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FRM DEPLOYMENT

GUIDELINES FOR FOREST MANAGERS AND TREE BREEDERS

Planted Forests Report

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Guidelines For Forest Managers and Tree Breeders

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INTRODUCTION

Historically, selection in forest has targeted the **phenotypically superior trees** that would provide an added value for wood production. The first breeding programs of the main commercial forest species in Europe were therefore improving traits such as growth, stem and branching quality and vitality. At that time, deployment guidelines were simplistic as improved materials were planted in the same region where breeding was done assuming that site and climate will remain the same.

New challenges and opportunities

Nowadays, forest regeneration is facing new challenges. Climate change is causing a mismatch between the current distribution area and the future climatic niche, leading to poor adaptation and dieback of trees in some parts of Europe. Moreover, some worrying signals are sent by seed orchard managers who report a decline of seed production for some forest species, supporting the idea of a rational use of the available Forest Reproductive Material (FRM).

On the other hand, the production of a wider range of varieties, crossings and breeding objectives is offering a large panel of FRM characteristics. With more options in the choice of FRM and a globalized market, it becomes possible to provide more advanced recommendations for their deployment.

Latest practical knowledge and tools

These guidelines provide forest owners and managers as well as breeders, seed producers and nurseries with tools to assist in choosing the right sources of FRM for specific sites or regions. The main aspects affecting deployment of FRMs are: site conditions such as climate, soil, and biotic and abiotic risks, as well as forest management (rotation) and wood end-use objectives.

Specific sections for 8 forest tree species

To be able to define deployment guidelines for FRM of forest tree species, a significant amount of data on the performance of different genotypes in different environments is needed. Such data is usually available only for tree species that are included in extensive breeding programmes with provenance testing, and thus for species that have been of commercial interest for quite some time. Among these, the B4EST project picked eight study species and FRM deployment recommendations will be given for those in the second part of the document :

Scots pine

Norway spruce

Douglas fir

European ash

© A. Dowkiw, INRAE

Maritime pine

Poplar

Eucalyptus

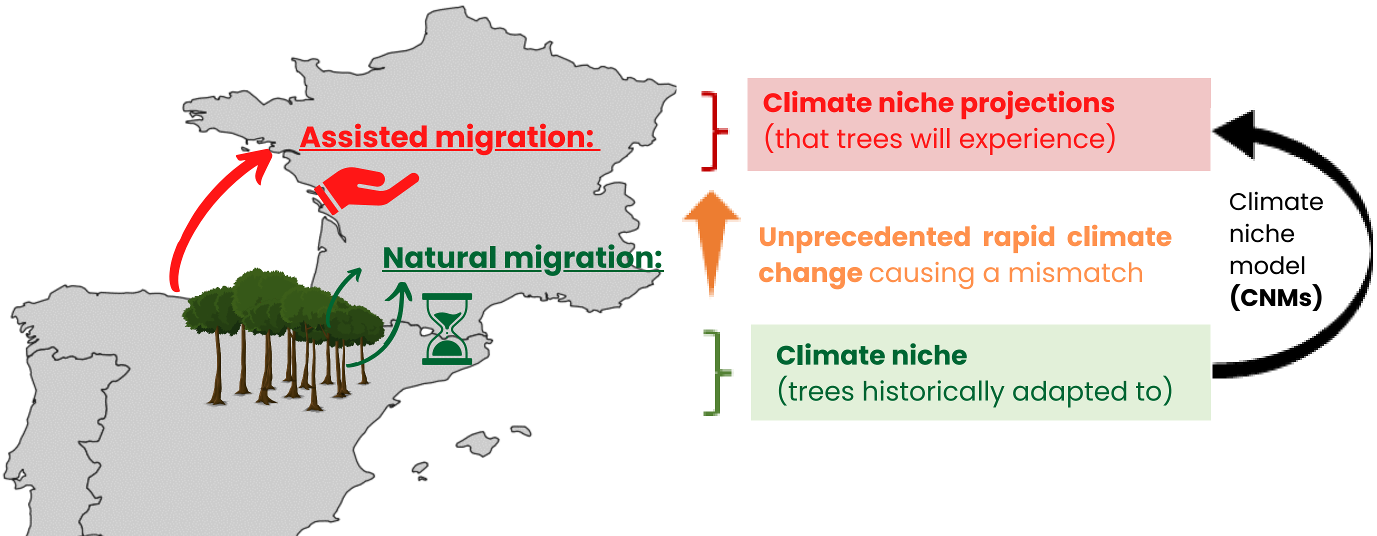
Stone pine

CONCEPTS AND IMPROVEMENT ON FRM DEPLOYMENT

COPING WITH CLIMATE CHANGE USING ASSISTED MIGRATION

Tree populations exposed to climate conditions outside their climatic niches will likely be **maladapted**, resulting in compromised health and functions of forest ecosystems, particularly the capacity of carbon storage for climate change mitigation. To ensure **forest systems' sustainability**, assisted migration has been proposed to help trees in alignment with a changing climate at both the species and population level.

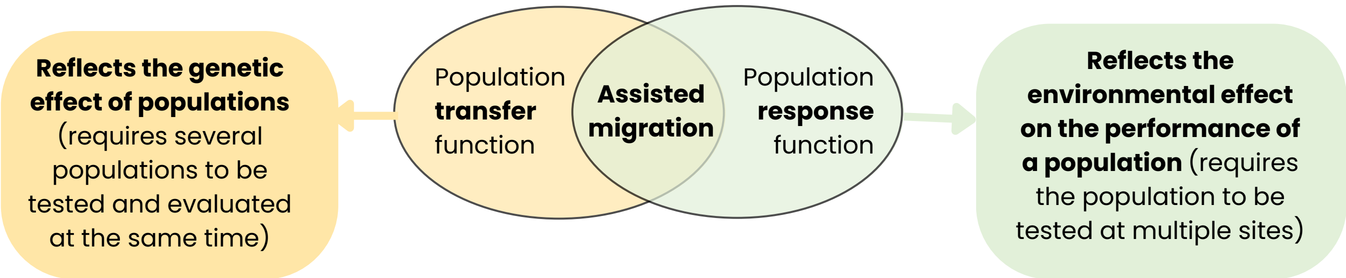
Assisted migration at the species level



Explanatory framework of the concepts around assisted migration

- Climate niche projections of a species can provide a scientific basis for assisted migration at the **species level** (addressed by Climate DT and the Climate Matching Tool)

Assisted migration at the population level



- **Universal Response Function** (URF) has been developed to integrate the genetic and environmental effects into a single model that still needs to be implemented. It aims to predict the performance of any population planted in any test site, with local or optimal populations.

  The B4EST project mainly addressed the prediction of tree performance by a better anticipation of future climate and species adaptation to it. **Provenance trials** across European countries for many important forest tree species were combined and provided the best opportunity to build URFs for **developing tools supporting assisted migration.**

ANTICIPATE FUTURE CLIMATIC CONDITIONS

To enable climate adapted FRM deployment recommendations, high quality climatic data were requiered despite some existing trade-offs between the criteria or some technical issues with the existing database.

Criteria expected for high quality climatic data

- **High spatial resolution**
- **High temporal resolution**
- **Relation to tree performance**
- **Compatibility with the newest climate scenario**

Climate DT: a portal for future climate projections

This tool developed by B4EST incorporates different climatic data sources in different geographic areas of **Europe**. The method is bringing together the CRU-TS historic monthly data at 50km resolution and the UKCP18 RCP2.6 and RCP8.5 scenario projections at 12km resolution for Europe. The downscaling algorithm mathematics makes the two datasets compatible.

Temporal resolution

1901 – 2098: 1 monthly time intervals

Spatial resolution

[1 - 12] km gridded climate variables

Input data:

Spatial coordinates and elevation (x, y ,z)

Outputs data:

Monthly minimum and maximum **temperatures**, **precipitation** and 39 other climatic variables and indices at a 1km grid precision

These data allow some analysis of the **occurence probability of extreme events** at a monthly time scale. The probability of late frosts, deficient precipitation or drought severity in the next decades could guide the choice of planted species.

AVAILABLE ONLINE

User friendly:

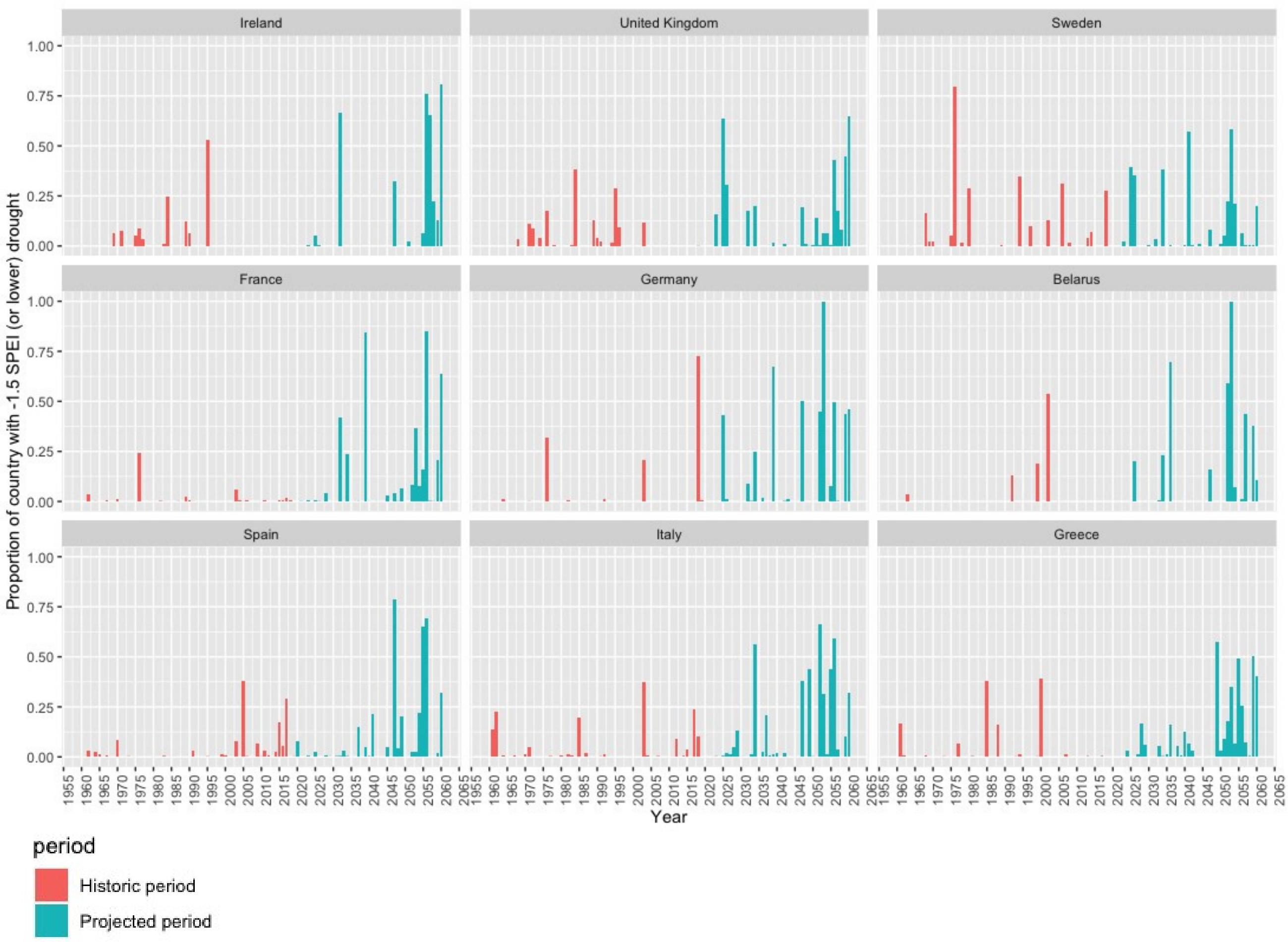
A focus on extreme climatic drought events

Among the climatic indices from Climate DT is the **standardized precipitation and evapotranspiration index** (SPEI) that has been calculated across Europe over the period **1955-2065**. These data have helped visualize and categorize known historic droughts in Europe and assess how historic events compare to the potential frequency and intensity of droughts from future projections.

The standardization measures **the frequency and intensity of extremes** compared to 'normal' variation from year to year. The spatially explicit nature of the climate data can show the **relationship between extreme events and damaging pest outbreaks.**

In all countries, we see a shift to **more frequent September droughts** caused by drier summer conditions. The increasing frequency of droughts in the future is of **real concern to forestry practitioners** :
- **Northern zone** (Ireland, UK and Sweden) will be affected by more frequent and extensive 3-month summer droughts
- **Central zone** (France, Germany and Belarus) will be confronted to a larger extent of drought conditions, frequently effecting half of the countries' area
- **Mediterranean zone** (Spain, Italy and Greece) will be confronted to an increase in frequency and spatial extent of September droughts beyond 2030

Proportion of the land area affected by drought across nine European countries:



The Climate Matching Tool

B4EST has also produced an update to the climate matching tool (CMT). The method uses three **climatic variables** (mean precipitation, average temperature and diurnal temperature range) to match the user-selected future climate projection of a location to the best fitting current climate (analog climate).

Temporal resolution:

2011 – 2079: 10 years' time intervals

Spatial resolution:

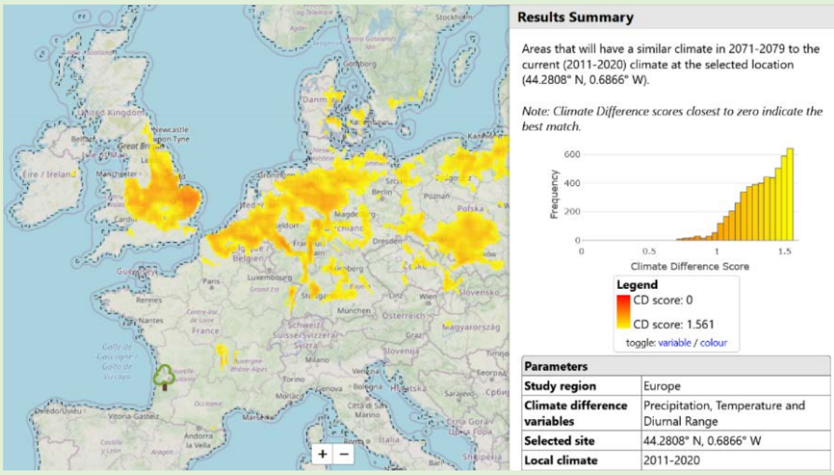
12 km gridded climate variables

Input data: select a location

Outputs data:

suggest similar analog areas in the current climate

For forestry practitioners, this could affect species choice, management systems and could help practitioners to **plan adaptation responses in forest management**. The CMT also works in reverse; e.g., to take the climate data of an area where an FRM perform better now, and see **the extent and range of best fit climates in the future**, ie. where the FRM may be suited in the future.



In 2071-2079, Northern Temperate Atlantic climates may be similar to those of South-Western France in 2011-2020

AVAILABLE ONLINE

User friendly:

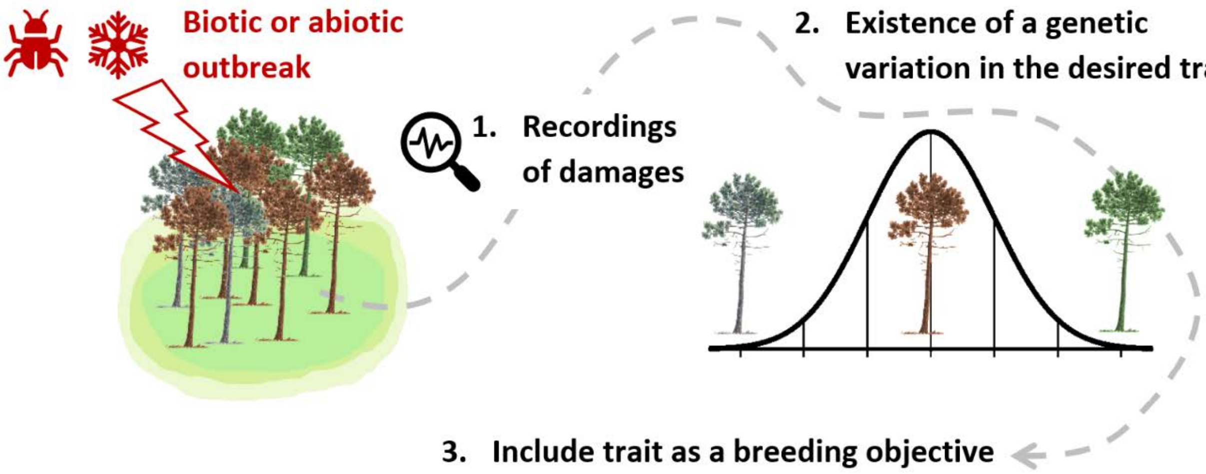
Legend: the closest to 0 the climate difference score is, the closest match it is (colour gradient can be changed)

Crossing the outputs of the Climate Matching Tool **with the results of long-term monitoring trials** under different climates can help clarify the best adapted species and provenances response. For example, REINFFORCE gather a network of 38 arboreta along a large climatic range of the European Atlantic coast to compare the performance of the same genetic materials in each site.

A SHIFT IN TREE BREEDING OBJECTIVES FOR MORE RESILIENT PLANTED FORESTS

The most common traits to improve have historically been related to **increased growth** (height, diameter), general vitality and quality traits. Explicit inclusion of improved performance against abiotic and biotic risk in the breeding objective is so far less frequent but is getting increasing attention as the effects of climate change starts to have a larger impact.

Conditions for traits improvement through breeding



But we first need to improve our knowledge on the relationship between extreme events and intraspecific variation

Most available tree performance data is accumulated over several years (e.g. in common gardens), excluding the short time-scale of extreme events (droughts, bark-beetle attacks, etc.). Identifying a genetic/provenance variation could be reached through :

Common gardens installation under a large range of climates

More intensive field assessments (yearly or more frequent, directly after an extreme event)

Using advanced genomic/data models

More dendrochronological studies

In the next page you will find some **examples of traits** already included in breeding objectives or where progress towards including them has been made

Examples of improvement on response to biotic and abiotic threats

© Lotte Grønkjære

Reduction of damages from late spring frost of Norway spruce

Young Norway spruce seedlings can be exposed to late spring frosts after plantation which can lead to reduced growth and quality defects such as ramicorns, forking and double stems.

The risk of frost damage is strongly related to the timing of bud burst, which is in turn a highly heritable trait. Late bud burst has been introduced as a selection criterion for those breeding populations that target frost prone locations.

© Ondřej Zicha

Increased defense against Scots pine blister rust

Scots pine blister rust (*Cronartium flaccidum*) is considered an increasing problem for Scots pine in northern Sweden. The attack of a field trial showed genetic variation in the defense capability. This has led to a genetic thinning of three seed orchards in order to increase the defense against blister rust. However it is not yet directly included in the breeding programme.

© Forest Research

Breeding against *Dothistroma* damages in Scots pine

Scots pine is the second most important conifer used in British forestry and is expected to rise in a climate change context. A biotic challenge facing Scots pine is Dothistroma needle blight (DNB), a disease caused by the fungal pathogen *Dothistroma septosporum*, usually more harmful to exotic pines. Recent provenance-progeny trials on native Scots pine populations indicate that there is a strong and favourable negative correlation between growth and DNB responses, meaning that selecting for early vigour might be an effective way of reducing vulnerability to DNB.

© DSF - F. Maugard

Increased resistance to Woolly Poplar Aphid damages

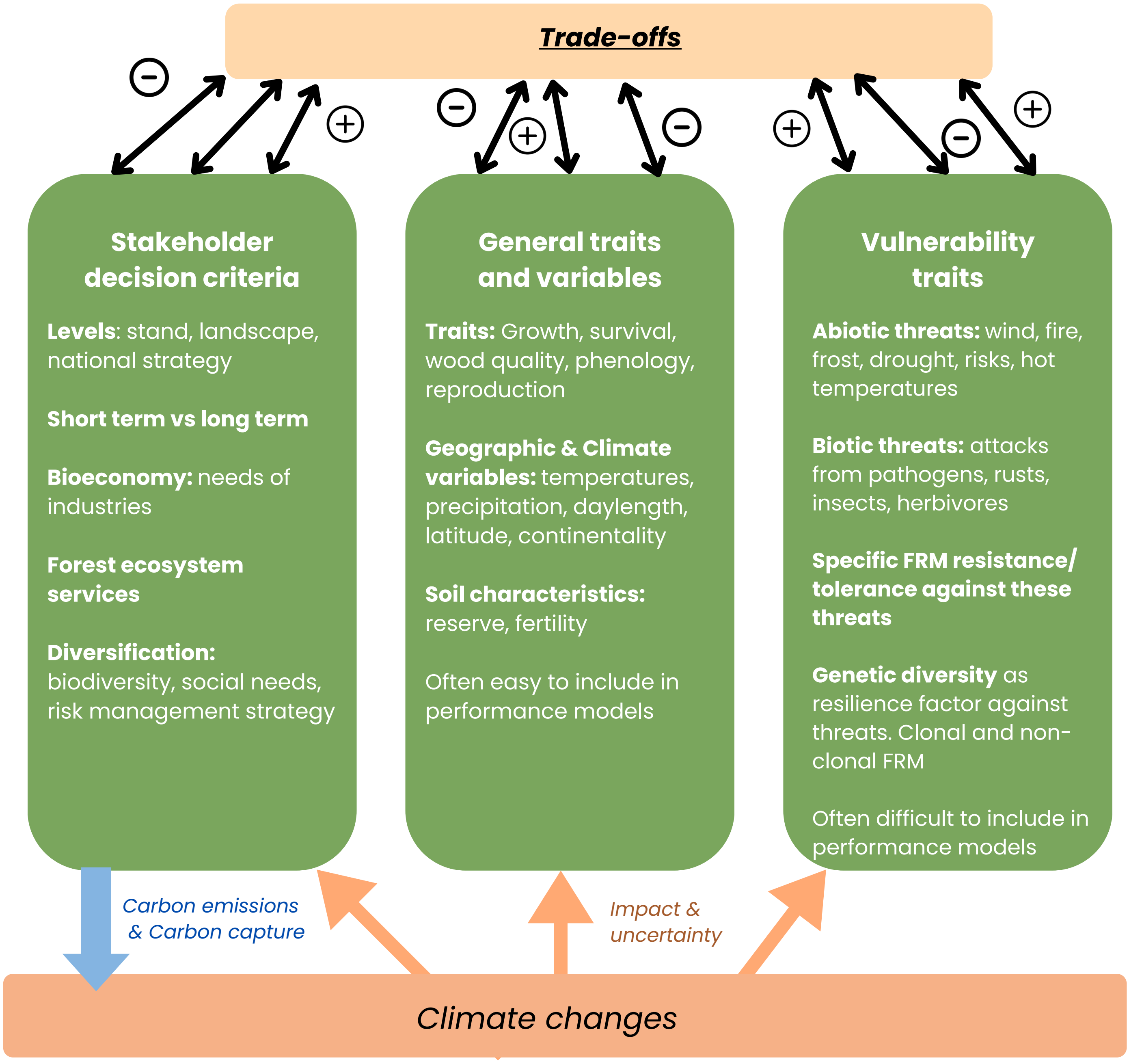
Among the main adversities on Poplar, *Phloemyzus passerinii* causes up to 10% of yield losses in European and American countries, where the majority of cultivated old clones are sensitive to this insect. The mechanism and genetic bases of the host plant resistance to this pest are still poorly known, although a high-level resistance has been observed on *P. deltoides*. Breeding and selection activities in progress allowed to select new *P. x canadensis* clones with higher growth rate and resistance to woolly aphid.

Trade-offs between multiple criteria and multiple traits

There are possible **trade-off relationships** among the desired traits of a species when designing a breeding program or selecting an FRM for deployment. In order to address trade-off decisions effectively, the first step when designing a breeding programme for any chosen species must always be to clarify the stakeholders's expectations in the traits to improve.

There are three levels of trade-off situations when targeting specific traits for FRM use. The first aspect covers stakeholders' expectations for the use of FRM, the second covers the biological feasibility of combining different traits in a same FRM and the latter covers traits mediated either by general inherent resilience or by phenological regulation.

Schematic overview detailing traits that potentially can be included in performance models:



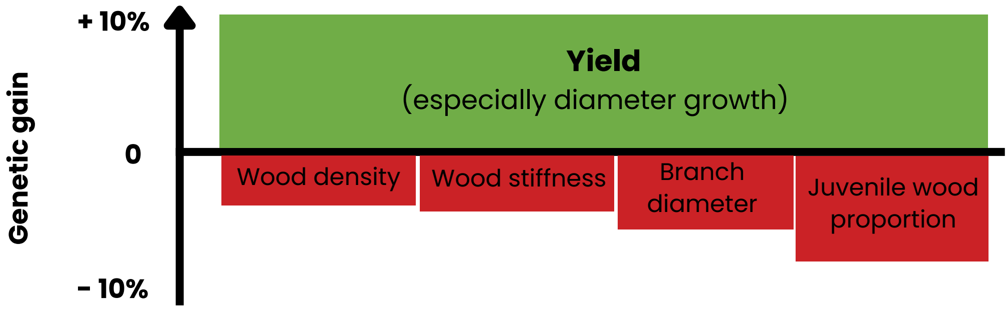
The approach for traits integration is highly species dependent (rotation time length, clonability, environmental gradients of deployment). It is thus difficult to propose a model or a platform for handling multitrait trade-offs that would be applicable to all European forest tree species. Frequently, the nature of the trade-offs are insufficiently explored so that it is not possible to simplify the process of optimizing the fulfilment of desired criteria.

SILVICULTURAL CHOICES IN RELATION WITH FRM

Interaction between genetics, silviculture and trees or wood properties

Breeding can be considered as a factor in forest management for optimization of high-quality biomass, CO_2-storage in forest or forest products with some expected **trade-offs**.

Unfavourable genetic correlations of tree breeding:



Some species affected (non-exhaustive list):

- Norway spruce
- Sitka spruce
- Maritime pine

Forest managers can also influence wood quality traits depending on the initial spacing during regeneration, species mixtures and thinning regime. In standard conditions, an **increased initial stand density** will **reduce juvenile diameter growth** of most species and will **facilitate the control of branch dimensions**.

Silvicultural options at the stand level to increase resilience

Polyclonal stands to mitigate risk in Poplar plantation

Clonal diversification represents an alternative model to monoclonal plantation in order to mitigate the risks deriving from climatic changes, biotic and abiotic stresses. Although no benefits of clonal mixtures have been shown for wood production, epidemiological risks are lowered. Indeed, these **risks are inversely proportional to the genetic variability of the cultivated material**.
Mixing the stand with 20 to 50% of two or more poplar clones with greater environmental sustainability would allow to pursue the European Rural Development Plan's strategic objectives. New cultivars with compatible growth curves were created in that sense.

Clonal forestry in Nordic countries

Research provided some guidelines for potential future operational use of Norway spruce clones:

- clonal stands should have a gene diversity of at least 90% compared to natural stands
- a mix of 25 clones is suggested when practicing vegetative propagation
- new well-adapted clone mixtures are continuously updated from the long-term Norway spruce breeding program
- an upper limit of ramets per clone is suggested

Complex landscape

Landscape complexity can promote resilience both to biotic and abiotic threats which are a main concern within the ongoing climate change. A complex landscape can be achieved with a mosaic of land cover uses, such as patches of forest, agriculture and of urban areas but also by diversifying tree species composition or genetic provenances. Combining selected material and natural regeneration can be an option to mitigate risk (ex: Norway spruce and birch in Nordic countries).

Heureka and Motti: simulation of alternative silvicultural regimes in Nordic region

Both tools are **stand-level simulation software** designed for assessing the effects of alternative silvicultural practices and management regimes in Nordic countries. They include a large set of models based on extensive measurement data from forest inventories and from long-term experiments for all major tree species growing in pure stands and mixed stands in boreal forests.

Input data:

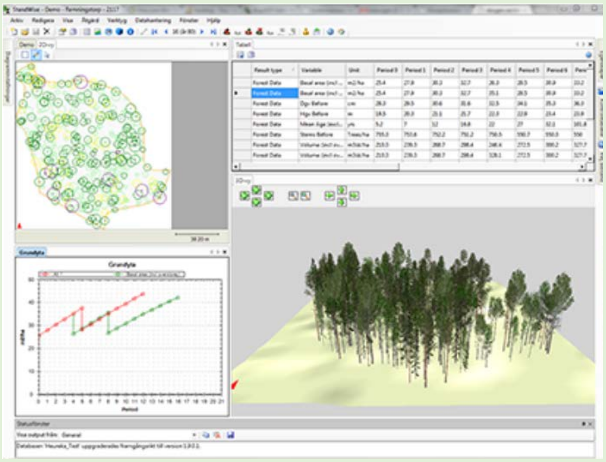
- Initialisation of the stand: localisation, climate, soil
- Choice of silvicultural practices (regeneration methods, pre-commercial and commercial thinnings, forest fertilization, and the use of improved material in forest regeneration)

Outputs data: both stand- and tree-level **growth and yields** models predict **stand dynamics** and **structural properties** of stands on response to sylvicultural practices. The models also predict the **genetic gain** in tree growth for Scots pine and Norway spruce.

Heureka StandWise

Country: Sweden

Developer: SLU



AVAILABLE ONLINE

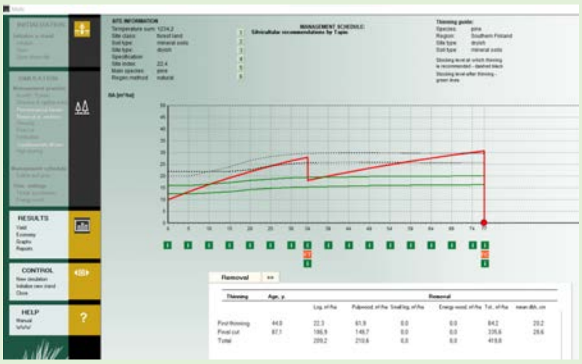
User friendly:

Motti

Country: Finland

Developer: LUKE

- Economical assessment included



AVAILABLE ONLINE

User friendly:

LUBERON 2: Interaction between silviculture and stand-level genetic diversity

This simulation tool developed on the CAPSIS modelling platform, allows to explore the role of **within-stand genetic variation** on forest performance and resilience and, reciprocally, the effect of silviculture and/or stochastic disturbance events on stand-level genetic diversity. The model reproduces the yearly time step evolution of even-aged stands of either **Douglas fir** or **Atlas Cedar** with **natural regeneration**. The model is also multi-generation by including sexual reproduction processes

Input data: **dendrometric** and **genetic** characterization of the **initial stand**

Outputs data: **stand response** to any silvicultural scenario (different types of thinnings and regeneration management options) in terms of performance and genetic diversity across generations.

AVAILABLE ONLINE

User friendly:

+ User manual available on the website

- Forest management (thinning) can generate high selection intensity for vigor, which ultimately results in selection on correlated traits
- The tool can be used to assess the effects of interactions between genetic variation, management and stochastic disturbance events.

SOCIOLOGICAL AND ADMINISTRATIVE BARRIERS TO FRM DEPLOYMENT

Stakeholder acceptance

There is a diversity of forest management regimes and traditions across Europe that matters for the deployment of FRM.

Awareness about climate change:
Forest owners and managers perceived climate change impacts less negative in Nordic countries and the UK, whereas impacts were seen dominantly negative especially in Spain, Portugal and Germany

Economical and environmental drivers:
Practitioners understand the need for climate change adaptation and large scale forest restoration but the main driver is the significant economic gain of using FRM with genetic gain on growth

Management tradition:
Less than 30% of European forests are established by afforestation and planting/seeding

Administrative constraints:
Nature conservation legislations are perceived as causing excessive constraints especially due to high bureaucratic burdens and increasing costs

FRM availability:
Practitioners may have limited options for tree species choice depending on the seeds produced by nurseries for planting stock

Administrative issues for assisted migration

There are several national and international legislations that seem to have large effect on the use of FRM in Europe with large variation in the regulations: Council Directive 1999/105/EC, Convention on Biological Diversity (CBD), FAO Global Plan of Action for the Conservation, Sustainable Use and Development of Forest Genetic Resources.

- National and regional policies often promote the use of native/local FRM and discourages the use of non-local and exotic material. Such regulations form serious obstacles for assisted migration, especially when country borders must be crossed.
- Finds out **how forest tree breeding can contribute to EU forest policy** in our B4EST policy brief

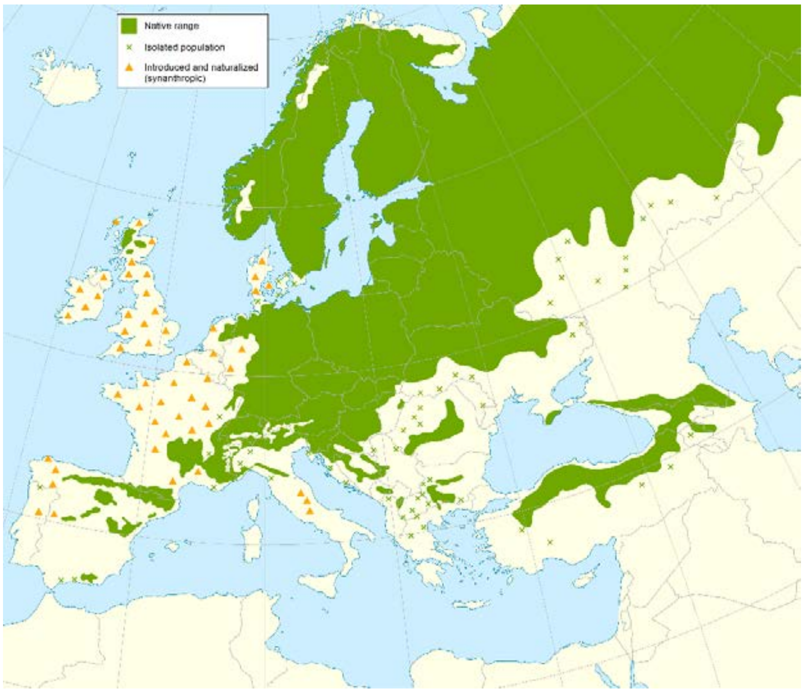
SPECIES DEPLOYMENT RECOMMENDATIONS

SCOTS PINE, *Pinus sylvetris*

Context

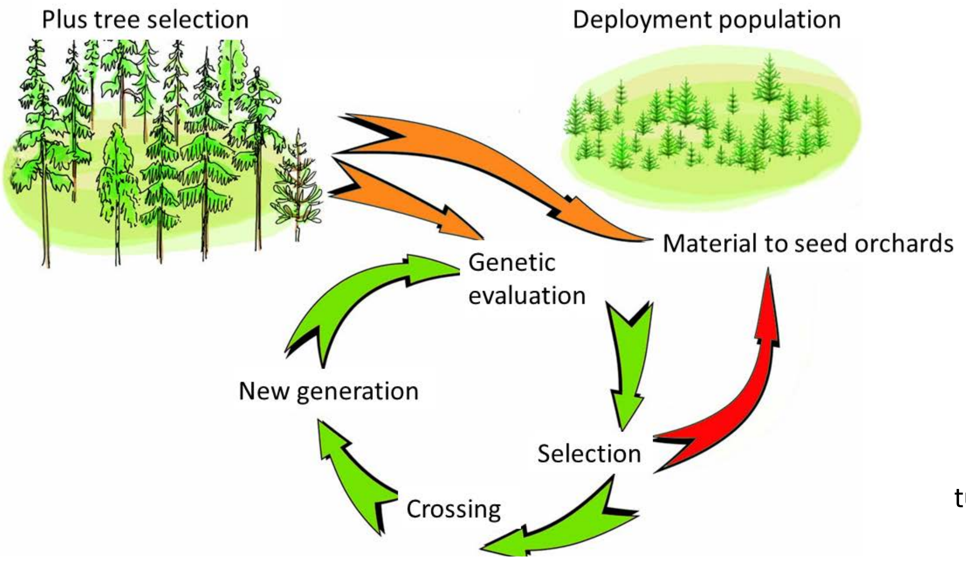
This description sheet is focusing on the **Scandinavian** perspective (applies to Sweden and Finland).

The breeding programs were initiated in the **1940's and 1950's** by visual assessment in natural stands. The figure below explains the different steps of the breeding process and its connection to the deployment population, **providing FRM for forestry.**



Distribution map of Scots pine in Europe. ©European Union, 2017

Breeding process



Complete generation turnover from selection to evaluation : 20-30 years

Differentiation of adaptation patterns

The breeding programs are based on **MPBS** (Multiple Population Breeding System) with several different sub-populations that are unrelated to each other and adapted to different combinations of photoperiod, temperature and altitude, as an **anticipation of warmer climates**.

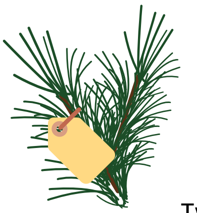
Breeding objectives

General purpose goals:

- **Growth** and **vitality** with a genetic gain of 10-15% (aerial production) per rotation
- **Stem** and **branching** traits
- **[Resistance to biotic threats** have only been evaluated on improved material**]**

Deployment strategies and recommendations

Currently available seed orchards present:



- Different levels of **genetic gain**: trees used in first generation seed orchards (1g), 1.5g and early 2g coming soon.
- Different levels of **adaptive properties**: necessity of a correct and climate adapted deployment to achieve maximum possible genetic gain

Two tools are available to provide FRM deployment recommendations one site at a time or at larger scale for large forest owners and/or plant producers.

New Planter's guide: practical deployment recommendations in Sweden and Finland

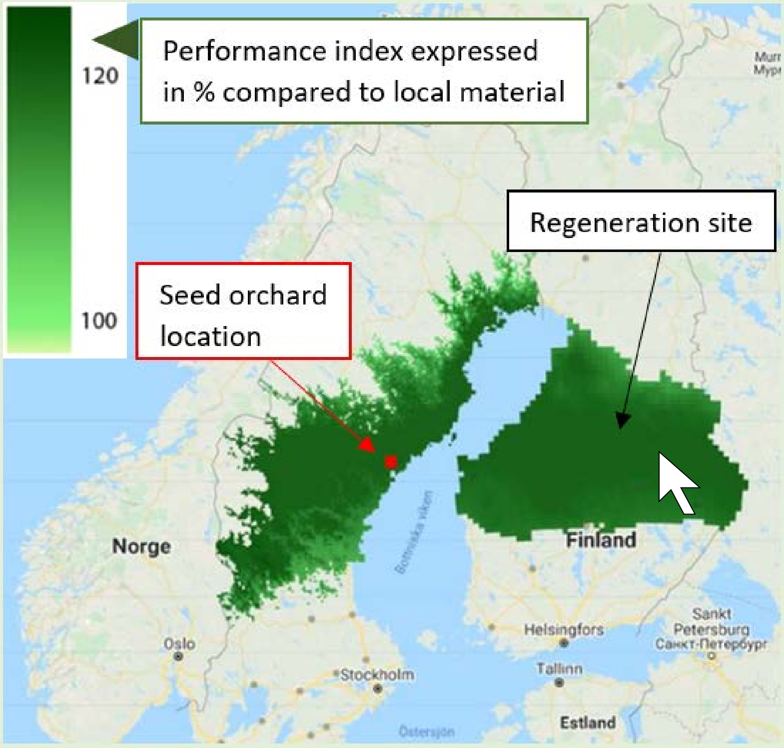
This tool developed by Skogforsk was released for **Sweden** and **Finland**. National formal deployment regulations were updated based on models for growth and survival and new climate data. This included the **characterization of contemporary improved FRM** which included estimates of genetic gain, calculation of standardized latitudinal origin, pollen contamination level and a performance index combining growth and vitality traits.

Input: select a location for a regeneration project and a climate projection among the four RCP-scenarios

Outputs: a ranking of the best seed orchards to source the most adapted FRM compared to local material.

AVAILABLE ONLINE

User friendly:



Plantval optimal: practical deployment recommendations for many regeneration sites

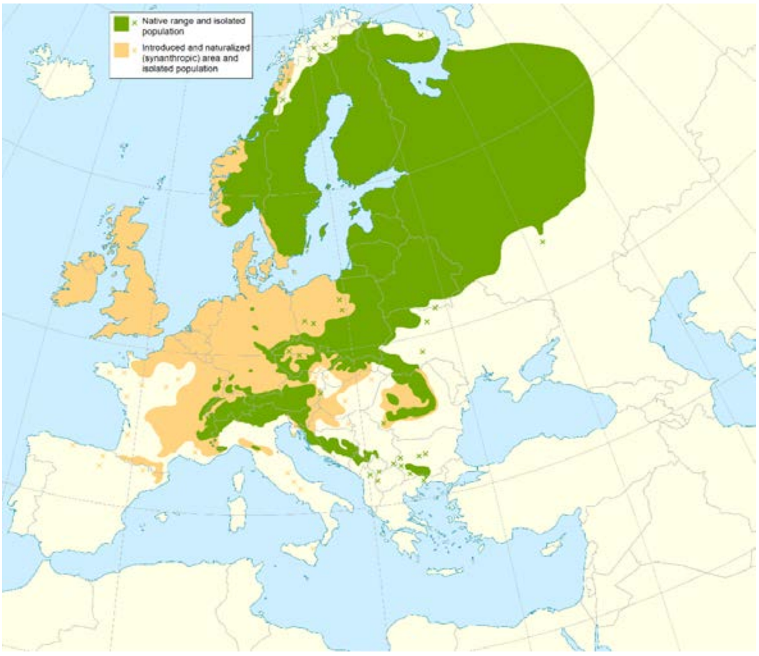
This tool based on the same model platform as Planter's guide **optimizes the use and distribution of improved FRM** in a large private forest with many regeneration sites and access to several different seed sources.

- First results showed that large Swedish forest owners could substantially increase forest production by optimizing the use and distribution of the plant material over their forest

AVAILABLE ONLINE

User friendly:

NORWAY SPRUCE, *Picea abies*



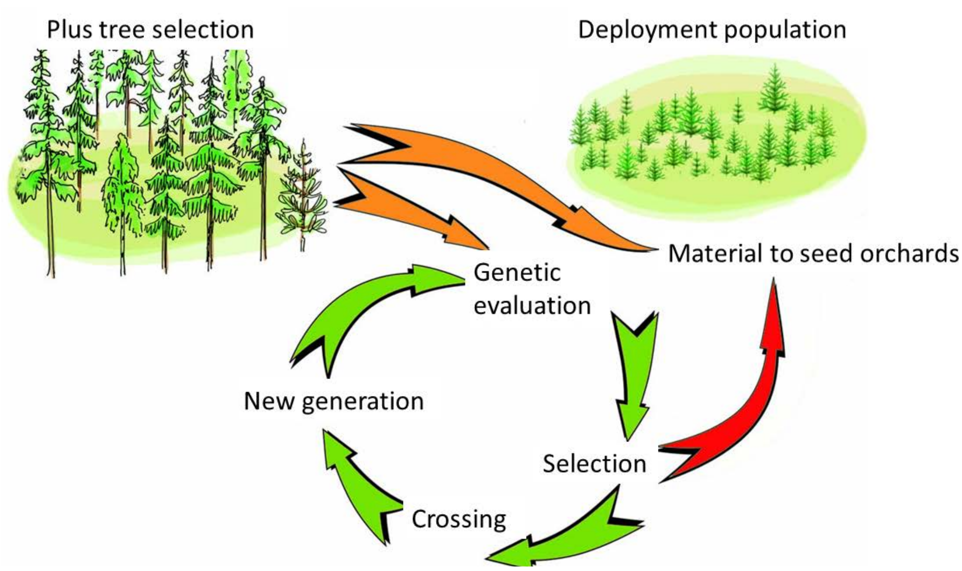
Distribution map of Norway spruce in Europe. ©European Union, 2017

Context

This description sheet is focusing on the **Scandinavian** perspective (applies to Norway, Sweden and Finland).

The breeding programs were very similar to the Scots pine breeding program. The figure below explains the different steps of the breeding process and its connection to the deployment population, **providing FRM for forestry.**

Breeding process



Differentiation of adaptation patterns

The breeding programs are based on **MPBS** (Multiple Population Breeding System) with several different sub-populations that are unrelated to each other and adapted to different combinations of photoperiod, temperature and altitude.

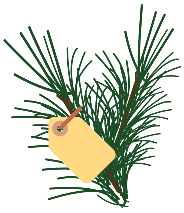
Breeding objectives

General purpose goals:

- Per hectare **volume production** over a rotation
- **Stem, branching** and **wood quality** traits
- Phenology: **timing of the bud burst** in the spring related to frost damages
- **Hardiness** in fall is important at higher latitudes and altitudes
- **[Resistance to some biotic and abiotic threats** are only under evaluation**]**

Deployment strategies and recommendations

Currently available materials present:



- Different levels of **genetic gain**: trees used in first generation seed orchards (1g), 1.5g and early 2g.
- Some orchards are characterized by their **phenology**
- **Vegetative propagation** by means of rooted cuttings and somatic embryogenesis can also be used in small-scale

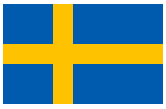
No joint deployment recommendations and decision support tools currently exist.

National deployment guidelines and support tools have been developed in each country separately

In Norway:

Use of seed and plant materials from abroad has to be **approved case-by-case.** Presently, 1g and 1.5g seed orchards supply 95 % of the seed consumption. Deployment of this FRM is following guidelines given specifically for the orchards and there are general recommendations for transfer to adapt to climate change.

In Sweden:



Transfer effect models have been developed for growth, adapted for improved FRM and implemented in national version of the Planter's guide tool.
The formal regulations for allowed transfer of FRM are provided separately from the Swedish Forestry Board.

In Finland:

The recommendation is to use **stand material transferred from the south** except for northern Finland where the use of local material is recommended. According to these guidelines, Estonian FRM is accepted for regeneration in the southernmost Finland. The deployment areas of seed orchards are defined in terms of temperature sum and confirmed by the Finnish Food Authority.

Test version of a joint Planter's guide for Norway spruce deployment recommendations and decision support tool

The model developed by B4EST will be able to:

- better **cover the different climatic condition** and altitudinal variability in the modelled region (Norway, Sweden and Finland)
- simultaneously **handle the wide variety of Norway spruce provenances** across western Europe used in the breeding programs and field trials, including growth rhythm (e.g. bud burst) and frost damage probability.

Input : select a location for a regeneration project and a climate scenario

Outputs: prediction of per hectare **volume production** over a rotation (performance index) + **frost risk** prediction for each improved FRM

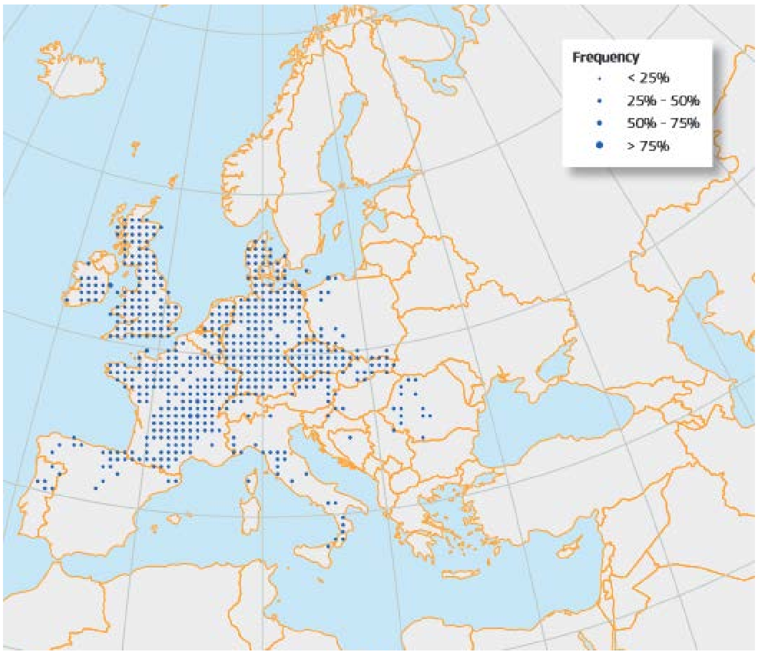
AVAILABLE ONLINE

This test version is **not** to be used for operational decision making yet but to evaluate how a future decision support tool should be designed

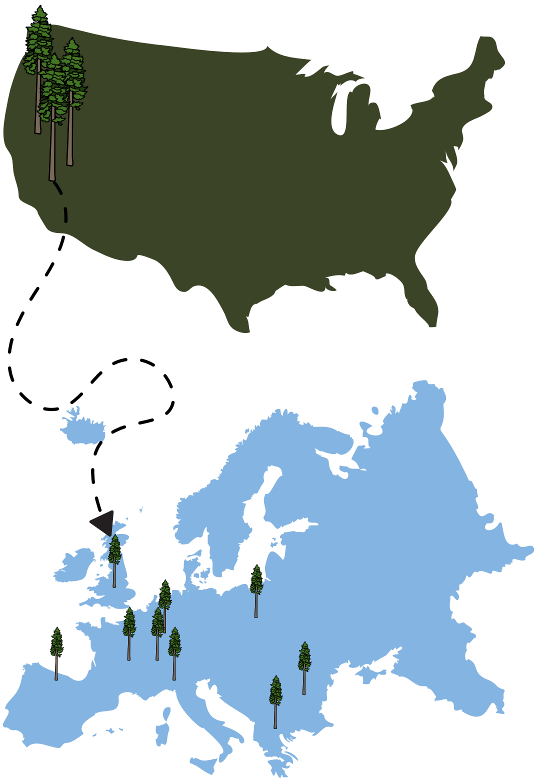
DOUGLAS FIR, *Pseudotsuga menziesii*

Context

Douglas fir is the second most cultivated **non-native conifer** tree species in Europe after Sitka spruce. Firstly introduced in Europe in 1827 by the Scottish botanist David Douglas using north American seeds, it became a **major reforestation species** after the Second World War.
Douglas fir is one of the fastest growing species in Europe and its wood is suitable for many uses.



Distribution map of Douglas fir in Europe. ©European Union, 2017



1965
IUFRO started a Douglas fir seed collection

1970
IUFRO international provenance tests

The results were used to produce the seed importation rules

1965
Field-test of the artificial populations along the IUFRO seed lots

1985
- 1000 ha of ex-situ gene conservation plantations
- Collection of 1000 open pollinated progenies collected in best IUFRO provenances
- 300 ha of progeny tests network

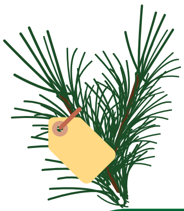
Breeding objectives

General purpose goals:

- **Growth**
- **Branching quality**
- According to climatic scpecificities, some breeding strategies paid special attention to bud flushing, growth cessation, drought or frost tolerance

Deployment strategies and recommendations

Today's Douglas-fir seed procurement in Europe relies both on seed imports from the natural range, and on seed harvest in European seed stands and seed orchards.



In Europe:

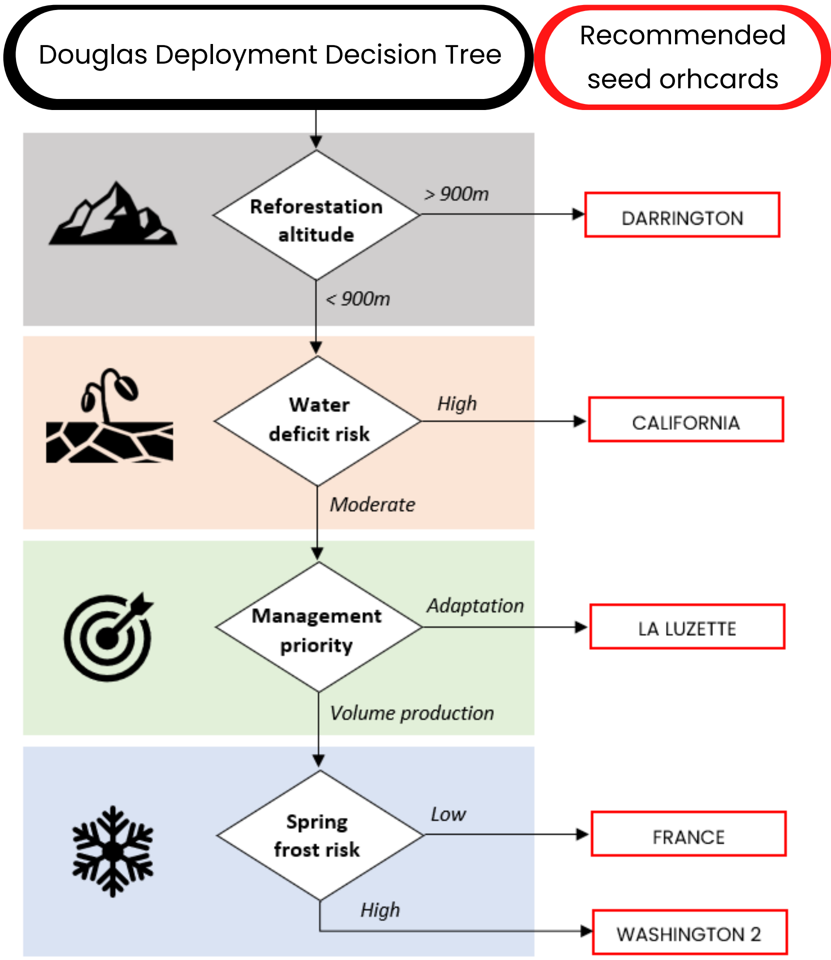
- around 600 Douglas-fir seed stands are registered in the selected category
- 67 Douglas-fir seed orchards are registered, covering a total area of 390 hectares

A 2 degree margin

A meta-analysis on long-term growth revealed that in Europe, Douglas-fir growth is optimal in areas where the average annual temperature is 2°C higher of their place of origin. This validate the current FRM deployment for the next few decades but, beyond 2050, we should use seed sources with forest reproductive material from more southerly forests.

Focus on FRM deployment in France:

Since 2011, a directive from the Ministry of Agriculture and Forestry **prohibits the importation of seeds from the natural area of Douglas-fir** for forestry purposes. The French supply of Douglas-fir seeds is based on about 1200 clones produced in eight seed orchards. From 2009 to 2016, a vast **network of evaluation tests of the state's Douglas-fir seed orchards** was hold. The results are driving the following deployment recommendations:



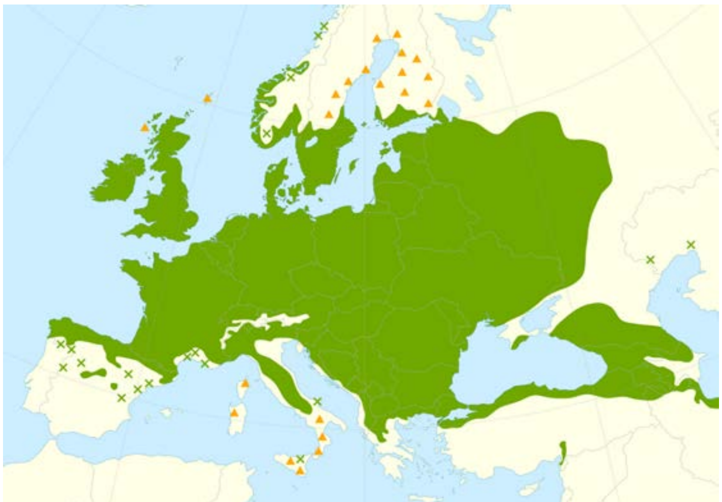
Notes

→ The overall expected genetic **gain in volume is of 20%**

- This variety has a clear lower height increment in the usual core use areas, but performs well in the **warmest and driest sites**

- This correspond to 3 seed orchards: France 1, 2 and 3 with high **juvenile vigour**
- This variety has the **latest** bud break dates

EUROPEAN ASH, *Fraxinus excelsior*



Distribution map of common Ash in Europe. ©European Union, 2017

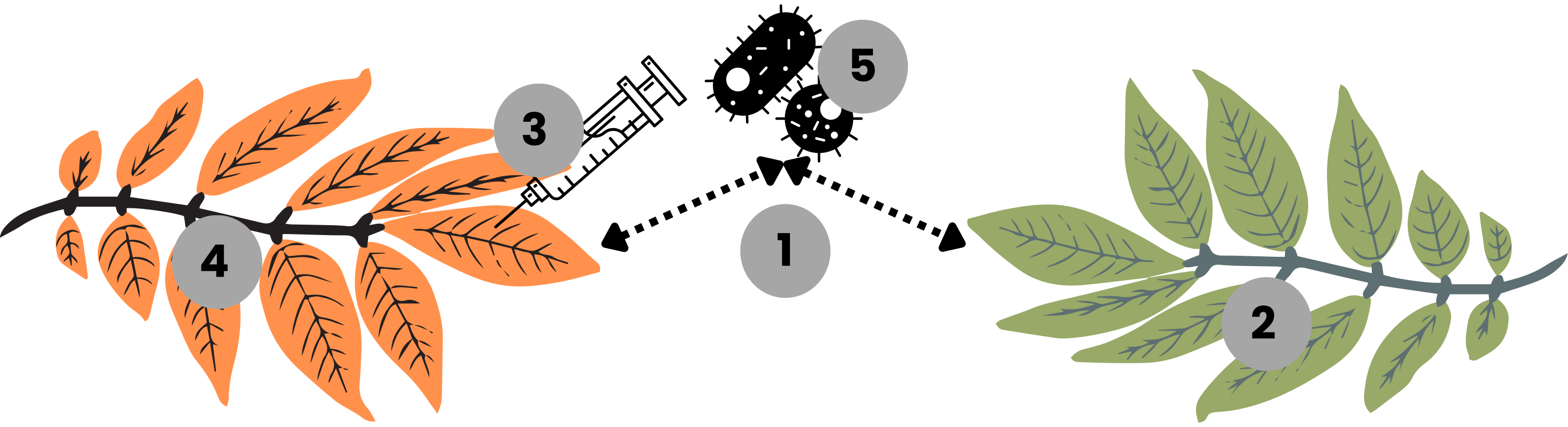
Context

The European Ash is a valuable hardwood species endemic in European countries. Ash was expected to benefit from climate change and to replace negatively impacted species like Beech. However, the species is **now threatened by Ash dieback** (ADB), an invasive fungal disease of Asian origin that has spread all over Europe.

Pre-ADB context in Europe	Post-ADB context in Europe
Breeding efforts	
Before 2013, at least 11 countries had Ash breeding programs, for a total number of 16 programmes.	All past breeding efforts and recommendations **have been cancelled**, but the network of breeding field trials turned out to be an opportunity for studying ADB resistance at the European scale.
Breeding objectives	
The focus was mainly on **timber production** (growth, stem form) 	 **Tolerance to ADB** has become the primary trait of interest
Material available	
• Most of the European Ash FRM consisted in "Source Identified Seed Stands" and "Selected Seed Stands" • Some of these programs resulted in at least 41 "Qualified Clonal Seed Orchards" among which 6 at least were productive • National and international efforts also led to 90 Provenance trials and 6 clonal trials	The only guidance that is currently applied in Europe regarding improved Ash FRM is **to stop planting** until resistant varieties are released.

Ash dieback guidance

All breeding efforts are now turned towards the species' survival. But in addition to the classic difficulties in tree breeding (long generation time etc.), breeding for ADB resistance is facing some major difficulties:



1 **A lack of knowledge on the host-pathogen interaction**. The response in the host is far from being understood, not only in terms of genetics. Disease-free Ash genotypes can be the outcome of any, or a mixture of the following processes: escape, avoidance, constitutive or induced resistances and tolerance.
Moreover, the disease can lead to **different kinds of symptoms**, some in the crown, some in the trunk, some at the collar, whose combination and timing over years will vary to result in the general health status of a tree at a given time. **Juvenile and mature trees** are also known to differ in ADB susceptibility.

2 **All published data conclude on a very low number of asymptomatic trees of 1 to 2%.** This makes it very difficult to obtain balanced numbers of trees in the susceptible and healthy categories as is required for sufficient power in genetic analyses.

3 **The difficulty to evaluate the trees**. The variability of Ash response to ADB are mostly based on field trials with natural disease pressure. Controlled inoculation methods are under development but not fully satisfactory. Inoculating with spores is more realistic but fungus are difficult to work with under laboratory conditions while using mycelium to inoculate stem wounds is effective but do not mimic the natural infection process.

4 **There seem to be some correlations between ADB susceptibility and other silvicultural traits of interest**. The main example is the trend found in many studies where early flushing trees tend to be less infected. If this correlation is confirmed, then selecting against susceptibility may lead to indirect selection for earliness which may in return lead to increased forking trees.

5 **The genetic diversity of the pathogen is not representative of its natural diversity in its area of origin**. **Introduction of new strains** that could overcome resistance built up through tree improvement would **devastate European breeding programme efforts.**

© A. Dowkiw, INRAE

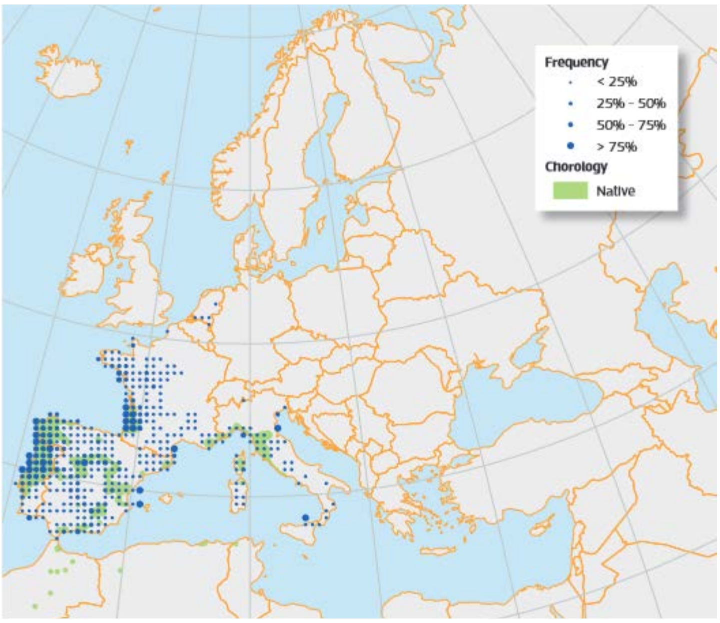
→ **None of the Ash breeding programs that have been set up in Europe against ADB has yielded any resistant variety yet.**

MARITIME PINE, *Pinus pinaster*

Context

Maritime pine is a fast-growing Mediterranean pine.

The ability of this forest tree to grow in a **wide range of environments** and to tolerate summer droughts and poor sandy soils, where few other species are of sylvicultural interest, has led to its use as a plantation species of **high socio-economic importance** in different countries.



Distribution map of Maritime pine in Europe. ©European Union, 2017

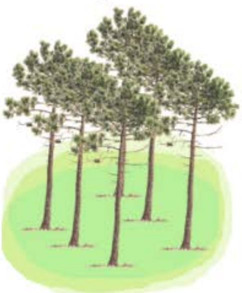
The "Landes de Gascogne" forest

Located in south-western France, this monoculture of 800 000 ha of local Maritime pine is one of the largest planted forests in Europe. The French Maritime pine breeding program is thus dedicated to this area since the 60s.

Breeding process

Crossings
Combination of favourable traits

Deployment population
(Improved FRM)



Breeding population

Testing
(progeny trial)

Seed orchard

Selection
of the best offsprings

Selection
of the best parents or the best offsprings

Breeding objectives

The aim of the Maritime pine selection is to improve wood production (quality and yield). It can be measured through the following criteria:

- **Height and circumference** at 8-10 years old
- **Stem, branching** and **wood quality** traits
- [**Presence of biotic attacks** (such as *Melampsora pinitorqua* stem rust or *Diorcyctria sylvestrella*) is systematically evaluated]

Deployment strategies and recommendations

As improved FRM are almost only used in the same area (Landes de Gascogne), only one breeding zone is considered and a unique breeding population is managed.

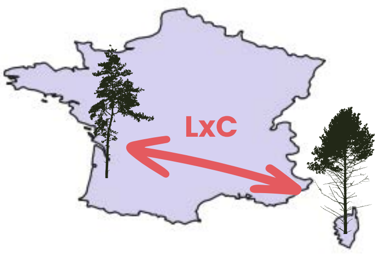
Landes seed orchards:

Vigor and Form series	Period of production	Genetic gain (compared to unimproved material)
VF1 (1st generation seed orchard)	1975 - 2000	**15%** for volume and stem straightness (realized)
VF2 (1,5 generation: tested plus trees)	1995 - 2020	**30%** (estimated)
VF3 (2,5 generation: tested 1st gen trees)	2010 -	**40%** (estimated)
VF4 (3rd generation: untested 2nd gen trees)	2025 - (expected)	/

Different series of **intraspecific hybrids Landes x Corsica** were also produced:

- **LC1** (1990 to 2000) and **LC2** (2010-2015) were produced by controlled crosses
- **HLC1** will be obtained in seed orchards with LxC hybrid material

On top of the improved Landes FRM good growth, those hybrids present a remarkable stem form thanks to the Corsican origin. Because of this high genetic quality but also because of its high cost of production and low yield, **the LxC is recommended for the more fertile sites only** to better exploit its high potential.



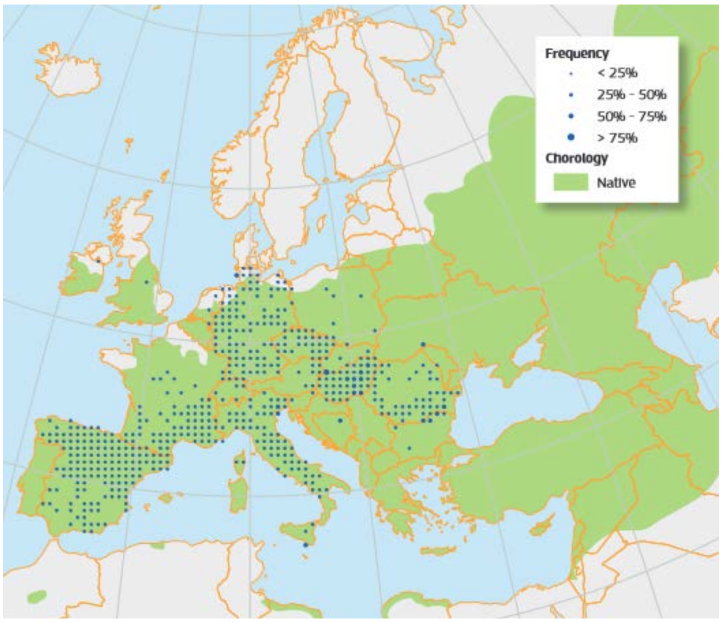
In Portugal and Spain, other breeding programs were started with the same productivity objective and based on local provenances (e.g. Portugal, Galicia), but natural regeneration preference and limited deployment of improved FRM led to a slow-down of these programs. However, new breeding goals such as **resistance to pine wilt disease** (Portugal, Galicia) and **resin production** (Spain) may bring new interest to improved FRM in those areas

POPLAR
Populus spp

Context

Specialized poplar cultivation has contributed for decades to the development of **important economic and productive sectors** such as those of paper, packaging, wood-based panels (i.e. plywood, veneer, fiberboard and particleboard) and furniture, by providing high-quality raw materials.

Poplar cultivation in EU amounts to **900 000 hectares** with France, Spain, Hungary and Italy being the most important countries for its production.

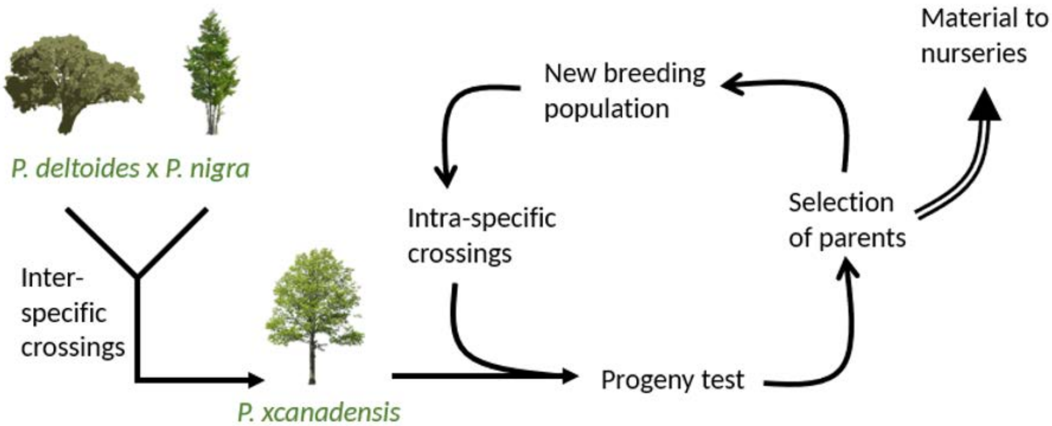


Distribution map of Populus nigra in Europe. ©European Union, 2017

Breeding program

Poplar breeding programs are in progress in different countries in Europe (France, Italy, Hungary, Belgium, Germany, Czech Republic, Serbia, Sweden) by both public research institutions and private companies, with the aim to develop improved FRM (poplar clones) **to be used in specialized plantations for various industrial and / or energy uses**.

An example of Poplar inter-specific hybrid crossing taking place at CRAE or INRAE:



Breeding objectives

Most of the traits of economic and productive importance are controlled by genes and so can be improved by breeding programs:

- **Growth rate, stem** and **crown shape**
- **Technological characteristics** of wood
- **Tolerance to biotic and abiotic stresses**

Other important selection criteria were recently adopted in new breeding program:

- **Photoperiodic adaptation**
- **Resistance to drought and salinity**

Deployment strategies and recommendations

The choice of which poplar to cultivate partly depends on the final destination of the raw material:

- Most hybrid clones were selected and tested for **production of veneers for plywood panels**: 'Aleramo', 'Diva', 'Moleto', 'Moncalvo', 'Tucano', 'Koster' and 'Vesten'
- Some clones can also be used for **biomass, energy and particle board production** when managed in short rotation coppice: 'Orion', 'Baldo', 'AF8', 'Skado' and 'SV490'

But the choice should mostly depend on the soil and climate characteristics of the growing site and any environmental restrictions. Those conditions are not covered here.

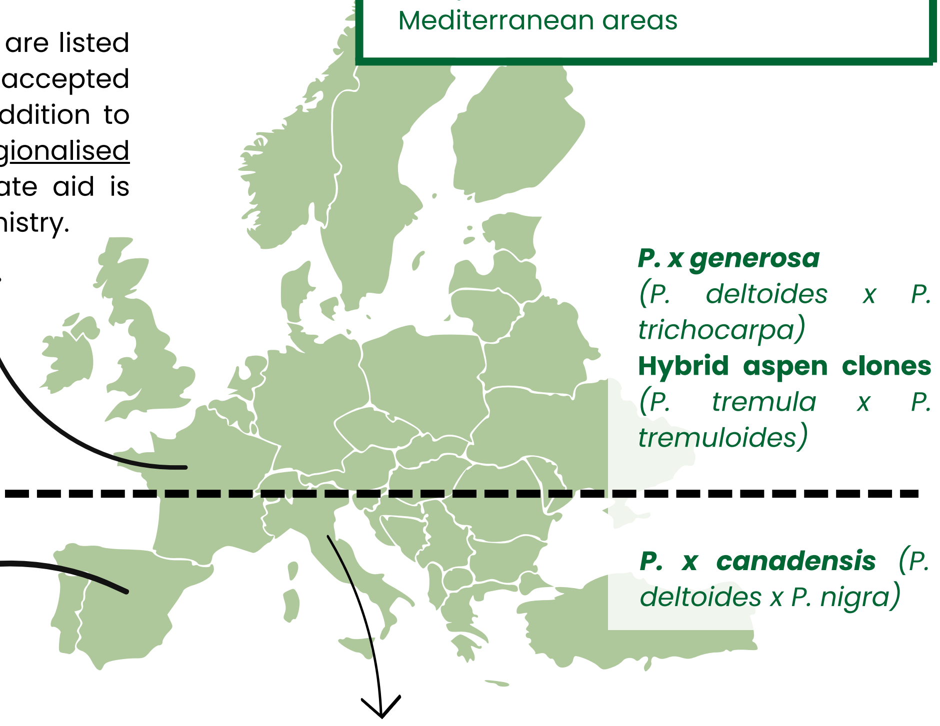
In Europe:

Clones can be chosen from among those included in the **National Registers of European countries**, with preference for those that can provide high-quality wood, resistance or tolerance to the main biotic and abiotic adversities and greater adaptability and resilience to climate change.

In France:

The country has a **strategy of diversification and risk mitigation**, which led to abondon the most productive clone.

The clones thar are suitable are listed in the National register and accepted in the tested category. In addition to the National Register, a regionalised list of clones eligible for state aid is published by the relevant Ministry.



In Spain:

There is a National Register and Catalogue of Basic Materials that includes those clones that have been systematically tested in the poplar cultivation area.

However, plantations can be made with any poplar included in the National Registers of other European Countries.

In Italy:

It is necessary to refer to the National Register of Basic Materials, tested category, and evaluation in multi-sites nurseries of the genetic materials developed in the breeding program.

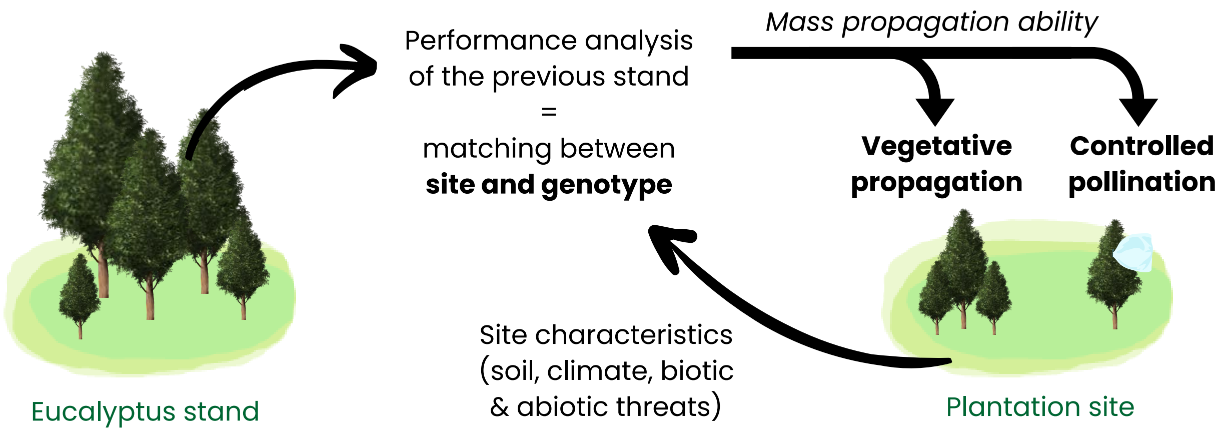
EUCALYPTUS, *Eucalyptus globulus*

Context

Eucalyptus is an essential source of raw material for a high-value-added industry. The existing legislation in **Portugal** prohibits planting new areas with this species, so it is crucial to **increase productivity and resilience** of existing eucalyptus plantations, breeding being a key to open this opportunity.

Plot distribution of Eucalyptus in Europe. ©European Union, 2016

Eucalyptus improved FRM are clones produced through **vegetative propagation** and **full-sib seedlings** produced through mass-controlled pollination. Then the process to achieve a successful deployment might imply the following steps:



Breeding objectives

Improved FRM present different strategies:

- **Generalist approach** (full-sib seedlings): good performance across a wider ecological space.
- **Specialist approach** (clones or full-sib seedlings): either competitors with high productivity or highly tolerant to abiotic factors. Use a narrow range of resources and conditions.

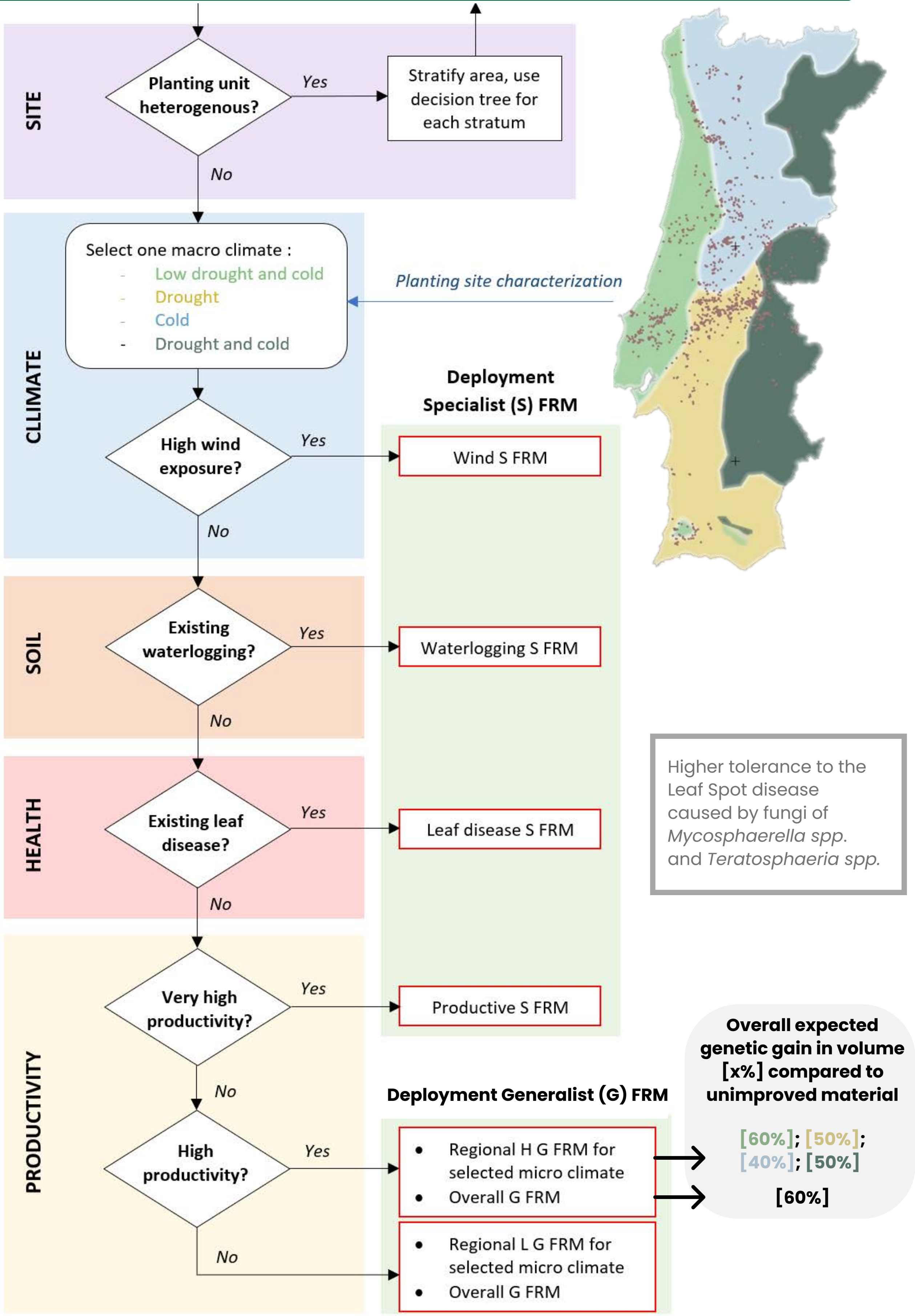
Deployment strategies and recommendations

Prediction analyses were conducted to characterize improved FRM:

- **Identifying** macro climate zones based on cold and drought exposure
- **Analyzing survival results** as the growth conditions are expected to be harsher
- **Considering the number of trials** in which the improved eucalyptus has been tested

Correct deployment is necessary to reduce the genotype-phenotype mismatch in planting environments and ultimately improve the efficiency, stability, and productivity of Eucalyptus.

Eucalyptus Deployment Decision Tree

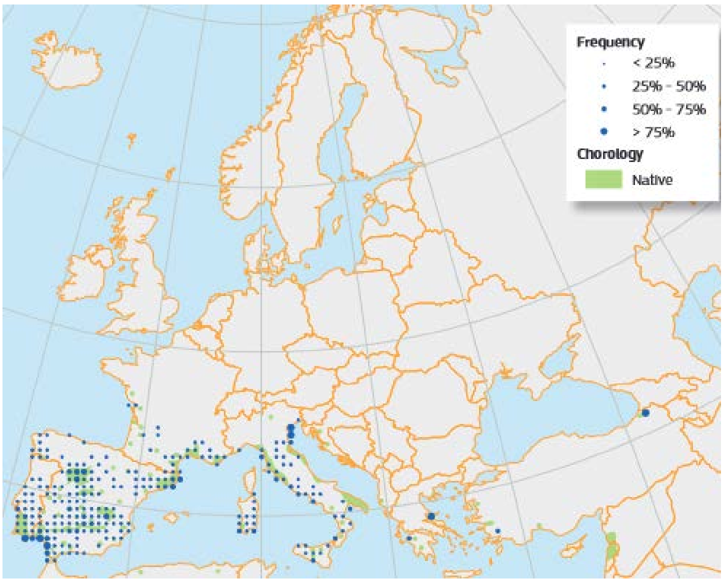


This decision tree was developed by the Altri company, specialised in Eucalyptus production

STONE PINE, *Pinus pinea*

Context

This species presence is restricted to poor sites with low productivity. A population bottleneck during the Last Ice Age might explain why it has been found such **genetically extremely depauperate.** The Mediterranean Stone pine is appreciated for its **edible seed kernels** that are esteemed for their fragrant taste and excellent nutritive values. On the other hand, timber production of Stone pine cannot compete with other more profitable trees species.



Plot distribution of Stone pine in Europe. ©European Union, 2016

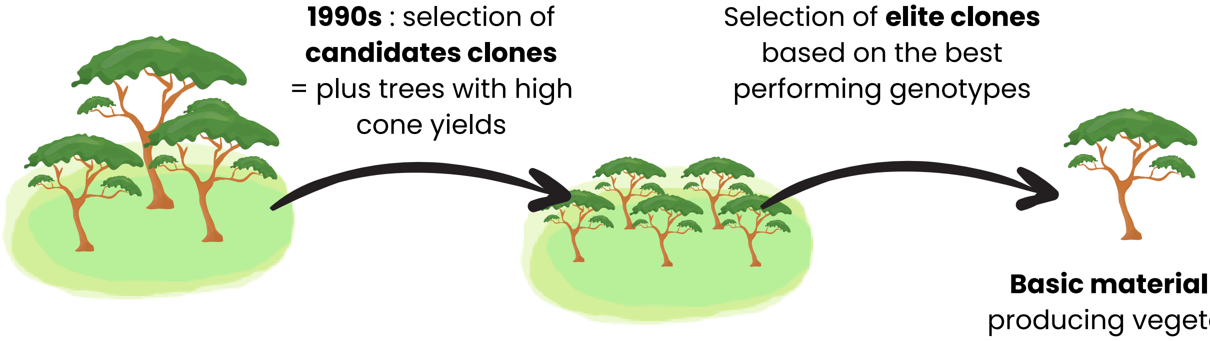
A late interest in selection

Employed forest reproductive materials (seeds or seedlings) have been **so far mostly unselected**, or even of unknown origin. Only in the last decades, private plantation management has increasingly evolved into agronomic cultivation, and this has raised **interest in grafting selected plant material** for enhanced cone production.

<u>Ongoing efforts in genetic improvement in Spain and Portugal:</u>

1990s : selection of **candidates clones** = plus trees with high cone yields

Selection of **elite clones** based on the best performing genotypes



Pine forests of Spain and Portugal

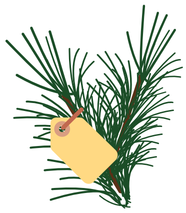
Scions collected and grafted in common garden trials

Basic material for producing vegetative FRM, viz. scions for grafted plantation

Breeding objectives

- Improved **commercial cone** and **seed production** [+ 10-30% in registered clones up to now]
- **Adequate vigour and general performance**
- Resistance to **drought** and main **biotic agents**
- Stone pine is still a relevant **option for afforestation**, ecosystem restoration and reclamation on degraded and eroded soils (selected seed stand have been registered in most growth region for this purpose, clearly differed from highly productive elite clones aimed for agroforestry on better soils)

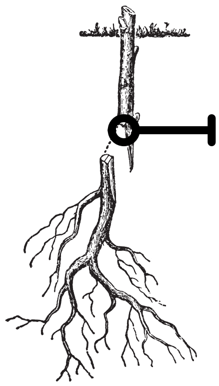
Deployment strategies and recommendations



The clones currently available only comes from the first grafted gardens

- Whose seed production was **above the average** at all sites where they had been tested
- Established **only in Mediterranean climate zones**, lacking in consequence experiences and data for potential cone production in other agroclimatic zones.

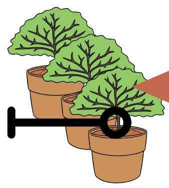
The pine clones registered as basic materials for graft scions provide opportunity to establish orchard plantations with **cone production after only a few years**, bypassing twenty years of the juvenile phase whitout cone formation in non-grafted pine trees. This is why sexual breeding has only been considered a secondary reproduction strategy in this species.



2 options for FRM establishment

In situ grafting on local rootstock for experienced Stone pine grower

Container-raised treelets grafted in nurseries, a commercial alternative and ready to go solution for newcomers or for establishing orchards in less favourable climate conditions



In Spain, commercial tree nurseries are still struggling to upscale the supply chain for grafted pine treelets to operability. It is the main issue for the deployment of the registered clones.

When establishing a grafted plantation:

- **Avoid monoclonal orchards** by using the maximum available number of different clones, thus increasing the resilience of the mixed stand.
  By labelling the genetic identity of each tree, the pine grower will be able to **compare their local performance and production**

Plantation management:

- Plantation density must be controlled to **avoid canopy closure** (Stone pine are very sensitive to lateral shade and good cone induction requires open-grown crown in full sunlight)
- The INCREDIBLE project produced a dozens of factsheets on Stone pine dealing about sanitary issues, innovative management techniques, tree vitality assessment, orchards material or management challenges.

Landscape integration:

- Combine profitable pine nut and biomass co-production with possible **other non-wood supplies** like with cork from *Quercus suber*, or pastures and pannage from Mediterranean oak species. It increases resilience against wildfire by understory discontinuity.

1000 kg/ha

It is the **mean annual cone yields** reached by the clonal field trails 10 years after grafting in favorable soils. This figure can help assess the profitability as there is not enough long-time research on well-managed plantations.

MAIN FEATURES OF EUROPEAN FOREST TREE BREEDING PROGRAMS

Species	Country	Starting year	Nº of improved generation	Cumulated trial area (ha)	Av. trial area established per year (ha)
Scots pine	Finland	1947	3	2250	3
	Sweden	1940-1950	3	900	10-12
	Norway	1947, restarted 2020	0	0	5
Norway spruce	Finland	1947	2	420	8
	Sweden	1939	2	1000	20
	Norway	1947	2	225	8-10
Douglas fir	France	1985	2	200	3-5
Maritime pine	France	1960	3	400-600	6-10
	Spain	1990	1	100	3
Poplar	Italy	1980	2	280-330	8-10
Eucalyptus	Portugal	1964	3	250	2
Stone pine	Spain	1989	1	20	0

CURRENT FRM DEPLOYMENT IN SOME EUROPEAN COUNTRIES

Species	Country	Type of FRM	Material sold per year	% of FRM in new planted area per year
Scots pine	Finland	Seedlings and seed	41M seedlings (+ 20 000 ha regenerated by direct seeding)	96 %
	Sweden	Seedlings	236M seedlings	98 %
	Norway	Seedlings	2M seedlings	99 %
Norway spruce	Finland	Seedlings	75M seedlings	70 %
	Sweden	Seedlings	140M seedlings	70 %
	Norway	Seedlings	40M seedlings	95 %
Douglas fir	France	Seedlings and seed	> 12M seedlings	99 %
Maritime pine	France	Seedlings	37M seedlings	> 95 %
	Spain	Seedlings	0.5M seedlings	< 5 %
Poplar	Italy and France	Clones	140K - 180K clones	10- 15 % [Italy] 40 - 50 % [France]
Eucalyptus	Portugal	Clones and seedlings	2.7M seedlings and 1.5M clones	62 %
Stone pine	Spain	Clones	< 1K clones	< 1% (still starting)
	Portugal	Clones	> 10K clones	< 5%

CONCLUSION

The deployment guidelines presented above for the eight selected species are showing **uneven maturity** according to the amount of data available, level of cross-country collaboration and integration of climate data. Some guidelines provide basic recommendation about the site characteristics adapted to a genetic resource when others are online tools using advanced model to analyse trade-offs and include climate change scenario comparisons.

The present deployment guidelines and decision support tools are based mainly on commercial interests, survival and wood production. Thus, there is a need to broaden this perspective and include other aspects that have become of importance, especially genetic diversity as well as other environmental aspects to support adaptation and mitigation measures to climate change. This also means that the use of FRM across borders or regions to support adaptation to climate change (e.g, through assisted migration) should be promoted and administrative barriers hindering this should be removed.

Moreover, it must be noted that these guidelines are not a full substitute to precise field and microclimate assessments or recommendations from local forest managers and nurseries, prior to any reforestation project. Somes species **require specific planting conditions** that were not presented in this document, i.e. site heterogeneity, soil depth and type, water level but also plantation design and spacing.

Advanced deployment guidelines help to avoid and/or reduce risks when establishing forest stands with improved FRM as they recommend well adapted material. However, also other aspects such as species diversity at a landscape level and genetic diversity within species need to be taken into consideration when choosing suitable FRM.

In the end, these deployment guidelines do not only emphasize the role of breeding programmes and their targeted traits to **improve the adaptation of our reforestation materials**, but they also mention **a large range of options** when it comes to silvicultural activities and the use of all kinds of forest reproductive materials. More resilience and forest stand adaptation can be reached through the valuation of intraspecific variation, the plantation of polyclonal stands instead of using one unique clone, under-storey or gap plantations, multiclonal, polycyclism, mosaics or the diversification of species whether through mixed plantations or stand enrichment.

ACKNOWLEDGMENT

This manual is derived from a deliverable of the B4EST project called "***Guidelines for deployment and silvicultural management of improved FRM accounting for climate projections, risks of natural disturbances and end-user requirements and acceptance***". Many more details on the topic and scientific references used can be found in this document here.

A special thank to all partners involved in the work :

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B4EST is an EU-funded H2020 project which focuses on adaptive breeding for productive, sustainable and resilient forests under climate change.

Climate change can increase forest vulnerability to damage and disease, reduce forest health and productivity, and cause economic losses. B4EST's goal is to increase forest survival, health, resilience and productivity under these circumstances, while maintaining genetic diversity and key ecological functions, and fostering a competitive EU bio-based economy. B4EST aims to provide forest tree breeders, forest owners, managers and policy makers with better scientific knowledge to deal with these issues.

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