are several different options and methods how to illustrate and handle this variation and to allow for better informed decision making yet still being user-friendly. Stakeholder and end-user feedback/interaction is key to investigate which methods and outputs that can provide a reasonable compromise between detail and usability. Thus, we have developed a software platform (Plantval generator) that can generate several “uncertainty maps” which illustrate this variation in different ways (Figure 2). Initially we are using adapted versions of methods used in other studies developed/used in B4EST (Hallingbäck et al. 2021; Petr et al. 2015) but depending on stakeholder/end-user feedback new or updated methods could be introduced.

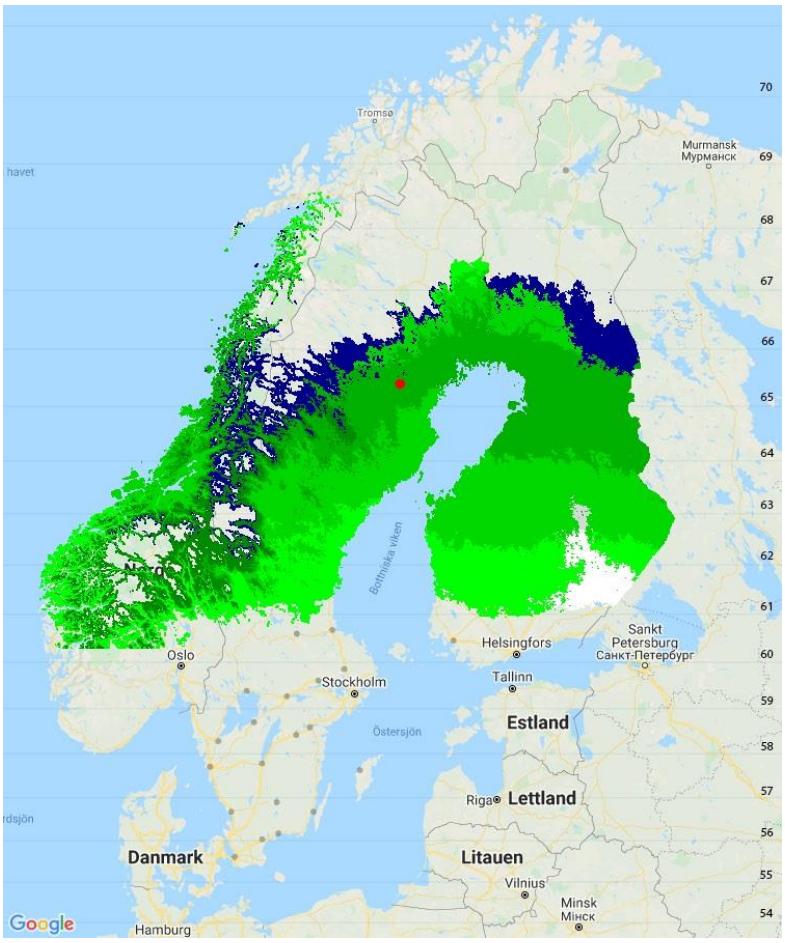

Figure 2: "Uncertainty map" of a seed orchard for RCP4.5 generated by the Plantval generator tool. The performance is calculated for each of the five GCMs separately and if a majority of them agree that performance is above a certain threshold the site is assigned a discrete class. In this case the classes are (percent gain in growth compared to unimproved local stand seed): 0-10% - light green; 10-20% green; >20% dark green. Blue is a restriction on too low survival (<50%).

3.4 Common system for characterizing improved FRM

When developing joint Nordic deployment recommendations, the improved FRM (i.e. seed orchards) have to be defined and characterized in a common way that can be used by the URF models and that makes FRM from different countries comparable. Such a common system was developed for Scots pine and included methods to calculate a latitudinal origin of the seed orchard crops (required as latitude/daylength is the transfer variable(s) used in the URFs) including pollen contamination and discrete classes of genetic gain levels for growth and survival based on different breeding generations (Berlin et al. 2019). Furthermore, the effects of seed orchard management (thinnings, selective harvesting) and design (unequal genotype contribution – linear deployment) were analyzed and it was concluded that discrete genetic gain levels could be used also here. The same analysis has only partly been conducted for Norway spruce but before such a species specific analysis can be fully completed we have

used the same methods to calculate latitudinal origin and derive genetic gain classes as in Scots pine.

By using this common system all contemporary and productive seed orchards in Sweden, Finland and Norway have been introduced in a common database for Scots pine and Norway spruce respectively. Each orchard has been assessed and classified according to the common system for characterization and are thus fully comparable and available for use in joint deployment recommendations and decision support tools.

3.5 Joint Nordic deployment recommendations

With the developed URF's valid for improved FRM, a joint database of Nordic seed orchards and data from both current and future climates we have the foundation for developing joint Nordic deployment recommendations. However, to make the deployment recommendations operational they have to be adjusted to: (i) reflect other sources of knowledge about tree performance not included in the URF-models, e.g. phenology characteristics and associated risks in Norway spruce; (ii) limitations of URF-model prediction performance and; (iii) comply with existing national rules and regulations.

For Scots pine, focus has so far been on (ii) & (iii) as there is currently no additional knowledge that would change the general deployment recommendations. In (Berlin et al. 2019) allowed transfer spans defined by temperature and photoperiod where the URF models were considered to perform well were derived for Sweden. For Finland allowed deployment zones were instead mainly defined by thresholds in the calculated performance index values, sometimes combined with a minimum level of mortality and maximum allowable transfer to the north (Ruotsalainen et al. 2016). Furthermore, the presented deployment recommendations have been adjusted so that they are fully compliant with the current national rules and legislation regarding FRM transfer. As a consequence of the development of these joint deployment recommendations, authorities in both countries have formally approved the use of improved FRM from the neighboring country[2][3].

For Norway spruce, joint common deployment recommendations for the entire Nordic region are still under development and are consequently not currently available. The deployment zones are currently only delimited by the maximum span of the field data and will have to be revised before operational use.

[2] https://www.ruokavirasto.fi/en/farmers/plant-production/forest-tree-seed-and-seedling-production/basic-material/deployment-area-maps/natural-resources-institute-finland--vilpas/

[3] https://www.skogskunskap.se/cd_20210603161325/contentassets/a0117bac201e4547a36ab7b27c6c7f6c/beslut-om-anvandning-av-finskt-plantagematerial-dnr-20-20-609.pdf

3.6 Decision support tools (Planter's guide)

The development of decision support tools has been ongoing for the entire duration of B4EST and has followed different paths. One path has been to use the already available Swedish-Finnish URF's for growth and survival for Scots pine (Berlin et al. 2016), develop joint deployment recommendations (Berlin et al. 2019) and releasing an operational joint Swedish-Finnish Planter's guide tool. Another path has been to develop novel and/or updated URF's for both Scots pine and Norway spruce based on state-of-the-art climate data allowing for a larger geographical coverage and compatibility with new climate scenarios. These models have been used to develop fully functional test (beta) versions of future Nordic Planter's guide tools for both species. Finally, one path has been to develop a new tool based on the same platform but focusing on large actors that want to optimize their use of scarce supplies of highly improved seedlings/seed. Each of the developmental paths are described below.

3.6.1 Currently operational Planter's guide

Based on collaborative work between Swedish and Finnish researchers in the FP7-Noveltree project[4] (2008-2012), Scots pine URF's for growth and survival valid in Sweden and Finland were developed and published (Berlin et al. 2016). The URF's were developed on two combined national climate data sets (PTHBV & FINADAPT) with a single climate scenario (SRES-A1B) (Bärring et al. 2016). National deployment guidelines were developed (Ruotsalainen et al. 2016) and a Swedish version of the tool was released in the autumn of 2016. Thus, at the start of B4EST no joint Swedish-Finnish deployment recommendations were available and consequently no joint tool either. One aim with B4EST was to take all this developed knowledge and swiftly develop joint Swedish-Finnish deployment recommendations and Planter's guide tool. This was accomplished in 2019 when both formalized common deployment recommendations (Berlin et al. 2019) and an operational Swedish-Finnish Planter's guide was released. This tool is available in a Swedish[5], Finnish[6] and English[7] version and is currently promoted and used by forest owners to select appropriate improved FRM.

3.6.2 Joint Nordic Planter's guide – test versions (not operational)

Although considered modern at the time of development, the climate data used in the operational Scots pine Planter's guide is now considered outdated and the limitation in geographical coverage is a severe drawback for regional expansion. Thus, to continue using this climate data was not an option in the development of joint Nordic models and tools. Thus, in the new Planter's guide platform the climatic databases had to be exchanged and several

[4] https://cordis.europa.eu/project/id/211868
[5] https://www.skogforsk.se/produkter-och-evenemang/verktyg/plantval-tall/
[6] https://metsainfo.luke.fi/fi/vilpas
[7] https://www.skogforsk.se/plantersguide

different climate scenarios introduced. In addition, systems to analyze the variability and uncertainty about the degree of global warming (Plantval generator – described in 3.3.3) have been developed.

For Scots pine this meant a two-step a re-analysis of the URF-models. The first step utilized the new climate data to re-evaluate the model coefficients and to analyze the predictive power of the model in future climatic conditions. It became clear that the model predictive power rapidly decreased in a substantially warmer climate, affecting the ability to reliably provide performance estimates. We also utilized the Plantval generator tool to produce new deployment maps and different "uncertainty maps" for the seed orchards in the database using the updated URF-models (see an example in Figure 2). The re-analyzed URF-models were used in the new Nordic Planter's guide tool which features several updates described below compared to the operational tool but shared the same basic design and functionality. The second step draws from knowledge gained from both collaborative work on Scots pine (Hallingbäck et al. 2021) where new climatic indices found important in Spain are tested in the Nordic region and from the Norway spruce modeling (Liziniewicz et al. 2022) where a new proxy for photoperiodic transfer (daylength) was tested. In addition, new phenotype data (i.e. field trial assessments) were introduced from southern Sweden and parts of Norway. The southern Swedish data contains tree phenotype data from warmer conditions than previously used and allow for developing models predicting performance better in a warmer future climate. The Norwegian data only cover parts of Norway but will be very valuable when extending the model there. In all this means a more complete re-modeling effort of the Scots pine URFs and as these models are still only preliminary, they have not yet been implemented in the Planter's guide test version.

For Norway spruce the new URF-model has been used in a Nordic Planter's guide test version. This tool is very similar in design to the Scots pine test version but as no survival URF model could be developed, performance is given by predicted growth ability only. Deployment maps for one climate scenario was produced by the Plantval generator tool and uploaded in the PG test version as an example. The entire Nordic region is included and in this test version also the Baltic States can be selected as planting sites. Although not part of the B4EST-community, phenotype data was collected from all three Baltic countries, but it was not included in the modeling in this stage. However, as we aspire to include the in the future we decided to include them already now in this test version.

Thus, the main features of the test version of Planter's guide tool for both species are described below.

Basics (same as the operational tool)

- The tools are designed in a sequential way. First the planting site is selected by either clicking in a map or explicitly giving the coordinates. Then a table of suitable seed orchards (and stand seed) are given ranked according to their performance at the site.
- For Scots pine and Norway spruce, growth is calculated at an approximate mid-rotation but for Scots pine survival is calculated in the current climate. Seedlings have to survive the establishment phase and utilize the growth potential in a future climate.
- This ranked table will change by altering/adjusting the site and climatic conditions at the selected planting site.

- By clicking on a seed orchard name, more information about the seed orchard is given including a deployment map.

New features (test tools only)

- For Scots pine it is now possible to select planting sites and get deployment recommendation also in Norway. For Norway spruce this applies for the entire Nordic region and the Baltic States.
- The site selection and map grids shown have a higher spatial resolution of 1x1 km in the entire potential deployment zone.
- There are only very simple and extensive limitations to the deployment zones in the test version. This, as we want to evaluate model performance and seed orchard outcomes but also as we do not currently have any joint deployment recommendations available for this larger geographic area.
- The Norway spruce tool includes all contemporary and productive seed orchards in Sweden, Norway and Finland.
- It is now possible to choose one of the four available RCP-scenarios (RCP2.6, RCP4.5, RCP6.0, RCP8.5) after the planting site has been selected. The seed orchard performance predictions are re-calculated based on GCM-ensemble averages and the orchards are re-ranked accordingly (Figure 3).
- It is possible to select two future points in time; the 2050's and the 2070'. The first represent planting today with mid-rotation around 2050 and the second represent future seedlings from ongoing establishment of new 2g seed orchards with expected availability 20 years from now (and mid-rotation 2070). The latter has been used for planning the establishment of the new 2g orchards and is not intended to be a part of the future operational tool (Figure 3).
- The current version of the tools cannot provide more than one deployment map per seed orchard so to serve as examples, the Scots pine seed orchards have been given an uncertainty map and the Norway spruce seed orchards have been given deployment maps from RCP4.5 with mid-rotation 2050.

The Scots pine test version can be found here:

https://wwwtest.skogforsk.se/english/products-and-events/software/plantval-3-uk-tall/

And the Norway spruce version can be found here:

https://wwwtest.skogforsk.se/english/products-and-events/software/plantval---gran-3-uk/

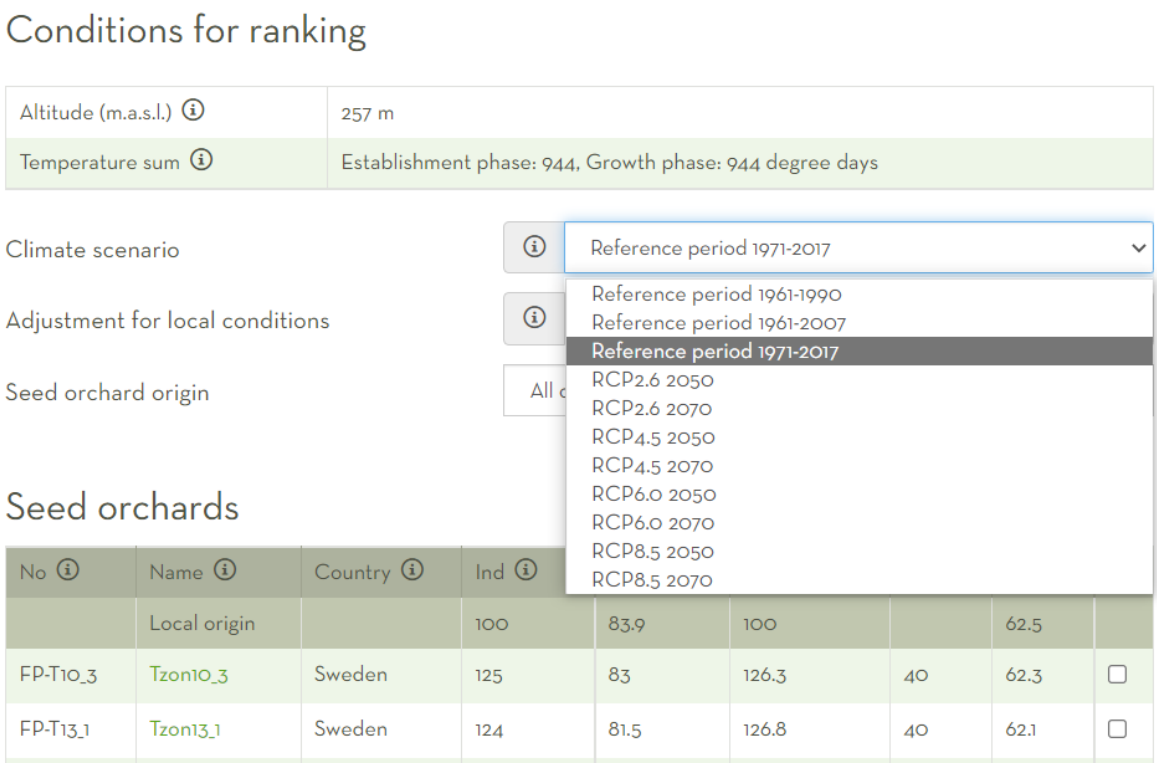

Figure 3: Screenshot of the Planters' guide test version for Scots pine. Different future climatic scenarios for different time periods are now available for selection.

3.6.3 Planter's guide optimization tool

The operational and test versions of Planter's guide described above are designed to provide decision support for one planting site at the time, which is highly desired by forest owners that are dealing with one or a few planting sites every year. Large forest owners have different needs for which the Planter's guide tool is less suited. They desire tools that can: (i) handle many planting sites at the same time; (ii) provide recommendations only for the FRM they have access to and; (iii) maximize predicted per hectare production with limited amount of seedlings per FRM they can produce. For that purpose, a complementary tool, Plantval optimal (Planter's guide optimization) was developed based on the same platform as Planter's guide. It makes use of all the functionality in the Planter's guide platform (1-8 in Figure 1) but it requires input data in the form of two plain text files. One containing information about all planting sites which apart from compulsory geographic data includes planting site area, site index and seed/seedling usage per site. The other file contains all different seed orchards (or provenances) available to that end-used and the supply of seed/seedlings from each FRM. The tool first automatically calculates performance prediction for all available FRM at all sites and then optimizes the use of the seed/seedlings by maximizing the mean annual per hectare volume production for all sites. This tool is freely available on the Skogforsk web in the same way as Planter's guide. However, as the development of the Planter's guide optimization tool was financed by Swedish forest companies it is currently only available in a Swedish version for the Scots pine and Norway spruce. Nevertheless, as the Scots pine version is based on the Swedish-Finnish Planer's guide platform the optimization tool is fully functional to use also

for Finnish end-users. The Planter's guide optimization tool has been used in case studies for several different Swedish forest companies and has shown substantial opportunities to increase administrative efficiency and increased forest production (Berlin 2021; Davidsson et al. 2018).

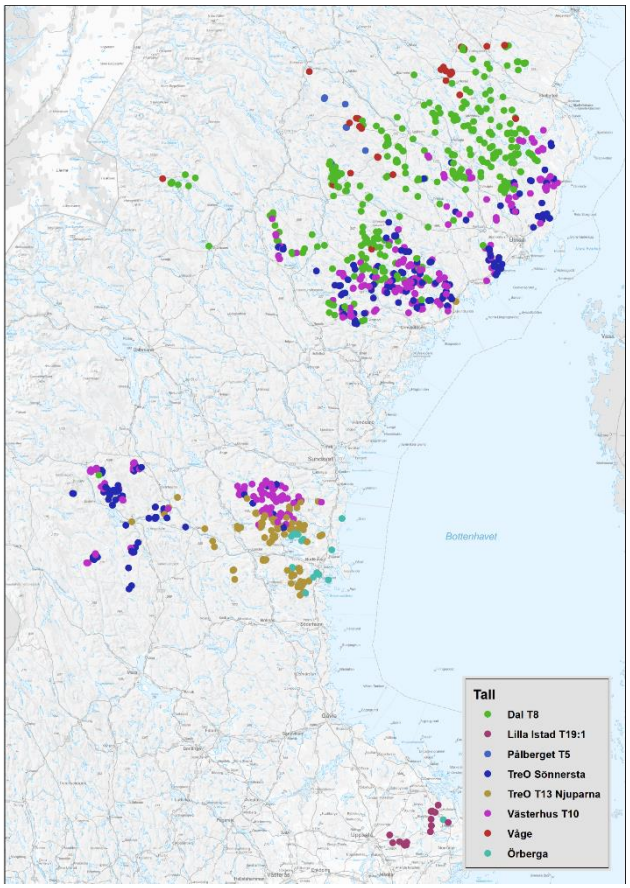

Figure 4: Optimized use of Scots pine seed orchard crops for a large Swedish forest company using the Plantval optimal tool. Each dot is a planting site and each color represent a unique seed orchard crop.

The Scots pine and Norway spruce versions can be found here

https://www.skogforsk.se/produkter-och-evenemang/verktyg/pvopt/

3.7 Stakeholder interaction and end-user feedback

During the development of the now operational Scots pine Planter's guide tool, both stakeholders (e.g. formal authorities, researchers from other disciplines) and end-users have been involved in different stages and steps of the platform and tool development. In particular, formal authorities have been closely involved regarding how to characterize FRM and in the development of deployment recommendations and how rules and regulations should be taken into account. They have also been important for enabling the formal approval of use of FRM from the neighboring country. End-users have been foremost involved in the design of the Planter's guide tool and have had suggestions to improve the design and functionality both

during the developmental phase and continuously when using the tool. A key topic for both parties is now a dialogue on how to take climate change uncertainties into account.

4 Future work

At the end of B4EST there is an operational Swedish-Finnish Planter's guide tool for Scots pine and joint Nordic test versions for both species. An obvious aim is thus to further develop the test versions and make them operational. To enable that, several research steps and collaborative efforts are required in the future. Furthermore, as more knowledge is acquired from research additional features could potentially be added to the Planter's guide platform and therefore this work can be considered as continuous upgrades of the system. Below some key research and implementation topics have been identified. Some are more theoretical and more or less species independent, whereas others are clearly species specific.

4.1 Improving performance prediction in future climates

During the B4EST-project it has been clear that methods to handle the effects of and variability/uncertainty associated with climate change is a key functionality in a future Planter's guide tool. There are several different tasks to address.

A major task is to continue the work started to develop methods to illustrate climate change variability. Even if one specific RCP-scenario is selected there is a variation in the predicted global warming magnitude and thus also in the predicted FRM performance. Several different methods have been tested within B4EST and must now be analyzed together with both end-users and stakeholders. One could even test mixing the outcomes of two or more RCP-scenarios if that is of interest.

Another major task is to address what we have defined as "beyond model limits", which are geographical areas where the developed URFs likely have a reduced reliability to predict performance in a (much) warmer climate. This is related to the limitations of the climatic distribution of the historic data used to build the URF and the fact that future climates are sometimes well beyond the historic data so that the URF models enter an extrapolation zone. There are several possible approached to pursue. The simplest option is to add more historic/phenotypic data from trials exposed to warmer climates than available in the current URF model database. This can be additional field trials from more southern locations (which has been partly tried in Scots pine by adding data from southern Sweden) or to access more modern field trials. Based on the currently available relevant field trial data this can only partly improve the model prediction power. Another approach is to study the URF models themselves and analyze their behavior under strong extrapolation. No "un-biological" behavior like e.g. non sensical exponential growth should be tolerated and post-hoc model or deployment adjustments could be made. A third approach is to add "biological constraints" from modeling in other disciplines. For example, it is unlikely that growth is linearly related to temperature when the temperature goes beyond a certain threshold. For example, in process based

modeling like stand simulators, such effects could be built-in and it is possible to draw from that knowledge and implement in the Planter's guide platform.

4.2 National rules and legislations

For a future joint Nordic Planter's guide tool to become operational it must be adapted to the national rules and legislations. This has required a considerable effort in the operational Scots pine tool and that is likely the case also for any upgrades of the Scots pine system and the entirely new Norway spruce tool. There will be a discrepancy between the state-of-the-art new modeling approaches included in the Planter's guide platform and the current national rules and legislation. It can be illustrated by the new methods to explicitly include future climatic conditions and to handle the associated uncertainty where the geographic area, in which a certain FRM performs well, can vary both within and between future climate scenarios whereas current national rules of transfer zones are currently static in their nature. It is desirable to have an transparent discussion with formal authorities which also includes possibilities to update and adjust rules and legislation if that is considered relevant.

During the B4EST-project it has been clear that a transparent and frequent dialogue with formal authorities have been very constructive and has led to updated deployment recommendations for Scots pine in both Sweden and Finland and has facilitated the use of non-national improved FRM in both countries.

4.3 Nordic and/or Baltic Planter's guide

The current test versions of Planter's guide allow the selection of planting sites in Sweden, Finland, Norway and the Baltic States. However, the URF-models for both species currently do not include any data from the Baltic States and for Scots pine only data from a smaller part of Norway. For the latter there has already been a preliminary discussion to use some kind of climate matching (i.e. expanding model validity to regions where the climatic factors included in the URF-models are similar to those in regions where there is field trial coverage) in combination of other imposed thresholds (likely altitude and degree of maritimity) to decide in what parts of Norway the Planter's guide performance predictions can be considered reliable. For the Baltic States there is a limited amount of field data collected for Norway spruce and none for Scots pine and this data has not been used in the URF-model development. Even if some Baltic data could be added it is likely that the climate matching approach previously mentioned has to be used as a complement if we would like to expand the URF-models to that region too. In addition, if any seed orchards from the Baltic States should be included, they would have to defined in the same way as the Nordic seed orchards have been on a common scale.

4.4 Validating the Norway spruce URF for improved FRM

As mentioned earlier, the URF growth model for Norway spruce has been developed based on information from stand seed assumed to be unimproved and autochthonous but the Planter's guide tool requires that the performance of improved FRM can be predicted. Thus, for Scots pine we used information from an extensive amount of progeny trials with where the progenies had known origin to test the URF model performance when predicting outcomes for those progenies and compare with actual assessments. By picking out offspring from either phenotypically or genetically selected genotypes we could analyze the URF performance for categories of material representing all contemporary productive seed orchards (Hayatgheibi et al. 2020). The analysis for Scots pine showed that the URFs can be reliably used to predict performance for all 1g – 1.5g seed orchards. For Norway spruce it would be possible to compile a similar amount of relevant progeny data and perform the same analysis as in Hayatgheibi et al. (2020) to validate the URF's performance for improved FRM.

4.5 Common system for characterizing Norway spruce seed orchards

In the current test versions of Planter's guide for Norway spruce, the Norway spruce seed orchards have been characterized using the same system as for Scots pine. However, it is not obvious that this system is directly transferrable to Norway spruce without adjustments and additional features. The pollen contamination level currently used at full production (40%) is probably too high according to some recent studies (Sønstebø et al. 2018). The discrete classifications of gain from different management regimes (thinning, linear deployment) should be analyzed also for spruce (other management regimes such as selective harvesting are not used and should be dropped). A difference between Norway spruce and Scots pine is the strong importance of phenology and in particular timing of bud burst in Norway spruce. The timing of bud burst is under strong genetic control and has a clear provenance differentiation (e.g. Hannerz et al. 1999; Lundströmer et al. 2020). In addition, studies have also shown that the temperature climate during seed maturation could substantially alter the timing of bud burst (e.g. Johnsen et al. 2005; Johnsen et al. 2009) which means that different seed crop years could behave very differently in this respect. This raises two important questions: (i) how could timing of bud burst be classified in a standardized, reliable way compatible to potential frost risk models (see below) and; (ii) how could the effect of seed crop year be included in the Planter's guide platform?

Breeding organizations that make selections for seed orchards weight the traits differently depending on the risk of e.g. spring frost, need for increased wood density, reduction of the frequency of lammas shoots, etc. Hence, we might see that the orchards are differentiated more in the near future.

There are different "standard" or "norms" for genetic diversity in seed orchards across the Nordic countries. This makes a difference for the selection potential within deployment zones and can affect genetic gain.

4.6 Frost risk modeling in Norway spruce

In B4EST models that could predict provenance specific risk of spring frost damages at an arbitrarily selected site were developed (Svystun et al. 2021). They rely on classifying different provenances timing of bud burst using the temperature sum in the spring as the trigger. In theory, such models could be included in the Planter's guide tool but the existing frost risk models are based on a different climatic data set with a much higher temporal resolution than the one used in the Planter's guide platform which is based on monthly averages. The models would have to be re-calculated for the new climate data set with appropriate approximations to allow for a lower temporal resolution. Furthermore, these models were developed for provenances and have to be adapted to work for seed orchard crops. Finally, there is more new data available to re-investigate the temperature sum model to predict timing of bud burst (which is likely more complex than only driven by temperature during spring).

Frost risk cannot always be modelled, and the representativeness of the experiments present today might not cover the range of extremes needed. It is therefore important with further investigation of the risk and uncertainties connected with the long transfers suggested by the URF models when there are established based juvenile height growth.

4.7 Planter's guide optimization tool

As described earlier the Planter's guide optimization tool utilizes the Planter's guide platform and it is therefore possible to develop a joint Nordic tool for both Scots pine and Norway spruce. The optimization part of the tool is simplistic in the sense that it (only) maximizes annual per hectare volume production and there are several possibilities to upgrade and improve the optimization model. For example, logistics and economy could be included (e.g. transport costs, distance to factory) and practical constraints (e.g. requiring that nearby planting sites should have the same seedlings). Furthermore, interaction between the optimization tool and stand simulator could help increase knowledge about optimal use and silvicultural management of improved FRM (e.g. https://www.skogssallskapet.se/forskning/alla-projekt/projekt/2022-05-23-framtida-blandning-av-gran-och-bjork---battre-riskspridning-och-okad-produktion.html).

4.8 Continued dialogue with end-users and stakeholders

The continued development of the Planter's guide platform and tools require continuous feedback from end-users and stakeholders. For a future joint Nordic system, end-users and stakeholders from all countries must be involved. In particular, we anticipate discussion about the handling of future climate uncertainty, the characterization of seed orchards and design and functionality of the tools themselves.

4.9 Other traits and extreme events

There may be other tree traits for which URF models cannot be developed and/or cannot be standardized on the common performance scale currently used. However, these traits can still be considered important and valuable. Such traits can be categorized in different classes. One class are traits that are related to perceived quality of the tree such as stem, branch and wood quality. For these traits it is very difficult to develop URF models due to lack of assessment data and/or difficulties to standardize assessments on a common scale. In addition, to be able to evaluate these traits on a common scale, that scale likely have to be in monetary units and it is very difficult to assign reliable economic weights to the traits due to the long rotation in Nordic conditions (Berlin et al. 2012). Another class relates to reducing damages from abiotic and biotic threats, which have the same difficulties in URF modeling as the quality traits (i.e. lack of data). Some of these traits are also strongly related to extreme events which are difficult to include in URF modeling due to their stochastic nature and need for a very high temporal (and spatial) resolution of both climate reference and scenario data data.

However, even if URF models cannot be developed and/or it is difficult to express all traits in a common scale it is still possible to include such traits into the Planter's guide platform and tool in different ways. For example, an additional calculation of expected risk of frost damages could be added as a separate information from the performance index and could still be used as decision support by forest owners.

5 Dissemination plan

The new joint Planter's guide tool and efforts to develop common Nordic deployment recommendations have been disseminated to stakeholders and end-users in all Nordic countries during the B4EST project using well-established national networks between the breeding organizations and forestry. In addition, results and multilateral efforts have been presented at different national and international conferences/meetings.

The Planter's guide platform is a key feature in the dissemination plan as it can include new research findings and thus be used as a test system when interacting with stakeholders/end-users. The web-based tools also have several options to include additional information such as popularized descriptions of the models and user guides. A group of Nordic breeders have already set up a "post-B4EST" task force with the aim of further collaborate on related research topics and to make the joint Nordic test versions operational.

National "spin-off" projects that use the B4EST results in future research and implementation are also planned or have already started. One such project started in the spring of 2022, where the "uncertainty maps" and methods developed in B4EST are being used for improving the design of the new 2g seed orchards, whose establishment are currently being planned in Sweden.

6 Partners involved in the work

Mats Berlin (Skogforsk), Henrik Hallingbäck (Skogforsk), Mateusz Liziniewicz (Skogforsk), Sven Tegelmo (Skogforsk), Aron Davidsson (Skogforsk), Curt Almqvist (Skogforsk), Ulfstand Wennström (Skogforsk), Torgny Persson (Skogforsk) Matti Haapanen (Luke), Seppo Ruotsalainen (Luke), Arne Steffenrem (Nibio), Thomas Solvin (Nibio), Maurizio Marchi (CNR-IBBR), Vanessa Burton (FR).

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