

TAKING
COOPERATION
FORWARD

 Central Europe

 **SUSTREE D.C.3.2 : Training Material for Schools and Universities**

 **SUSTREE (2016-2019)**

PART 1

SUSTREE PROJECT



PROVENANCE RESEARCH OF FOREST TREE SPECIES

SUSTREE is a transnational project promoting climate change adaptation and genetic diversity of forest ecosystems in Central Europe.



Participants of the SUSTREE project



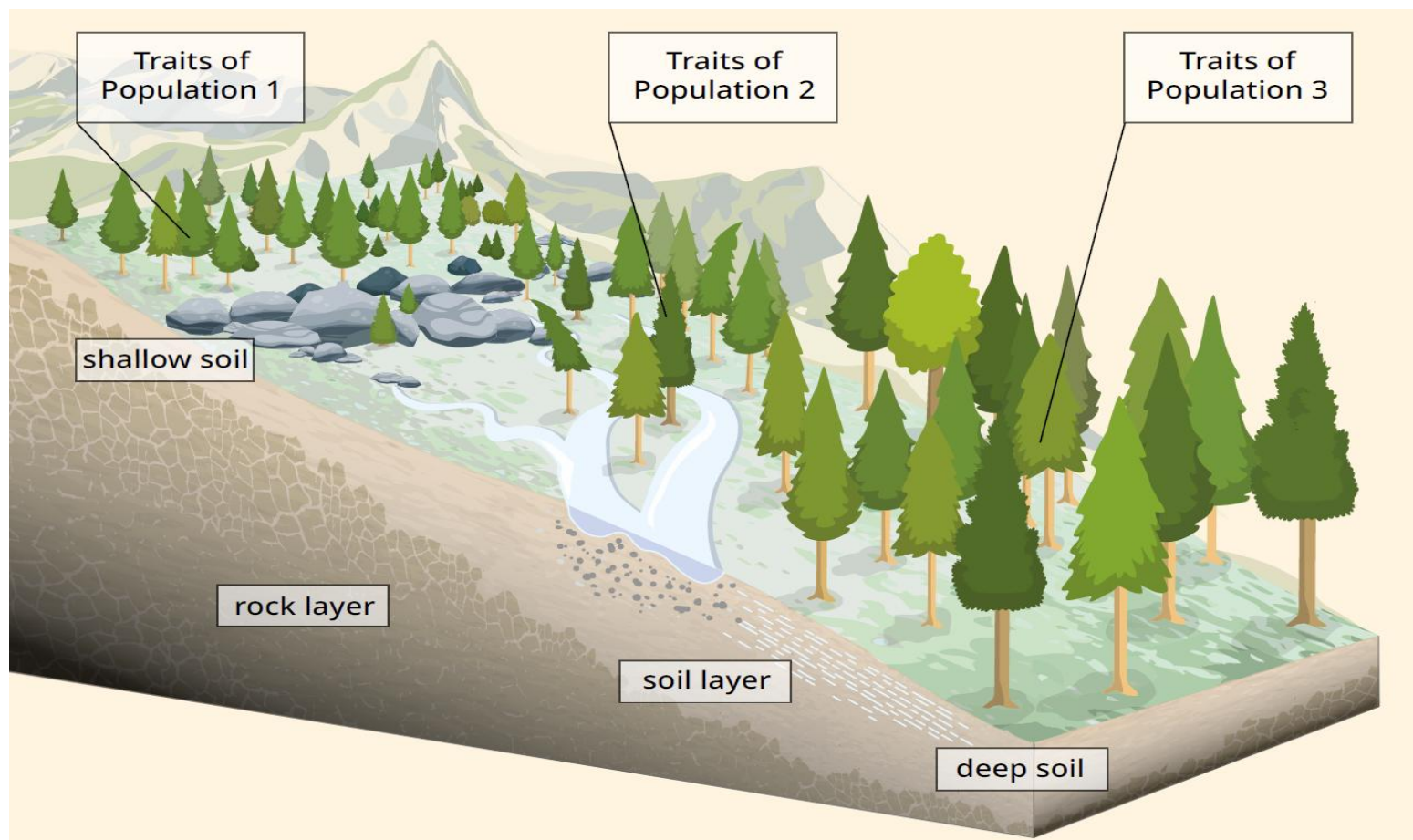
PROVENANCE RESEARCH OF FOREST TREE SPECIES

Key messages of SUSTREE :

- Forest trees exhibit manifold local adaptations to the climate of their habitat guaranteeing optimal growth and survival under stable environmental conditions.
- Climate change disrupts the link between climate and local adaptations thereby challenging the “local is best” paradigm.
- Regions of Provenance, defined within European and National legislations, differ among countries and do not reflect climate conditions nor support adaptive management in climate change.
- Legislations governing reforestation and seed transfer should be based on range-wide local adaptation of trees to assist management of genetic resources under climate change.



PROVENANCE RESEARCH OF FOREST TREE SPECIES



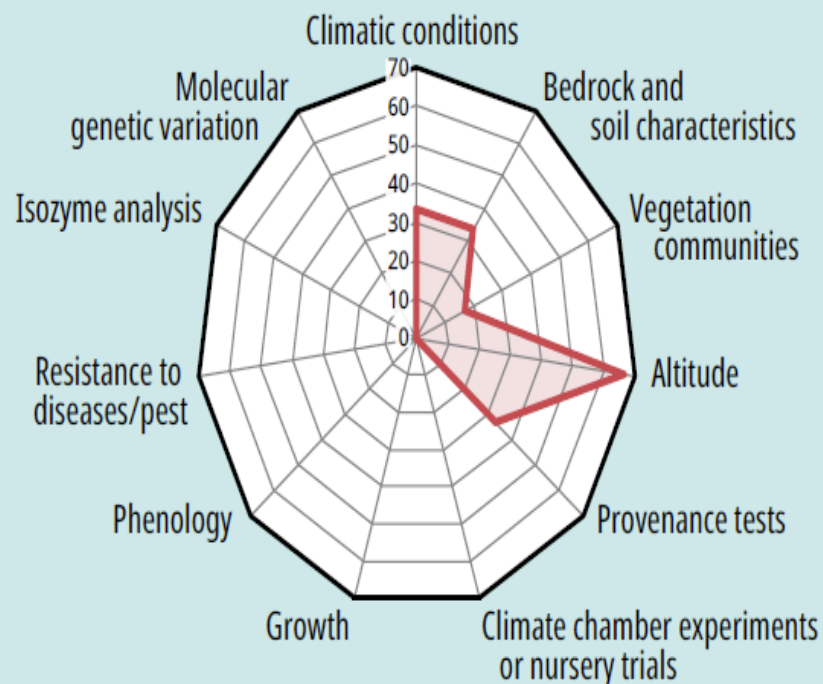
Conifer population variability caused by altitude gradient and soil



SEED TRASFER AND EUROPEAN LEGISLATION

Criteria for defining Regions of Provenance

Basis for defining provenance delineation

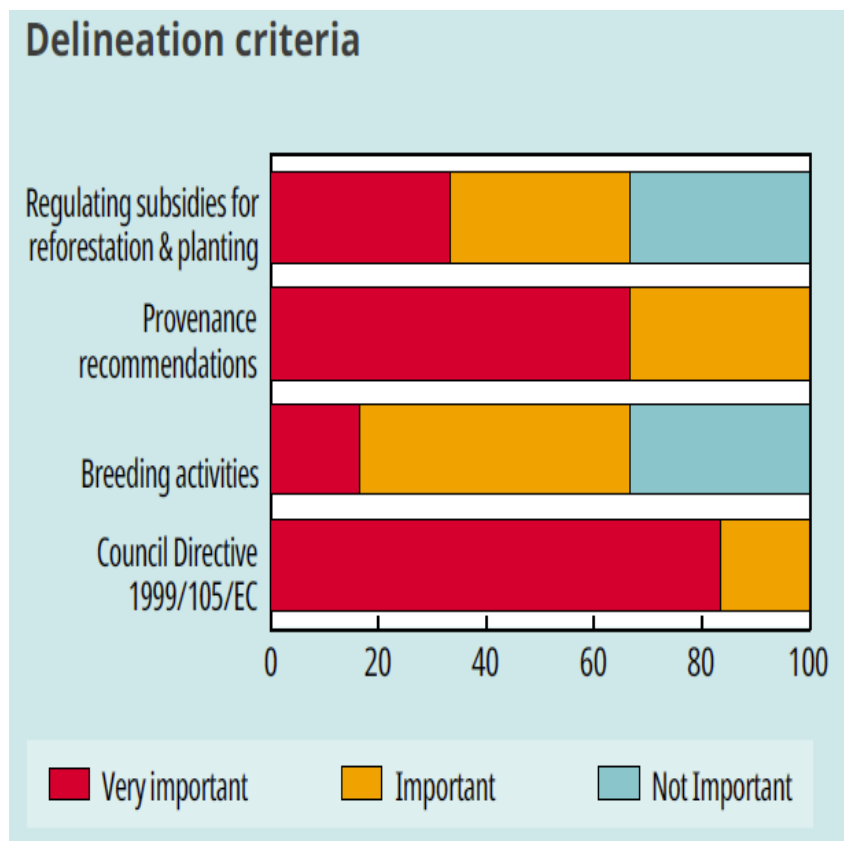


Regions of Provenance and the criteria on which they are based, for instance ecological units, vegetation zones or genetic similarities, vary between countries.



SEED TRASFER AND EUROPEAN LEGISLATION

Functions of the Regions of Provenances



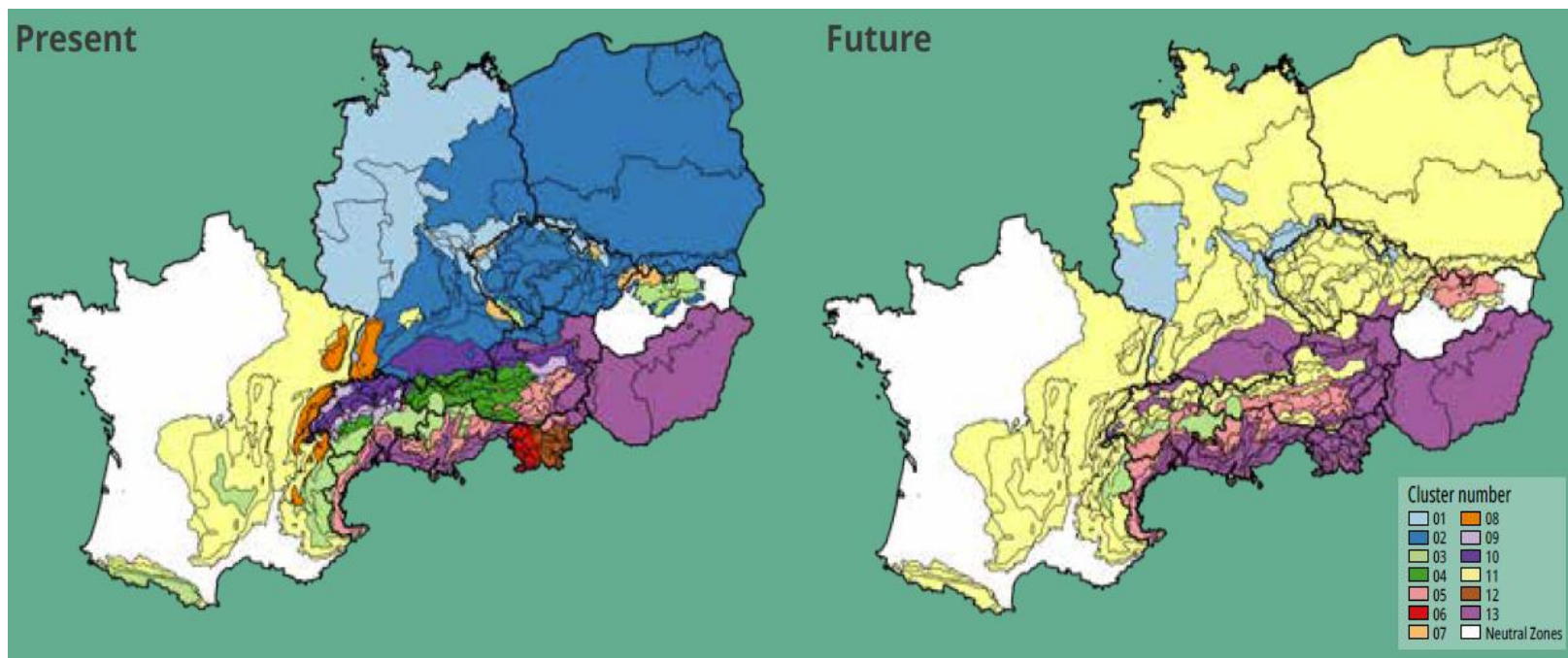
National regulations might indirectly hinder adaptive management under climate change by restricting transfer of FRM between Regions of Provenance and between countries.

For example, the transfer of forest seeds and seedlings across borders to Poland, Slovakia and Czech Republic is constrained.



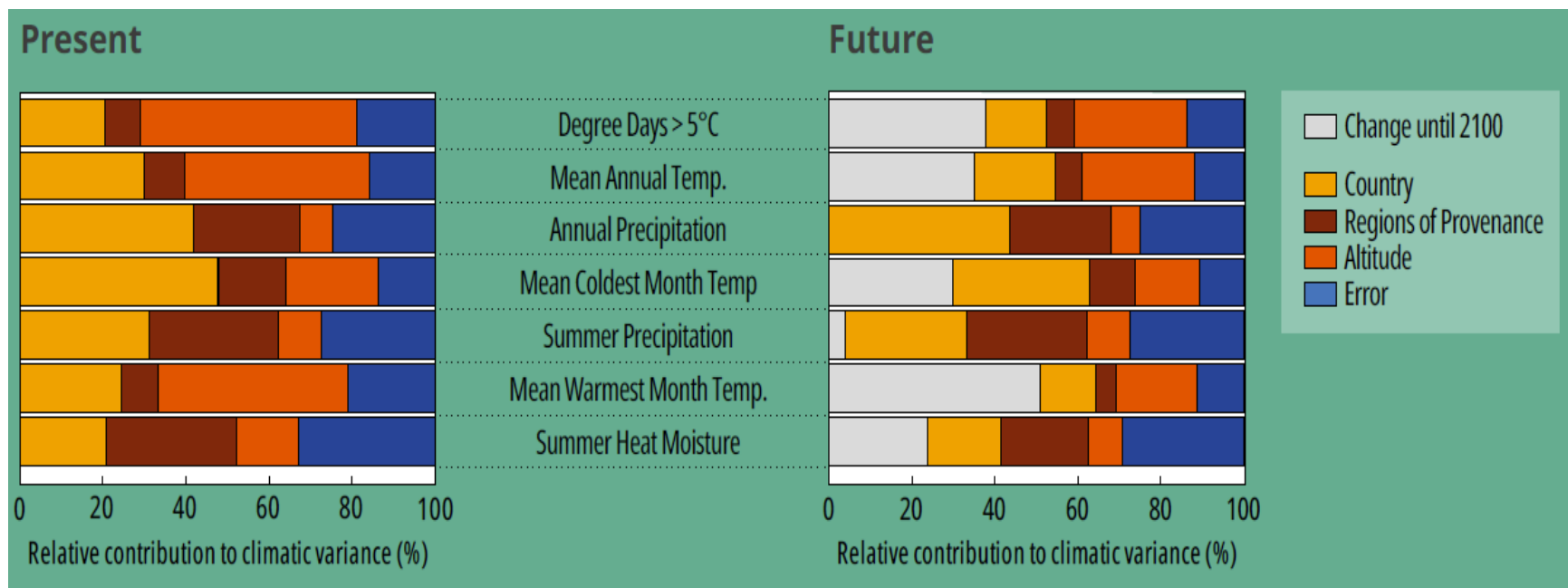
REGIONS OF PROVENIENCE IN CLIMATE CHANGE

*Climatic similarity among Regions of Provenance for Norway spruce (*Picea abies*) under present climate (left) and the expected shift and expansion of south-western and pannonic climate regimes throughout the Regions of Provenance.*



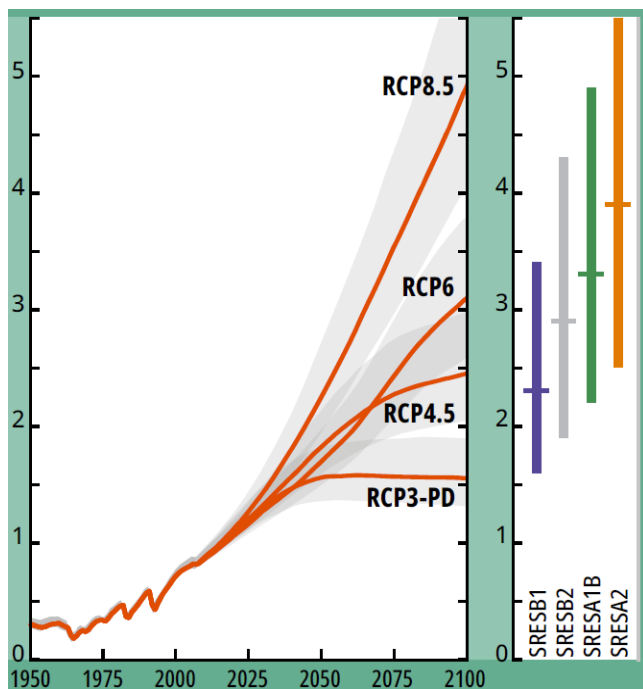
REGIONS OF PROVENIENCE IN CLIMATE CHANGE

How well do Regions of Provenance, Country borders and Altitude reflect the variation of climate parameters to which tree populations are locally adapted?



REGIONS OF PROVENIENCE IN CLIMATE CHANGE

Observed and simulated global average temperatures near the surface for the period 1950-2100, shown as deviations from the mean temperature of 1980- 1999, for four representative concentration pathways (RCPs). Source: Rogelj et al. (2012)

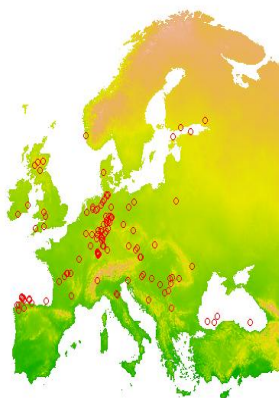


Considering expected changes of climate in the future, demonstrates that neither Regions of Provenance nor country borders can explain the temperature variation in European forests. Thus, the role of national borders and Regions of Provenance to guide seed transfer should be strongly scrutinized.

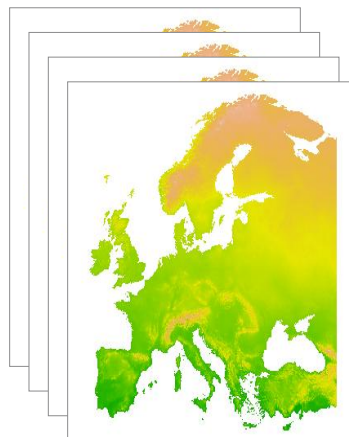


MODEL DEVELOPMENT

Provenance trial data



Environment data



Data matrix (Prov trial+Environment data)

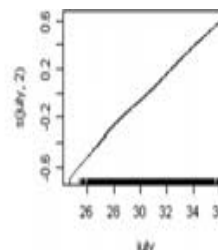
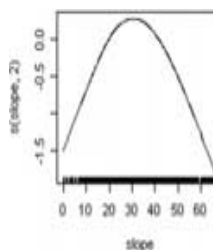
x	y	Env1	Env2	Env3	Douglas-fir
25.4499998	71.1500011	1.50	4.25	21.90	1
25.5499998	71.1500011	1.27	4.46	22.40	1
25.6499998	71.1500011	1.42	3.46	20.06	1
25.7499998	71.1500011	1.46	3.94	21.57	1
25.8499998	71.1500011	1.79	3.28	18.67	0
27.6499998	71.1500011	0.47	3.86	20.17	0
27.7499998	71.1500011	1.25	3.90	21.52	0



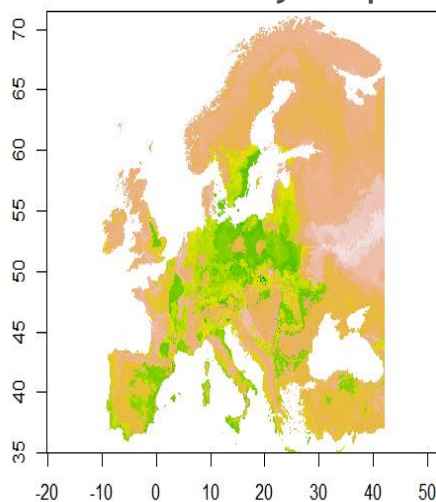
Statistical model fitting

$$\text{Productivity} = f(\text{Env}_1 + \text{Env}_2 + \text{Env}_3 \dots \text{Env}_n)$$

Model evaluation and tuning



Productivity maps



UNIVERSAL RESPONSE FUNCTION

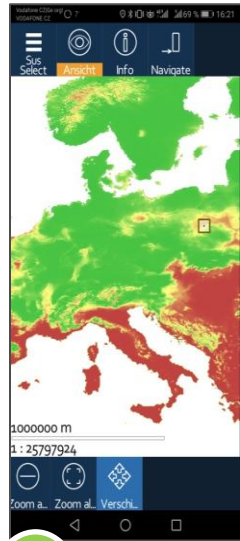
$$\text{Productivity} = f(\text{Env}_1 + \text{Env}_2 + \text{Env}_3 \dots \text{Env}_n)$$

With Quadratic Function

With random Forest

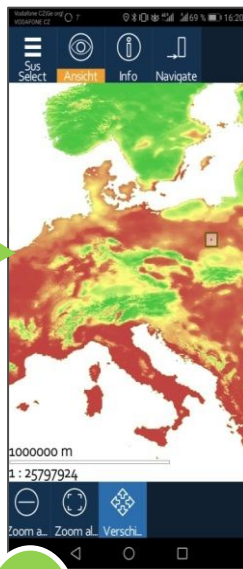


SMARTPHONE APP: SUSSELECT



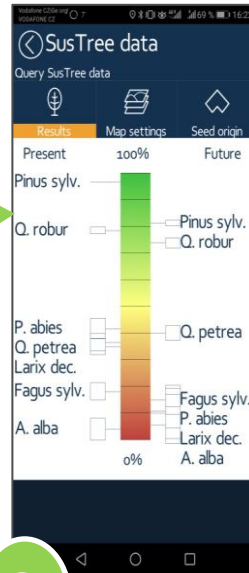
1

Map the vulnerability of tree species under current climate



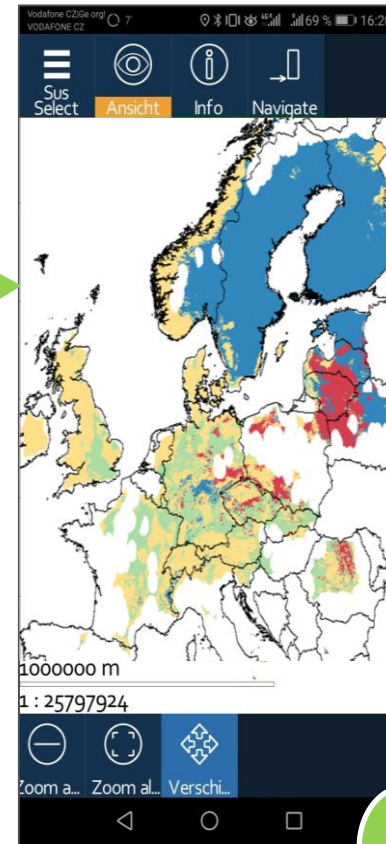
2

.....under future climate



3

Compare species vulnerability



4

Find the best planting material

SusSelect mapping application of the SUSTREE Interreg displays the current and future vulnerability of 7 European tree species, and suggests locations for seedling selection



PART 2

PROVENANCE RESEARCH OF FOREST TREE SPECIES



PROVENANCE RESEARCH OF FOREST TREE SPECIES

Provenance = origin

Definition: Provenance is a population or a group of individuals of the same species occurring within or originating from one more or less rigorously defined geographic area.

Provenance experiments (common garden tests) contain genetic entries (provenances) whose seeds were collected in geographically different localities (origins). These entries should represent a much larger area than an individual stand.



Contrasting diameter growth performance of provenance of Douglas-fir originating from WA (Washington and Interior British Columbia (BC) in North America when planted in common environment in East of Austria
(Photo: Lambert Weißenbacher, BFW)



HISTORY OF PROVENANCE RESEARCH

The main reason for establishment of provenance trials was bad experience with quality, wood production, and health state of forest stands, which had grown from foreign seed sources.

The trees whose seeds originated from other areas varied widely and reacted to new growth conditions.



PROVENANCE RESEARCH OBJECTIVES

The objective is to evaluate how the same provenance grows in different site conditions.

Gaining information on the geographic variability of a species in wood production, quality as well as sensitivity to environmental factors as a basis of subsequent selection of the best provenances for reforestation needs (or for introduction of the species tested).

- Delimitation of possible seed transfer (direction distance and limitations).
- Gaining material for further breeding.
- Predicting species/provenance distribution for future climate.

In other words: Provenance research gives information on:

- Characteristics of individual population (ecotypes) studied.
- Their wood production potential.
- Their adaptation potential.
- Phenotypic plasticity/ stability



FACTORS INFLUENCING GEOGRAPHIC VARIABILITY:

AREA OF NATURAL DISTRIBUTION

Species with large areas (e.g. *Pinus sylvestris*, *Picea mariana*) have generally higher proportion of genetic diversity than those with smaller areas (e.g. *Pinus radiata*, *Picea omorika*).

→ Influences global climatic and ecological differences (especially due to continental vs oceanic climate) → gradual change of characters in accordance with the geographical gradient called a “cline”.



GEOGRAPHIC DISTRIBUTION



Picea mariana



Picea omorika



GEOGRAPHIC DISTRIBUTION



Pinus sylvestris



Pinus uncinata

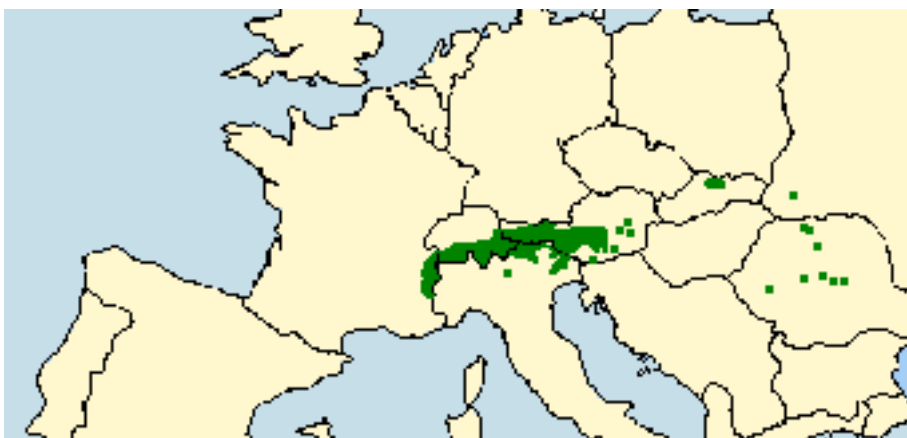


DIVERSITY OF THE ENVIRONMENT

Occurrence of mountains, altitudinal range - influences local climatic differences and soil type.

CHARACTER OF THE AREA OF NATURAL DISTRIBUTION (continuous vs discontinuous)

Discontinuous areas consist of several small parts; within them no gene flow can take place (e.g. *Pinus cembra* or *Larix decidua*).



Pinus cembra



GENERAL TRENDS OF THE GEOGRAPHIC VARIABILITY

- **Trend north - south** is the strongest trend of the clinal variability.

It is a consequence of the latitudinal differences (variable growing season, lower average and extreme temperatures in the north, differences in photoperiod, ...)

- **Trend dry - humid areas**

Comparison of provenances originating from areas with different moisture regimes.

- **Altitudinal trend** - Altitudinal difference of 1000 m represents a climatic change corresponding to 10° of latitudinal difference (about 10°C in average temperature). This is called dry adiabatic lapse rate
- This dry adiabatic gradient is influenced by air humidity, convection and heat radiation from the ground resulting in a actual lapse rate of 0.5- 0.65 °C per 100 m.



DESIGN OF PROVENANCE TRIALS

- A provenance experiment of the first step (test, trial) should cover the whole area of natural distribution of a species.
- In order to control the north-south as well as the east-west trends, about **10 - 15 provenances** should suit the purpose.
- When taking into account deviations from these trends, the number of provenances needed increases to 20 - 30 within species with small areas and to 50 - 100 within species with large areas of natural distribution.
- The largest provenance test in the former Czechoslovakia (between 1964 and 1968) comprised of 1100 Norway spruce provenances).



DESIGN OF PROVENANCE TRIALS

➤ NUMBER OF PROVENANCES INCLUDED IN A TEST

is a function of the natural area of distribution of a species (the larger the area, the more provenances needed) as well as of its variability within this area.

➤ NUMBER OF PROVENANCE TRIALS

is a function of heterogeneity of the target area (the Czech Republic is quite heterogeneous, thus more comparison trials must be established).



DESIGN OF PROVENANCE TRIALS

➤ NUMBER OF REPETITIONS (BLOCKS) WITHIN A TRIAL

is a function of the site heterogeneity within the trial.

Most often 3 or 4 blocks (i.e. all the provenances repeat 3 - 4 times, thanks to which genetic and environmental variability can be distinguished).

➤ NUMBER OF TREES WITHIN A PLOT

depends on duration of the experiment as well as on the tree species tested.

Most often 25 - 36 individuals, spacing differs depending on the space available and individual requirements of the species (e.g. 2 x 2 m).



DESIGN OF PROVENANCE TRIALS

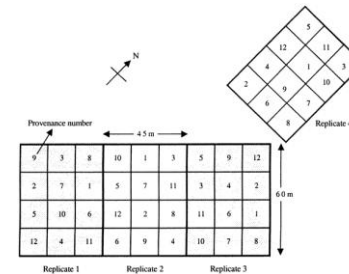
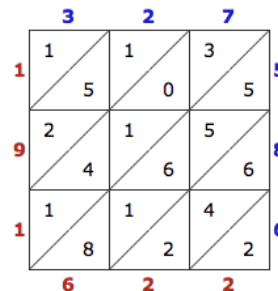
ESTABLISHMENT OF PROVENANCE TRIALS - methods of layout of provenances

BLOCK METHOD

- Each block comprises all the provenances tested, the layout of which is random.
- The number of blocks is optional, should not drop below 3 (commonly 4).
- A progressive method; appropriate for subsequent statistical analysis.

LATTICE METHOD

SINGLE - TREE PLOTS



DESIGN OF PROVENANCE TRIALS

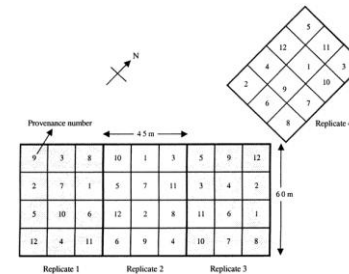
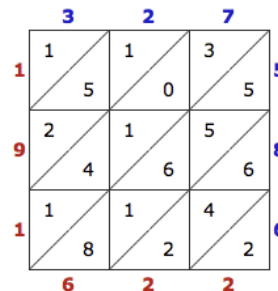
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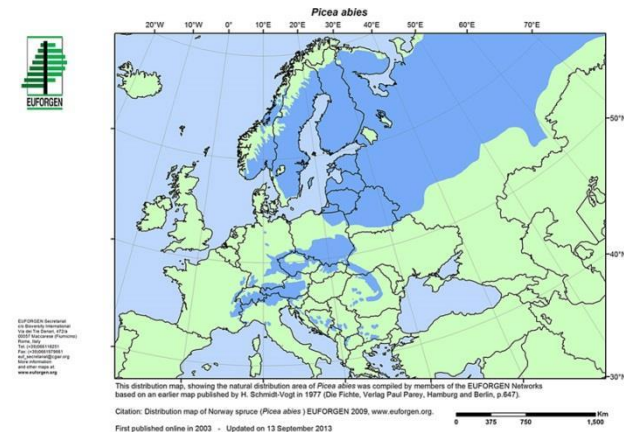
LATTICE METHOD

SINGLE - TREE PLOTS



NORWAY SPRUCE POPULATIONS IN EUROPE

- Main region Alpine - South European
regions: South European, South Alpine, North Alpine
- Main region Hercynian - Carpathian
regions: Hercynian, West Carpathian (Sudetic),
East Carpathian
- Main region Nordic - Baltic
regions: North Polish, East Baltic, Central Scandinavian,
North Scandinavian





Species Location





Trees representing three European populations of Scots pine growing on the IUFRO 1982 trial in central Poland





Differences in branching



PROVENANCE RESEARCH OF FOREST TREE SPECIES



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PROVENANCE RESEARCH OF FOREST TREE SPECIES



PROVENANCE RESEARCH OF FOREST TREE SPECIES



PART 3

Conservation alternatives



CONSERVATION ALTERNATIVES

- preservation of actual (ecosystem, species, genetic) diversity
- conservation of evolutionary potential of species
- maintain options for future generations, while satisfying present needs



direct impacts

- decrease effective population. size
- increase spatial isolation
- decrease population densities
- local environment changes

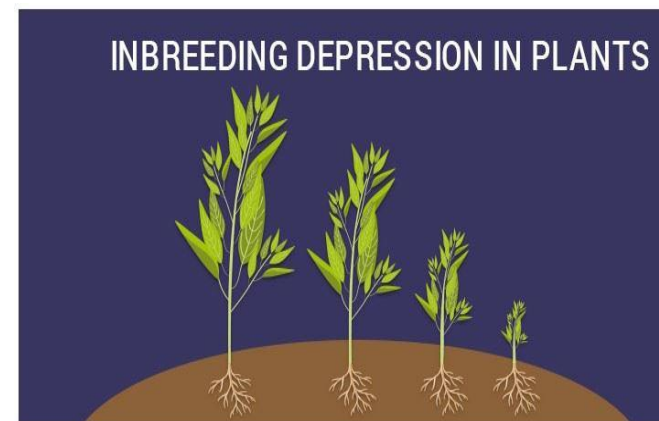
genetic processes

- genetic drift
- gene flow
- mating - inbreeding
- selection



INBREEDING DEPRESSION IN ACACIA MANGIUM

Seed source	Seedling height (cm)
1st generation	32.5
2nd generation	20.7
3rd generation	18.1



Source:
Byjus.com



HOW BIG IS “BIG ENOUGH”?

- **50/500** rule (Franklin 1980)
- **50** - inbreeding depression to acceptable level
- **500** - sufficient for new variation from mutation to replace that lost by genetic drift
- Numbers refers to effective population size (N_e) rather than survey numbers (N) - so may need many more!
- In trees N_e smaller than N due to: overlapping generations, dioecy, asynchronous flowering, fecundity differences between individuals



WHERE SHOULD WE CONSERVE?

In situ - Ex situ

In situ - reserve system of undisturbed, protected areas within natural distribution (*ecosystem based*)

Ex situ - artificial maintenance of populations outside natural distribution (*species based*)



CONSERVATION OF BIODIVERSITY *IN SITU* : TREES AS A PARADIGM

Ideal reserve model

Emphasis: large, continuous, protected areas

Limitations: location, size, distance, security, biology

- Movement of animals
- Extensive distribution of many species
- Gene flow between populations
- Upland, non agricultural areas
- Diverse habitat

Essential but not sufficient



CONSERVATION OF BIODIVERSITY

EX SITU : METHODS AND LIMITATIONS

seed banks - *problems of regeneration*

plantations - *changes in gene frequencies, few populations*

botanical gardens - *deficiencies for gene pool conservation*



CONSERVATION OF BIODIVERSITY

EX SITU: METHODS AND LIMITATIONS

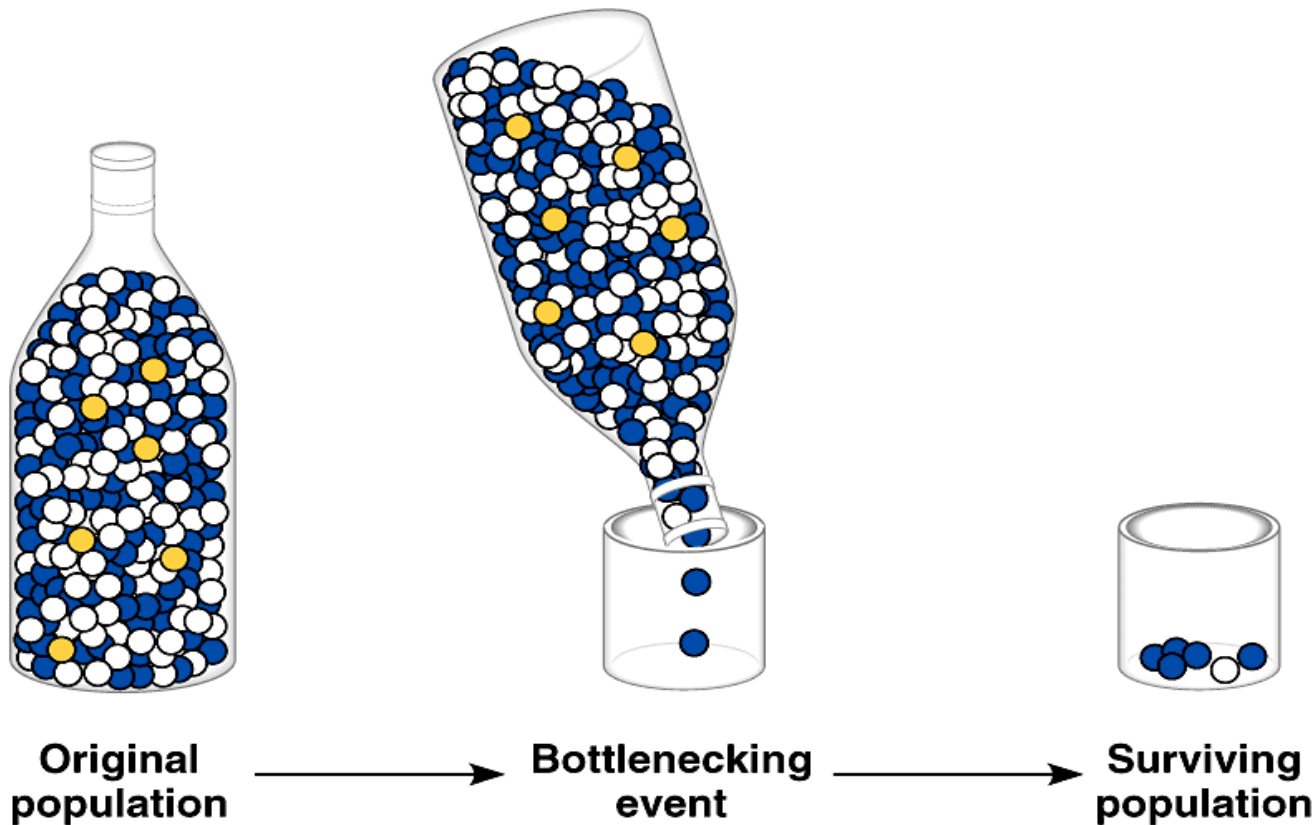
- useful, but resources limit application to few species (usually commercial)
- last gasp holding for highly endangered species
- complimentary to other approaches



CONSERVATION OF BIODIVERSITY

EX SITU: METHODS AND LIMITATIONS

Bottleneck → genetic drift

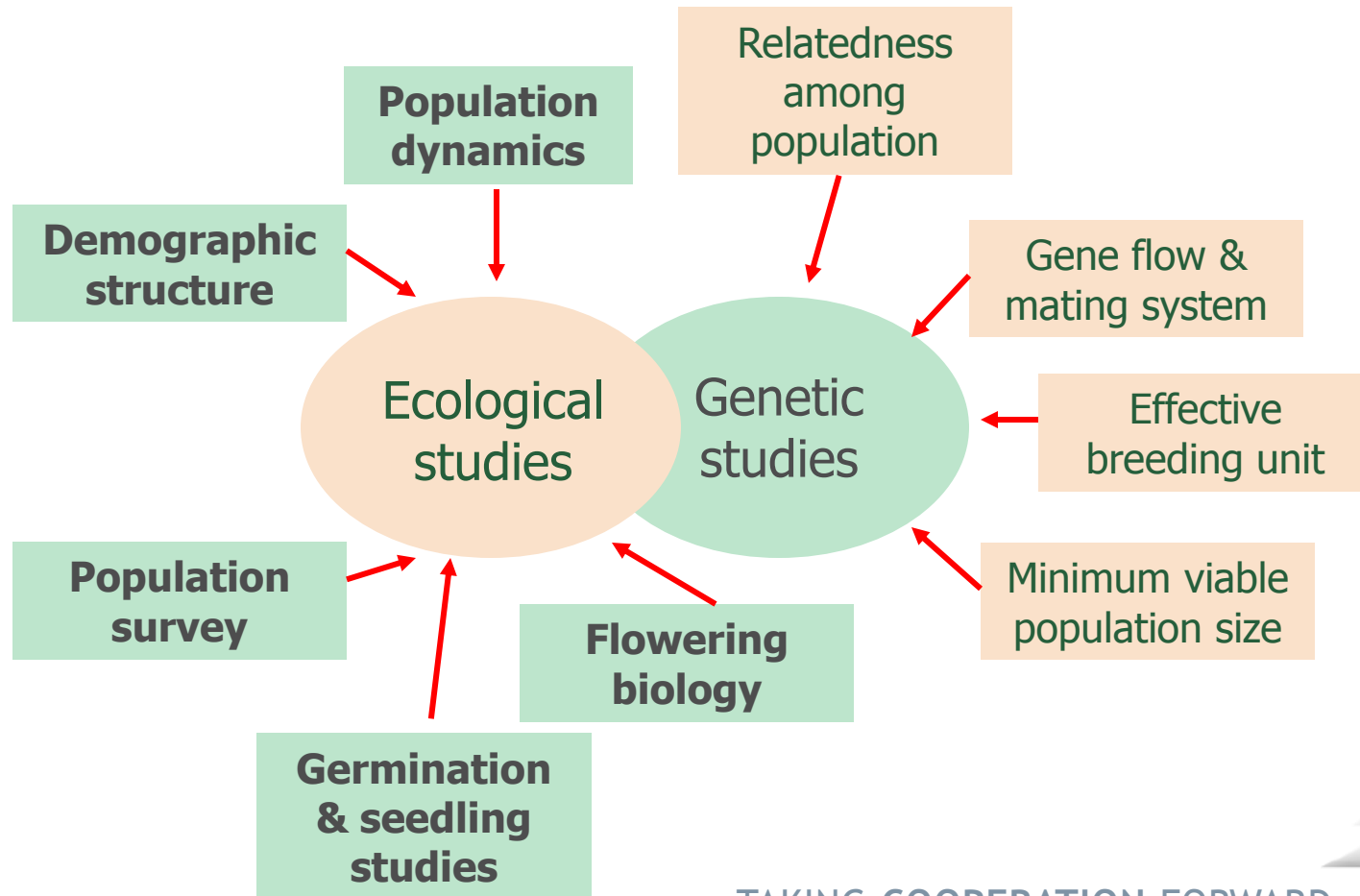


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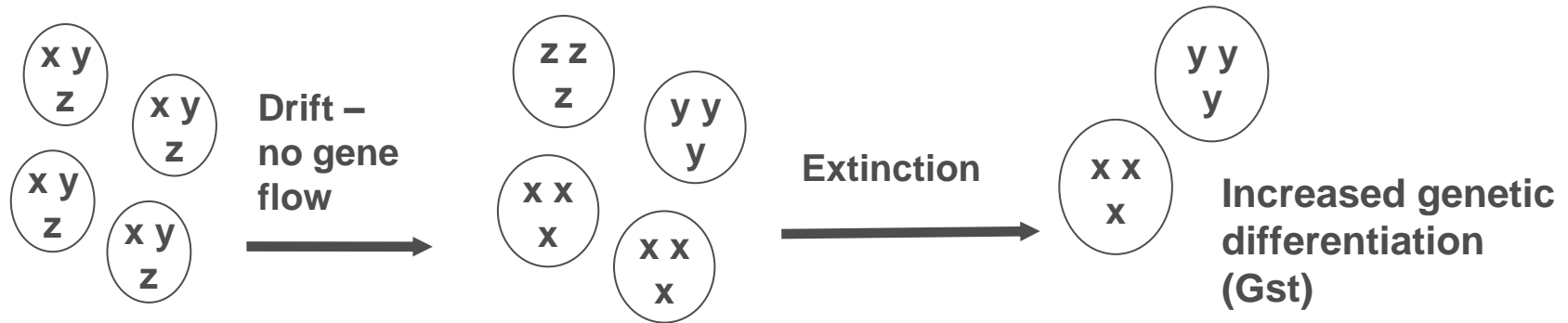
CONSERVATION OF BIODIVERSITY

➤ It is important to note that ecological and genetic studies are complementary and not either/or.

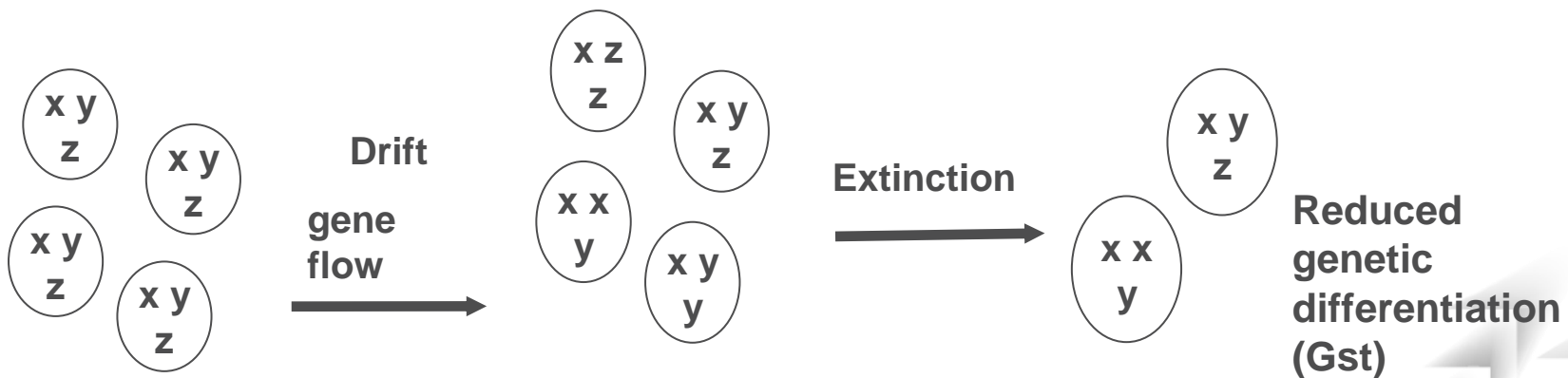


CONSERVATION OF BIODIVERSITY: GENETIC PROCESSES

A: Drift and extinction: loss of genetic diversity

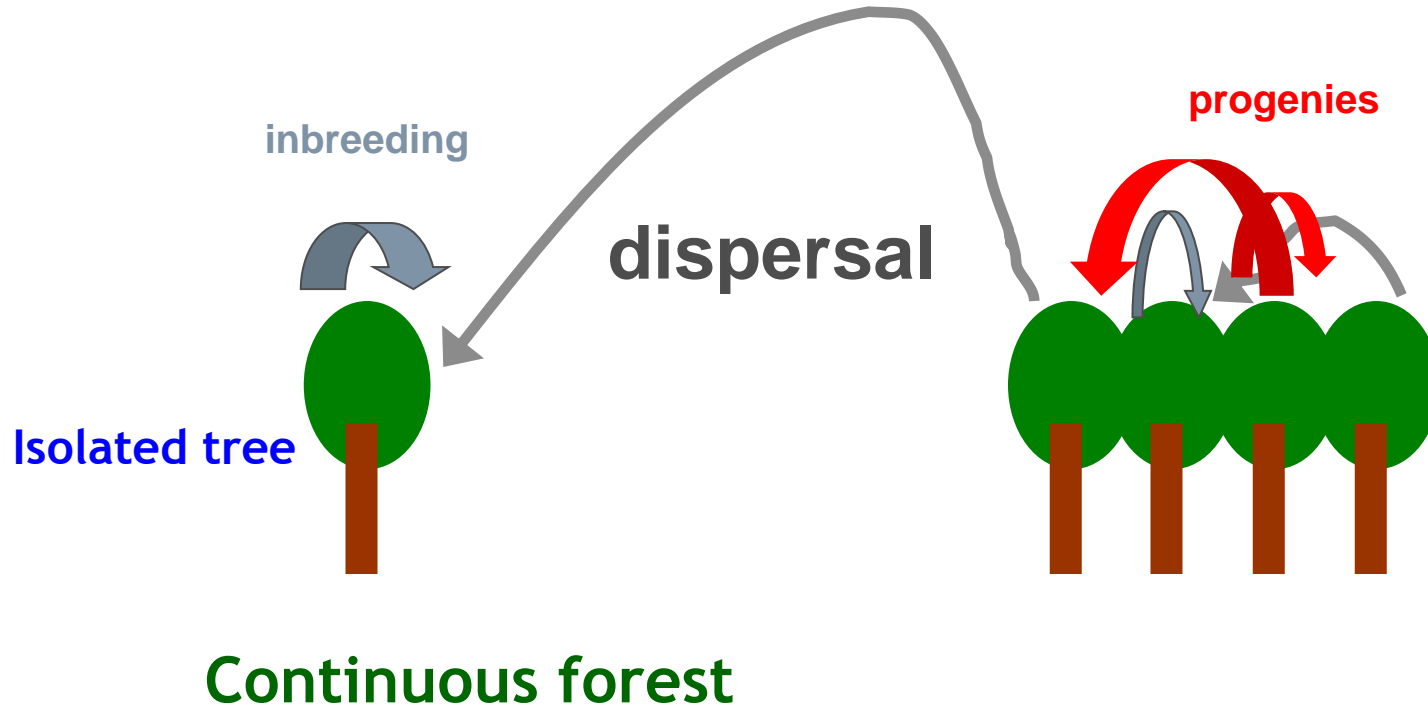


B: Gene flow reduces loss of genetic diversity

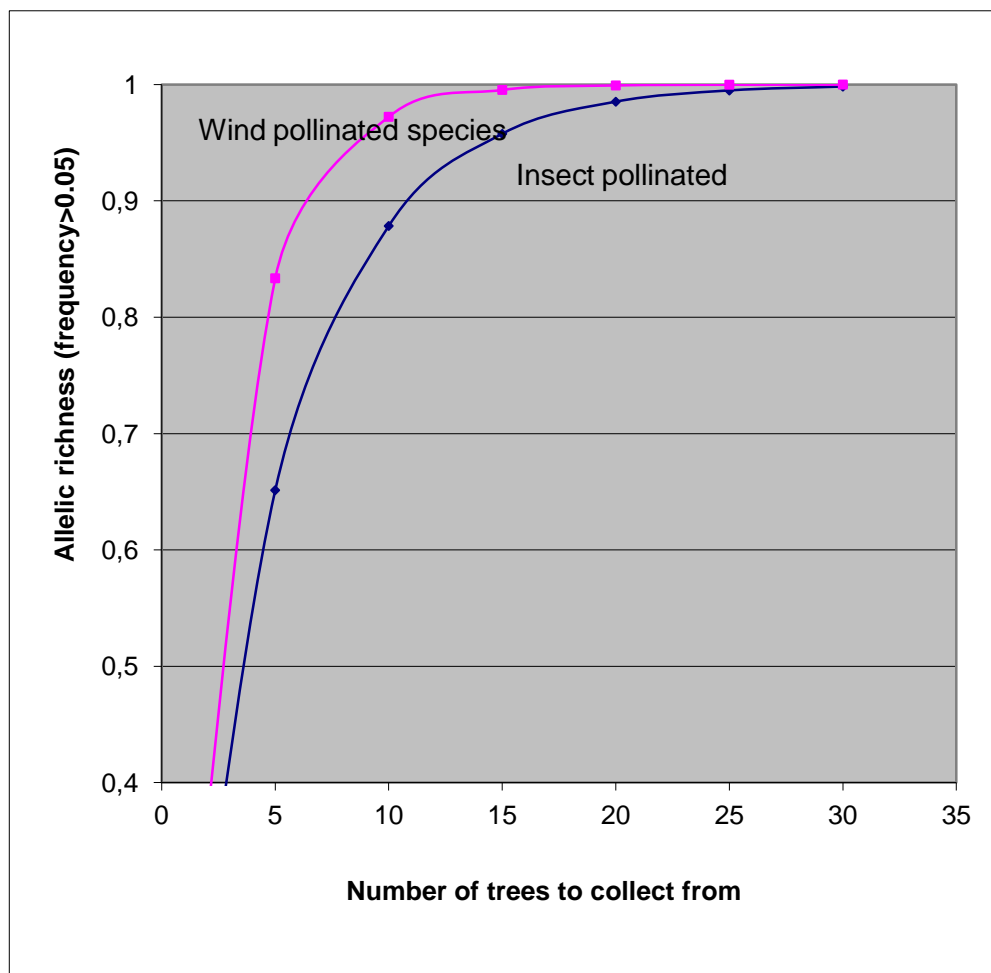


ALTERED MATING PATTERNS IN FRAGMENTS

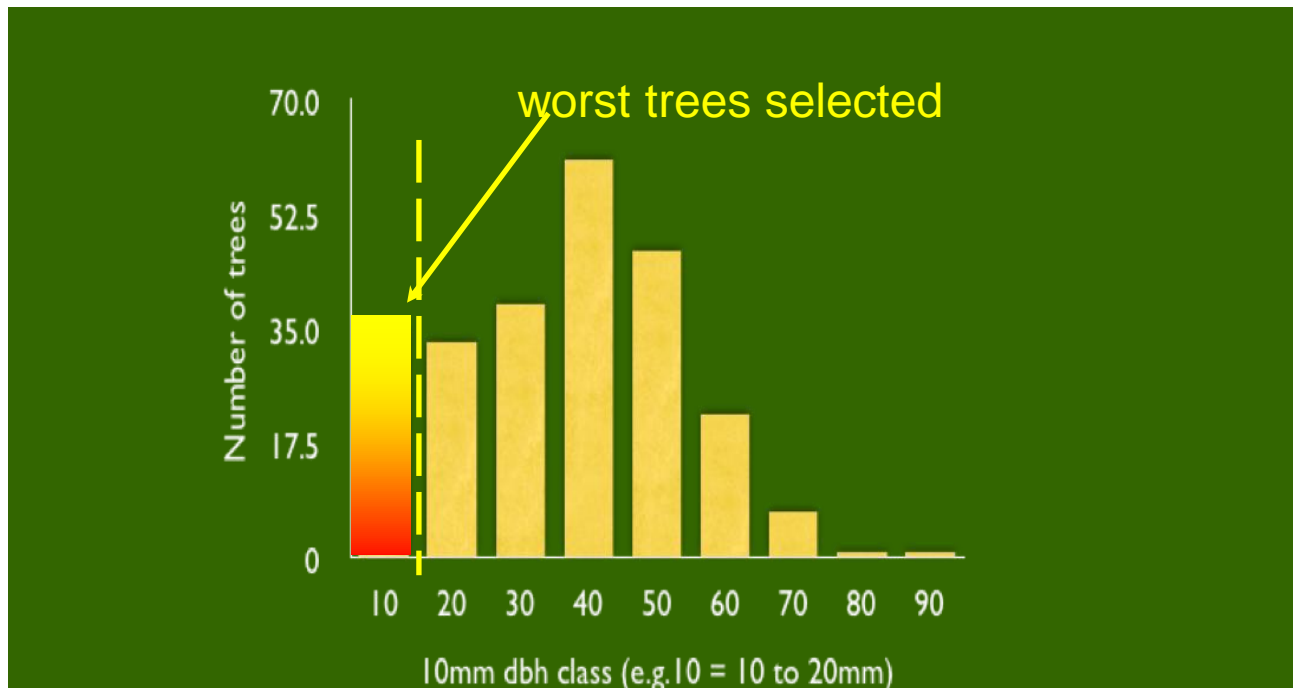
Predictions: increased inbreeding
greater pollen dispersal
fewer sires



HOW MANY TREES TO COLLECT FROM?



- Dysgenic selection is selection that leads to an undesirable **directional** change in genetic quality over one or more generations



CLAIMS OF DYSGENIC SELECTION AND VARIATION PATTERNS

“...another noteworthy feature is the lack of distinct variation patterns in relation to latitude and longitude; this may be due to the fact that the natural forests around the Mediterranean have been disrupted by man and subject for centuries to dysgenic selection” (Palmberg 1975)

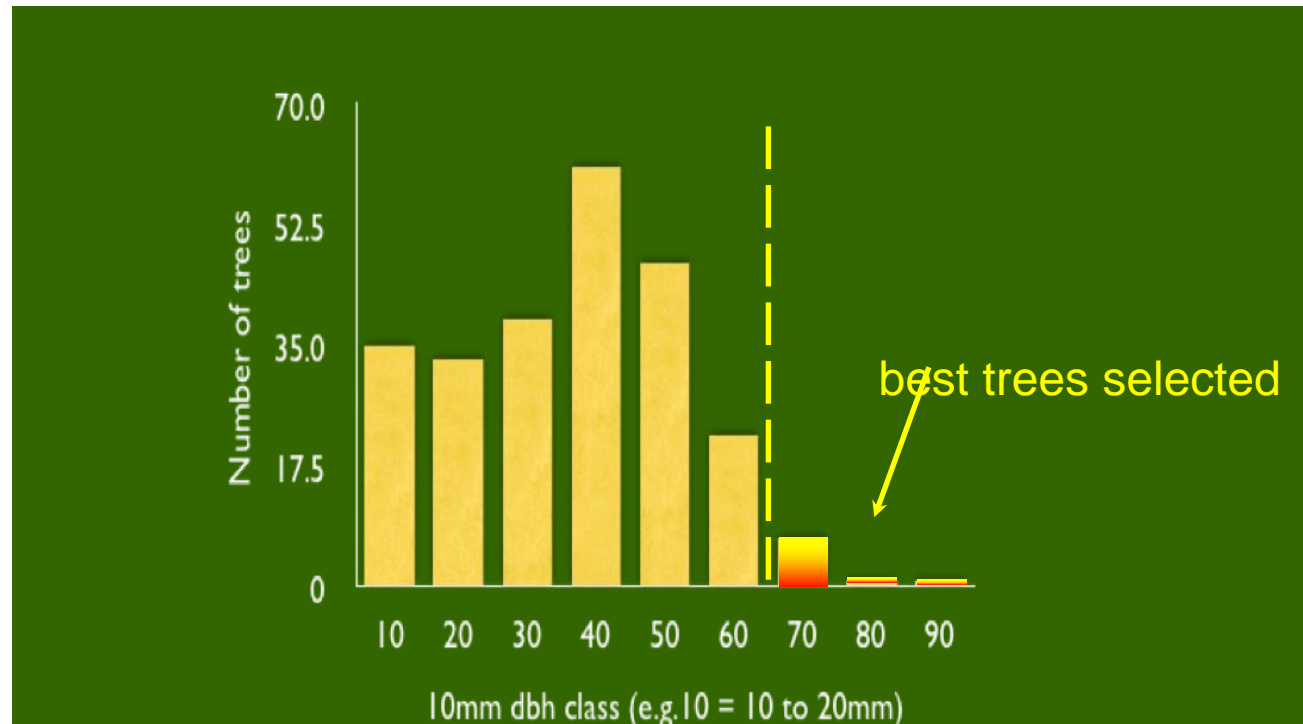


CLAIMS OF DYSGENIC SELECTION AND SELECTIVE LOGGING

“...in most areas this once famous tree now occurs as little more than a much-branched bush or small tree, a prime example of extreme genetic erosion due to past over exploitation of the best genotypes”
(Pennington et al. 1981)

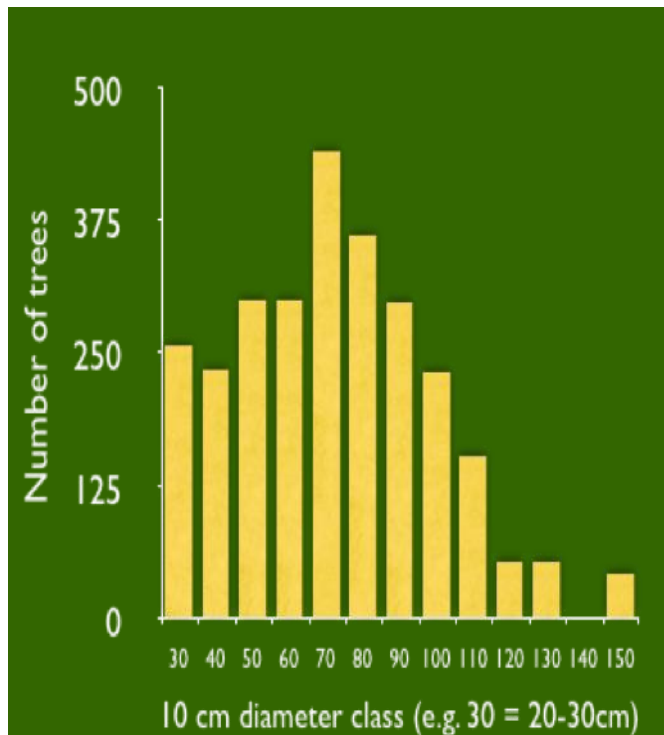


POSITIVE PHENOTYPIC SELECTION AIMING AT GENETIC IMPROVEMENT

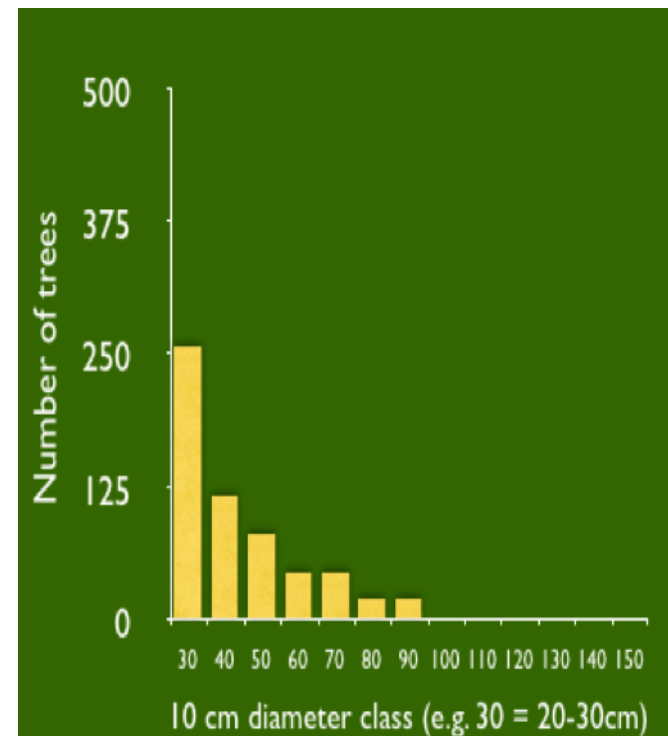


SELECTION CAUSED BY LOGGING

before
logging



after logging



based on Grogan et al. 2008

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THE BREEDERS' EQUATION

Response to selection (R) = selection differential (S) x heritability (h^2)

- ...allows us to predict the effect of phenotypic selection, whether positive (improvement) or negative (dysgenic)



$$\text{RESPONSE TO SELECTION (R)} = \text{SELECTION DIFFERENTIAL (S)} \\ \times \text{HERITABILITY (H}^2\text{)}$$

- Selection differential = the difference between the mean of the selected individuals and the mean of the population
- If plus-tree mean dbh is 40 cm and population mean dbh is 20 cm, then $S = 20$ cm
- Selection differential is a within-generation measure of phenotypic superiority and will usually reflect environmental differences as well as genetic differences



THE BREEDERS' EQUATION

RESPONSE TO SELECTION (R) = SELECTION DIFFERENTIAL (S)
X **HERITABILITY (H^2)**

Heritability = the degree to which the superiority measured in the selection differential is passed on to the progeny of the selected individuals

- The value of heritability varies from zero to one



THE BREEDERS' EQUATION

RESPONSE TO SELECTION (R) = SELECTION DIFFERENTIAL (S) X HERITABILITY (H^2)

$$h^2 = \frac{V_A}{V_P}$$

$$h^2 = \frac{V_A}{V_G + VE}$$

$$h^2 = \frac{V_A}{V_A + VD + VI + VE}$$

➤ In determining heritability, only narrow-sense heritability is used, because only the variation due to additive effects permits predictions due to selection.



- FRANKLIN, Ian Robert. Evolutionary change in small populations. 1980.
- PALMBERG, Christel. Geographic variation and early growth in south-eastern semi-arid Australia of *Pinus halepensis* Mill. and the *P. brutia* Ten. species complex. *Silvae Genetica*, 1975, 24: 150-160.
- PENNINGTON, Terence D., et al. *A monograph of neotropical Meliaceae (with accounts of the subfamily Swietenioideae by BT Styles and the chemotaxonomy by DAH Taylor)*. 1981.
- GROGAN, James, et al. What loggers leave behind: impacts on big-leaf mahogany (*Swietenia macrophylla*) commercial populations and potential for post-logging recovery in the Brazilian Amazon. *Forest Ecology and Management*, 2008, 255.2: 269-281.

