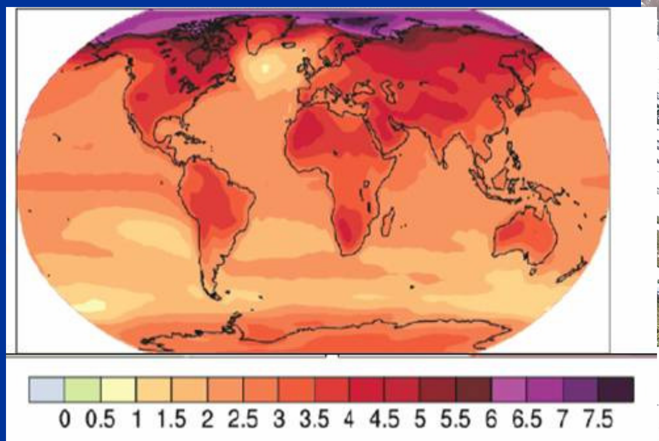
Influence of climate change on the natural distribution of tree species. Diaporama

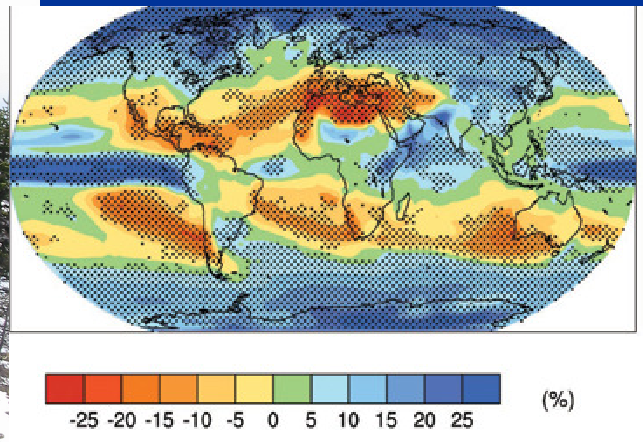
Bruno Fady

Influence of climate change on the natural distribution of tree species.

Bruno Fady

INRA – URFM, Avignon, France





***NordGen Forest conference*, Selfoss, Iceland**

20 August 2008

INRA

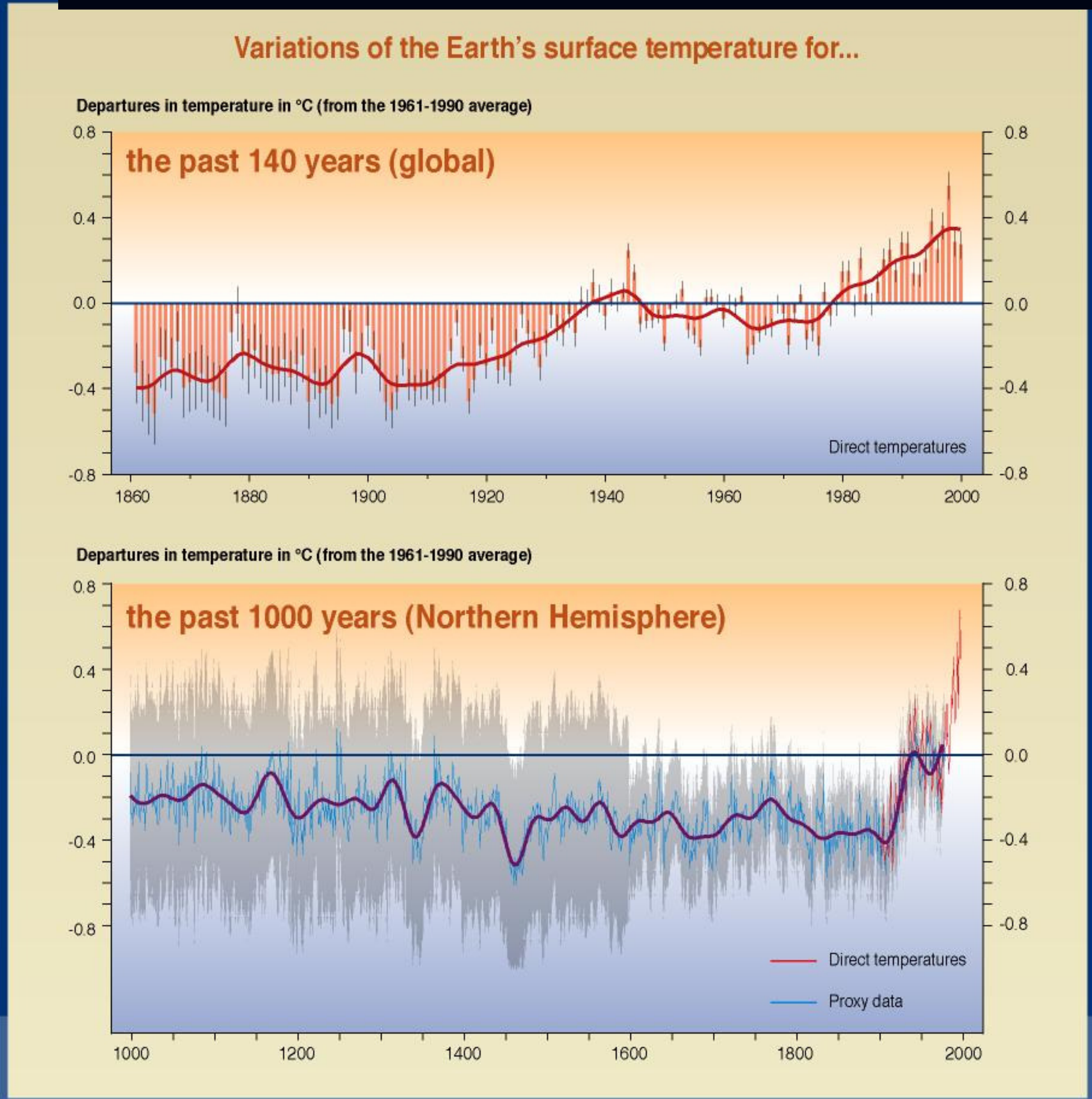
Influence of climate change on the natural distribution of tree species.

NordGen Forest conference, Selfoss, Iceland, 20 August 2008

Climate change is now a reality. Climate change is here and now. It has happened and is predicted (with the highest level of confidence) to continue to do so for centuries to come.

What will its effect be on trees and forest ecosystems? What can **they** do to cope with change? What can **we** do to preserve our forests?

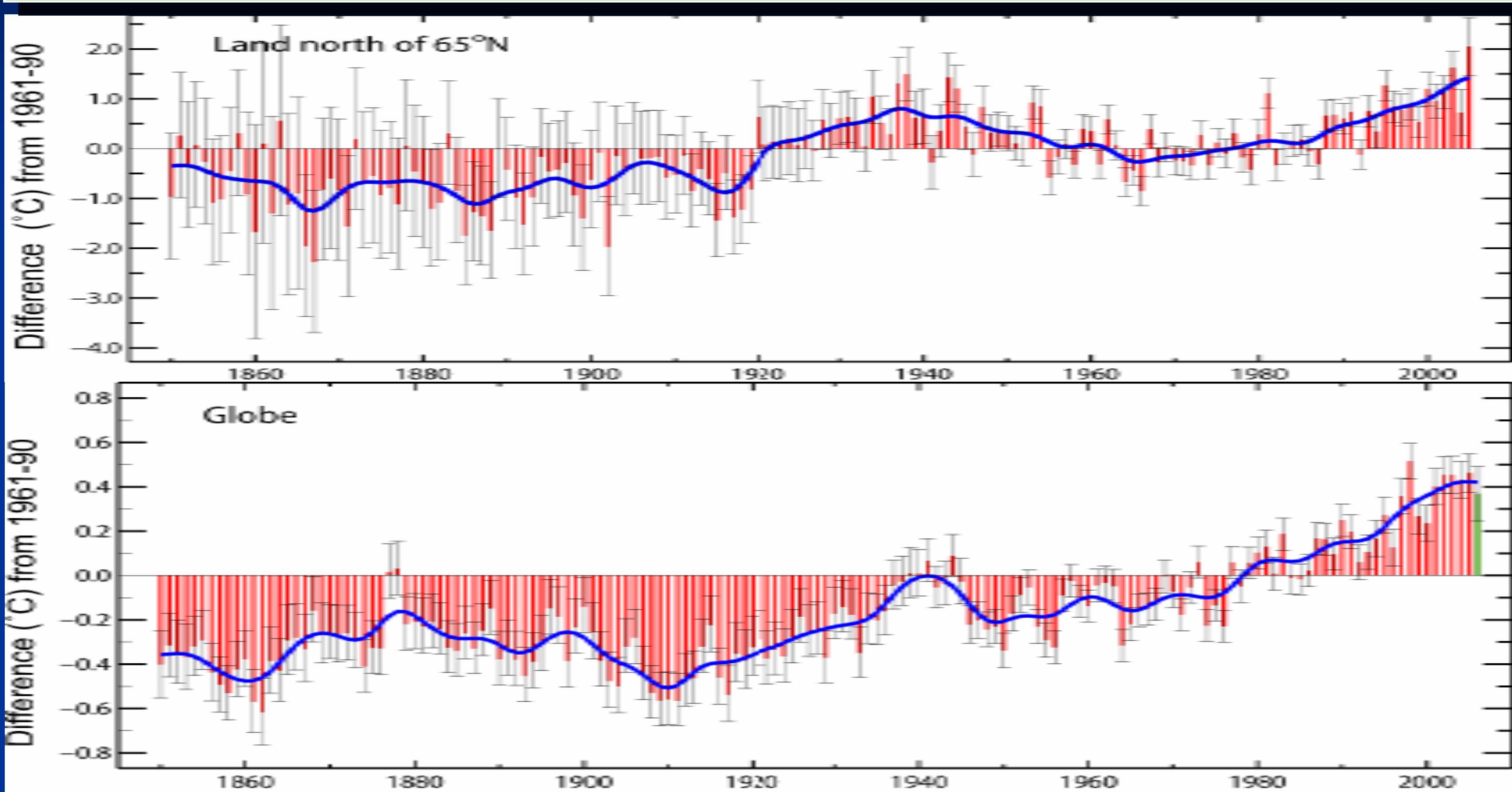
Climate change: What has already happened.



- Mean increase of 0.4℃ compared to 1961-1990 average
- Widespread changes in extreme temperatures
- Cold days, cold nights and frost less frequent
- Hot days, hot nights, and heat waves more frequent.

(All graphics on climate change are from http://www.ipcc.ch/graphics)

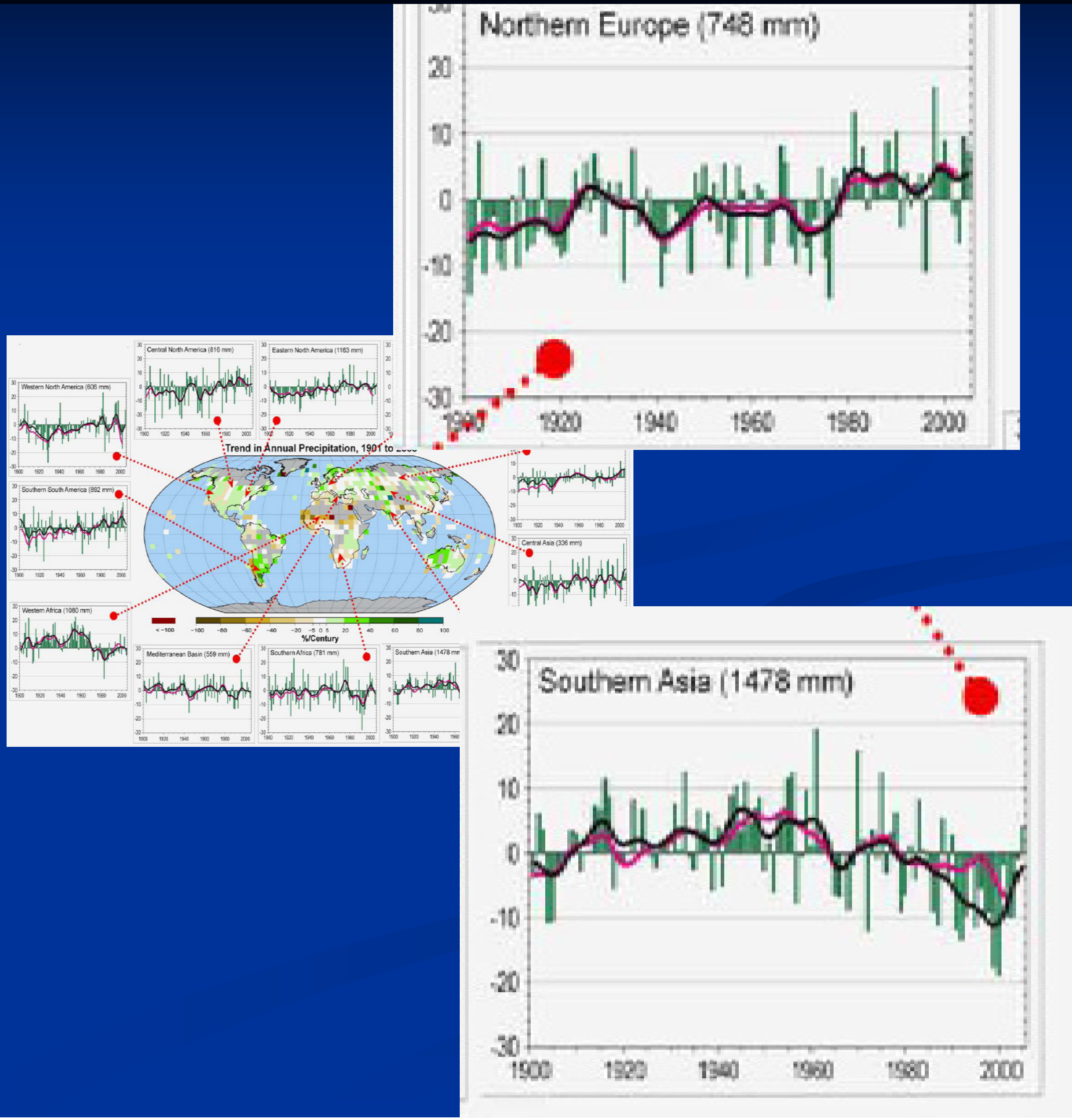
Climate change: What has already happened.



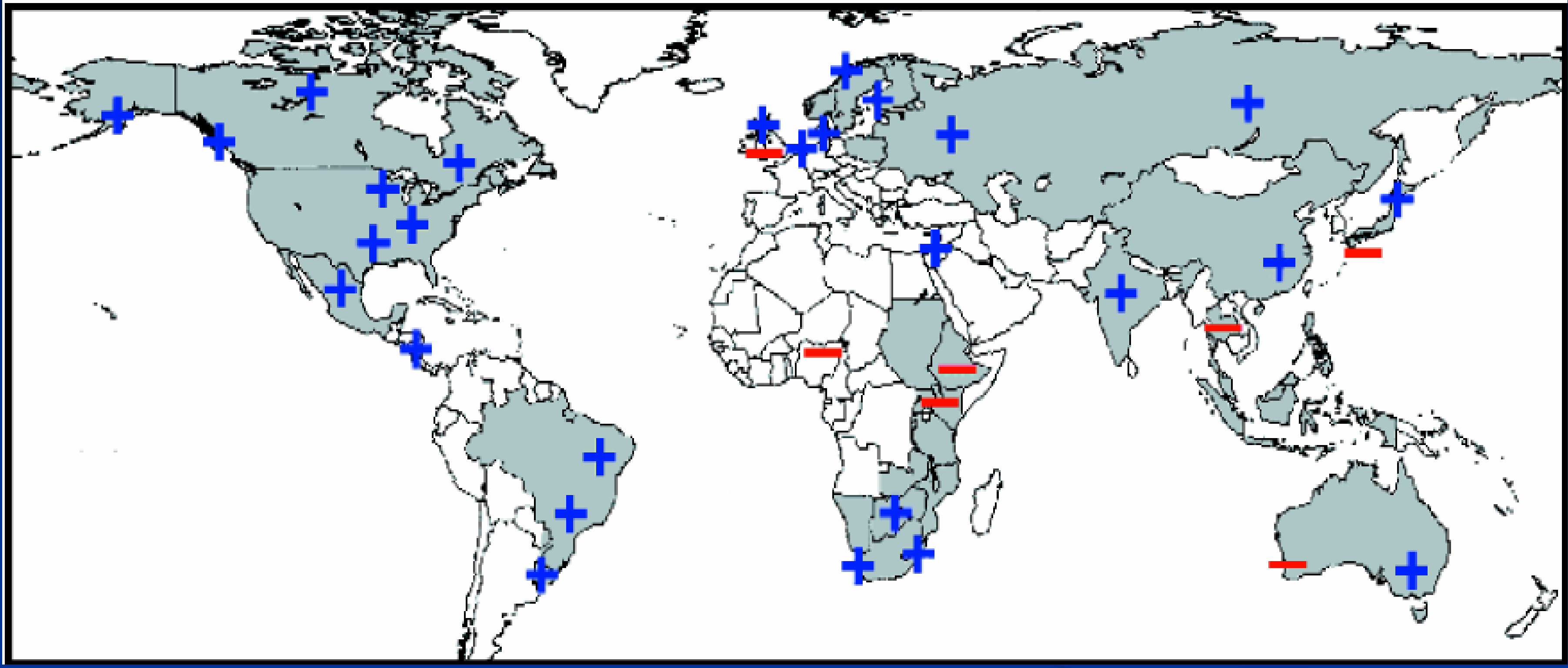
Warming in the Arctic is **double** that for the globe from 19th to 21st century and from late 1960s to present (note different scales). Annual average Arctic sea ice extent shrunk by 2.7 % per decade,

Climate change: What has already happened.

- Land precipitation is changing significantly over broad areas
- Significantly increased precipitation in eastern parts of North and South America, northern Europe and northern and central Asia.



Climate change: What has already happened.



The frequency of heavy precipitation events has increased over most land areas.

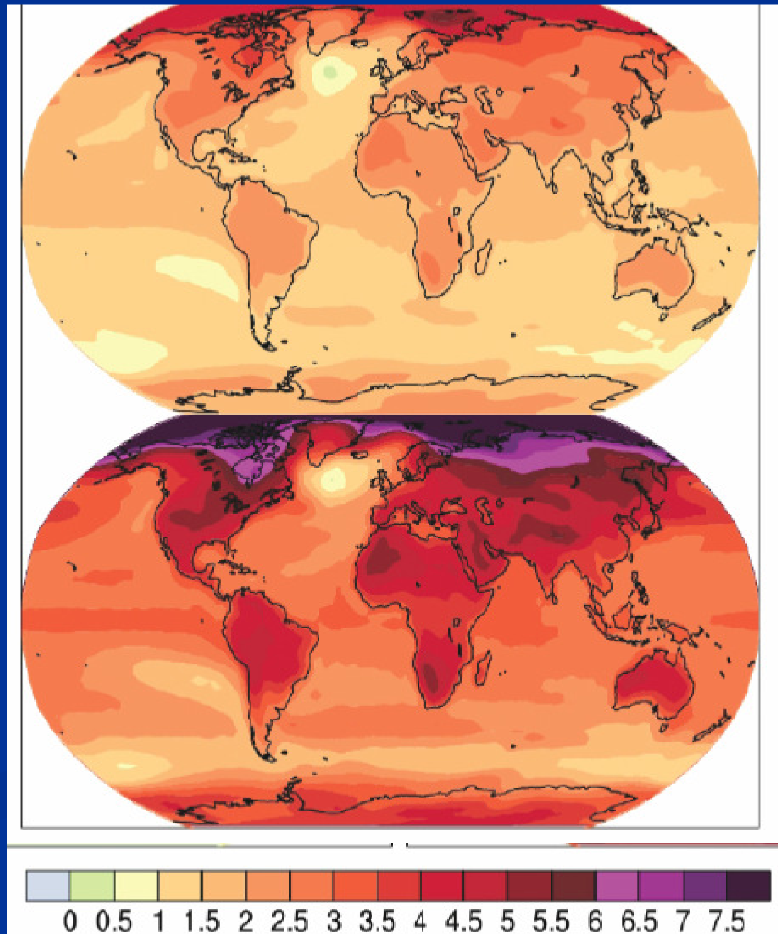
Figure shows regions where disproportionate changes in heavy precipitation were documented as either an increase (+) or decrease (–) compared to the change in annual and/or seasonal precipitation

Climate change: What will happen soon

Projected warming in 21st century is expected to be ***greatest*** over land and at northernmost latitudes and ***least*** over the Southern Ocean and parts of the North Atlantic Ocean.

Best estimate for low scenario (B1) is 1.8℃ (*likely* range is 1.1℃ to 2.9℃),

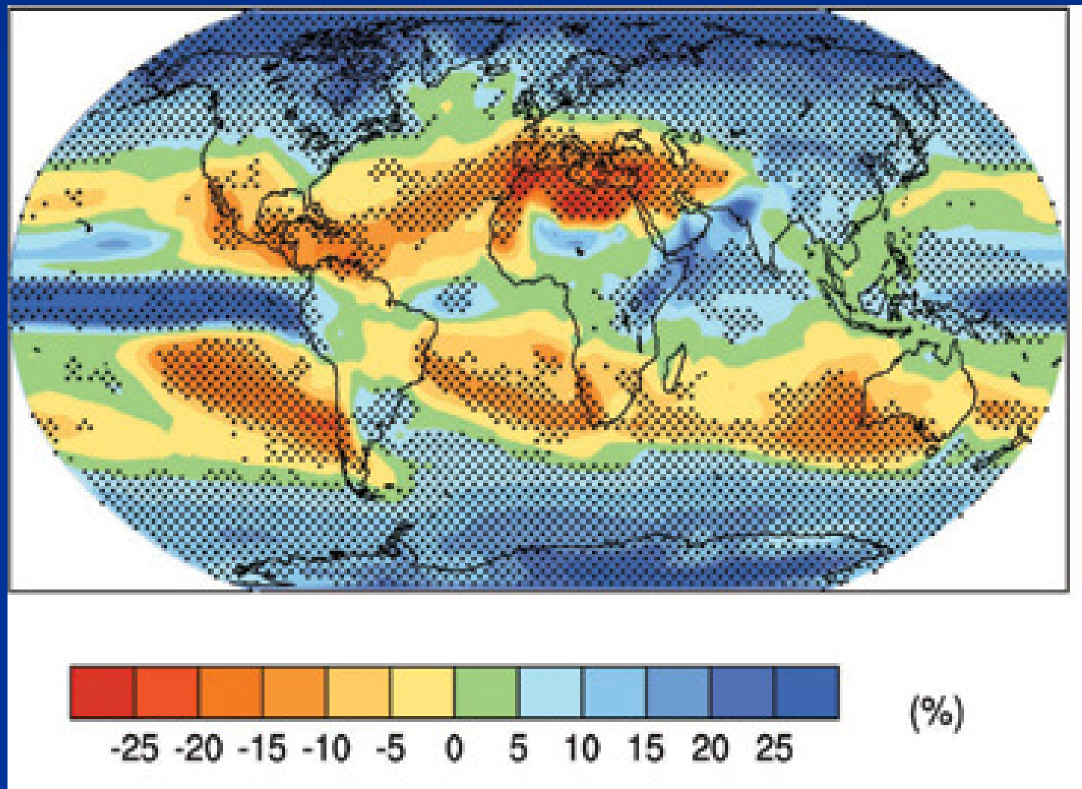
and for high scenario (A1FI) is 4.0℃ (*likely* range is 2.4℃ to 6.4℃).



Climate change: What will happen soon

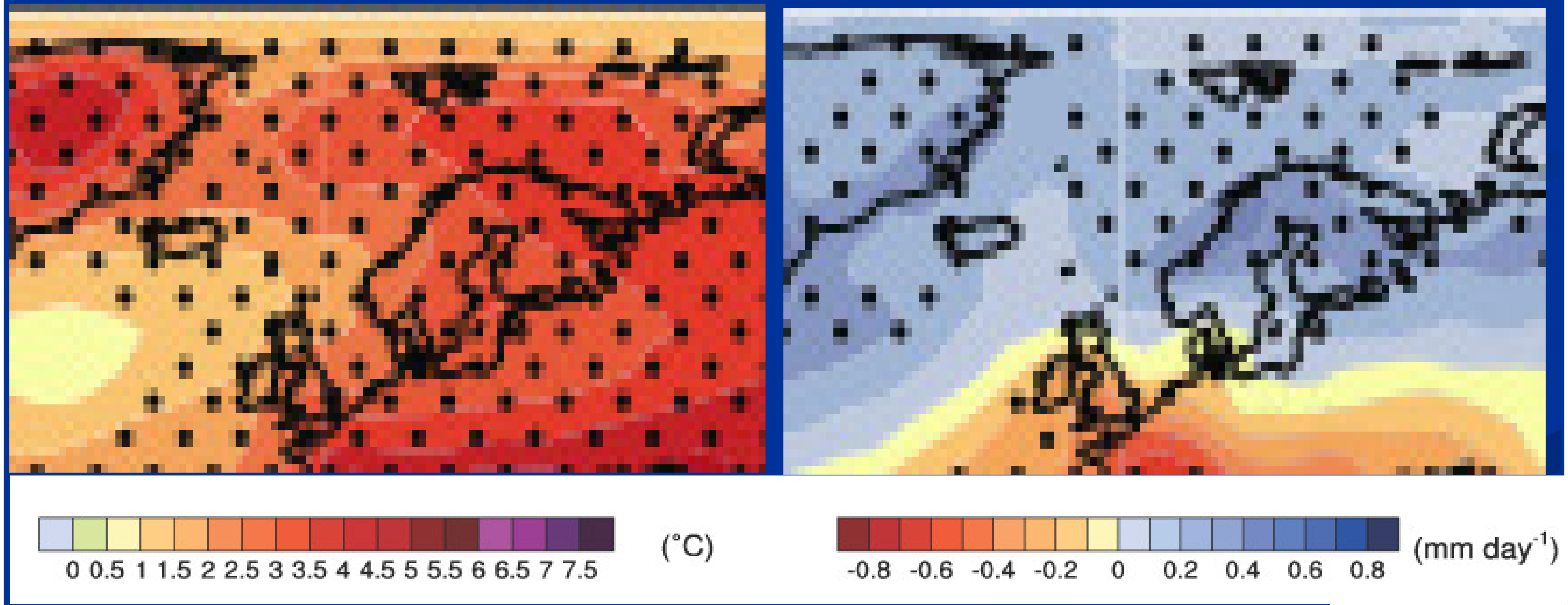
- Precipitation increases are *very likely* in high latitudes
- Decreases are *likely* in most subtropical land regions.

Worldwide mean: -0.2 to -0.4 mm per day.



Nordic scenario (A1B, JJA 2080-2099)

= increased *summer* heat (+2 to 4.5℃) and rainfall (0.1 to 0.3 mm / day)!



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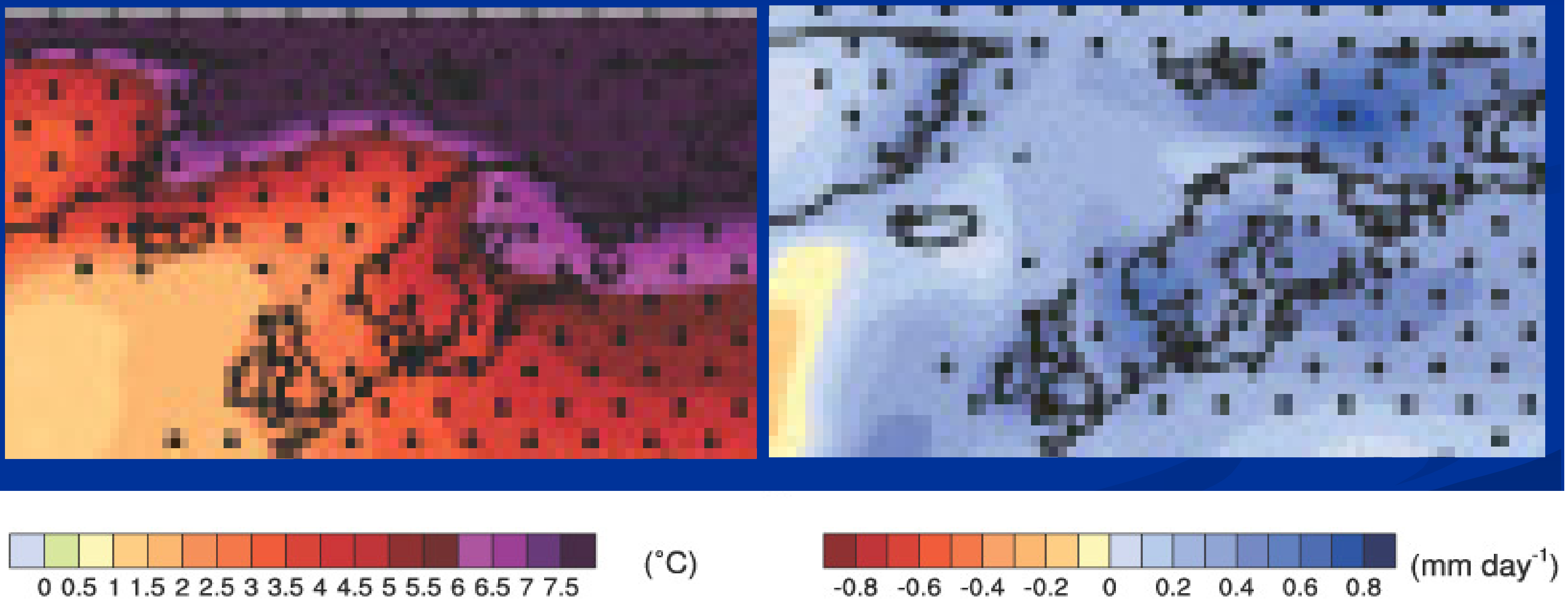
Nordic scenario (A1B, DJF 2080-2099)

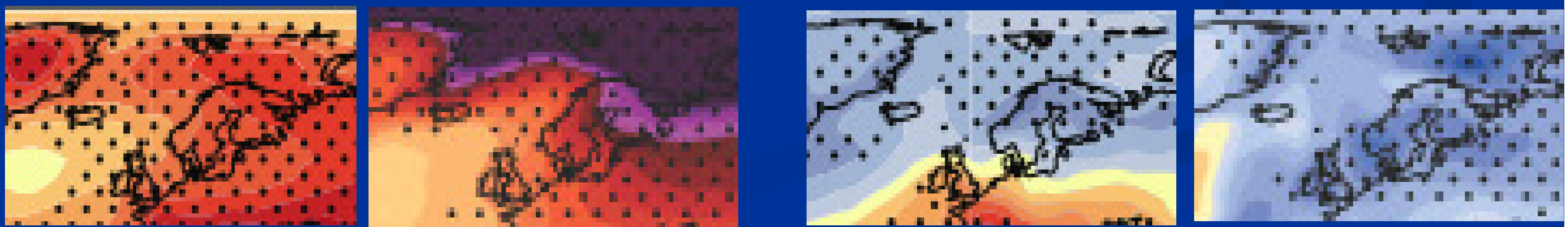
= increased *winter* heat (+2 to 7°C) and rainfall (0.1 to 0.4 mm / day)!



Climate change Nordic scenario

Significant increase in summer and winter temperatures and precipitations

=> Significant consequences on survival and distribution of forest tree species and ecosystems



What can trees do to cope with climate change ?

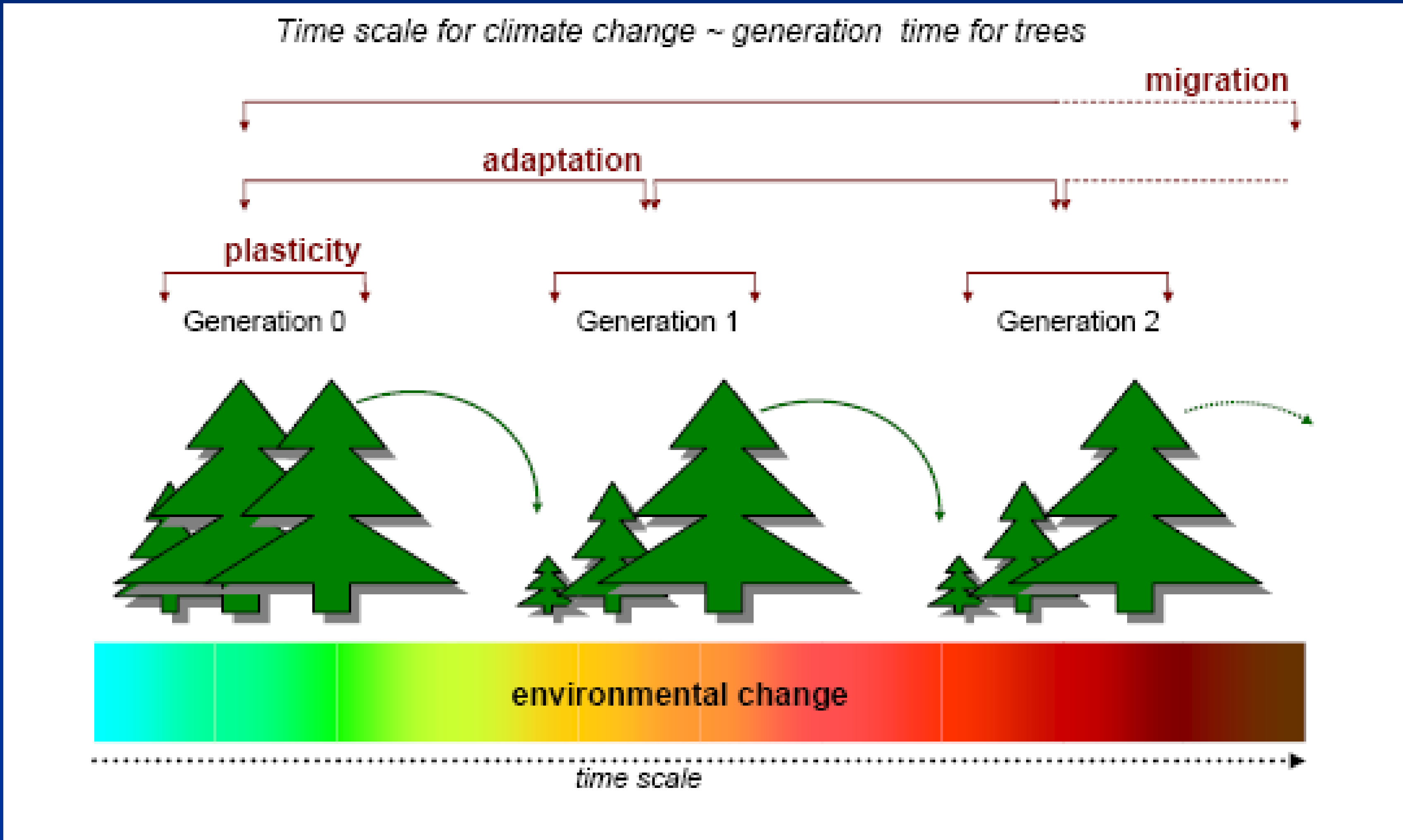
Trees may use 3 strategies to face any ecological change:

- **plasticity** / acclimatization (trees will continue to survive, grow and reproduce locally because their biological requirements are flexible)

- **adaptation** (selection of progeny with highest fitness)

- movement through **dispersal** (regeneration under friendlier environments after long distance dispersal or hybridization)

What can trees do to cope with climate change?
A question of time



What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

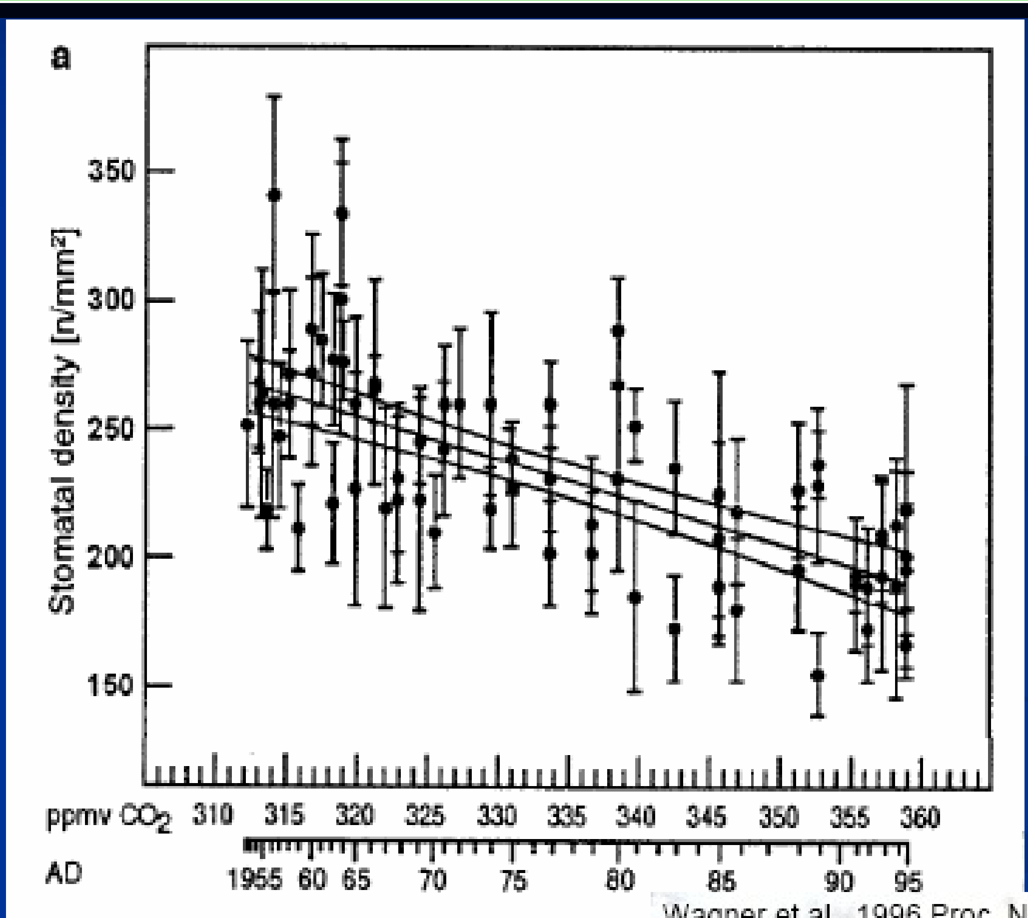
Phenotypic plasticity

Trees are able to survive, grow and reproduce when the environment changes because their biological requirements are flexible and they are able to modify their biological functions.

A “plastic” species will show no GxE interaction

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Plasticity *and its limitations*



Wagner et al., 1996 Proc. Natl. Acad. Sci. USA 93: 11705-11708

Evolution of leaf stomatal density in a single *Betula pendula* tree with increasing CO_2 concentration

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Plasticity and its limitations

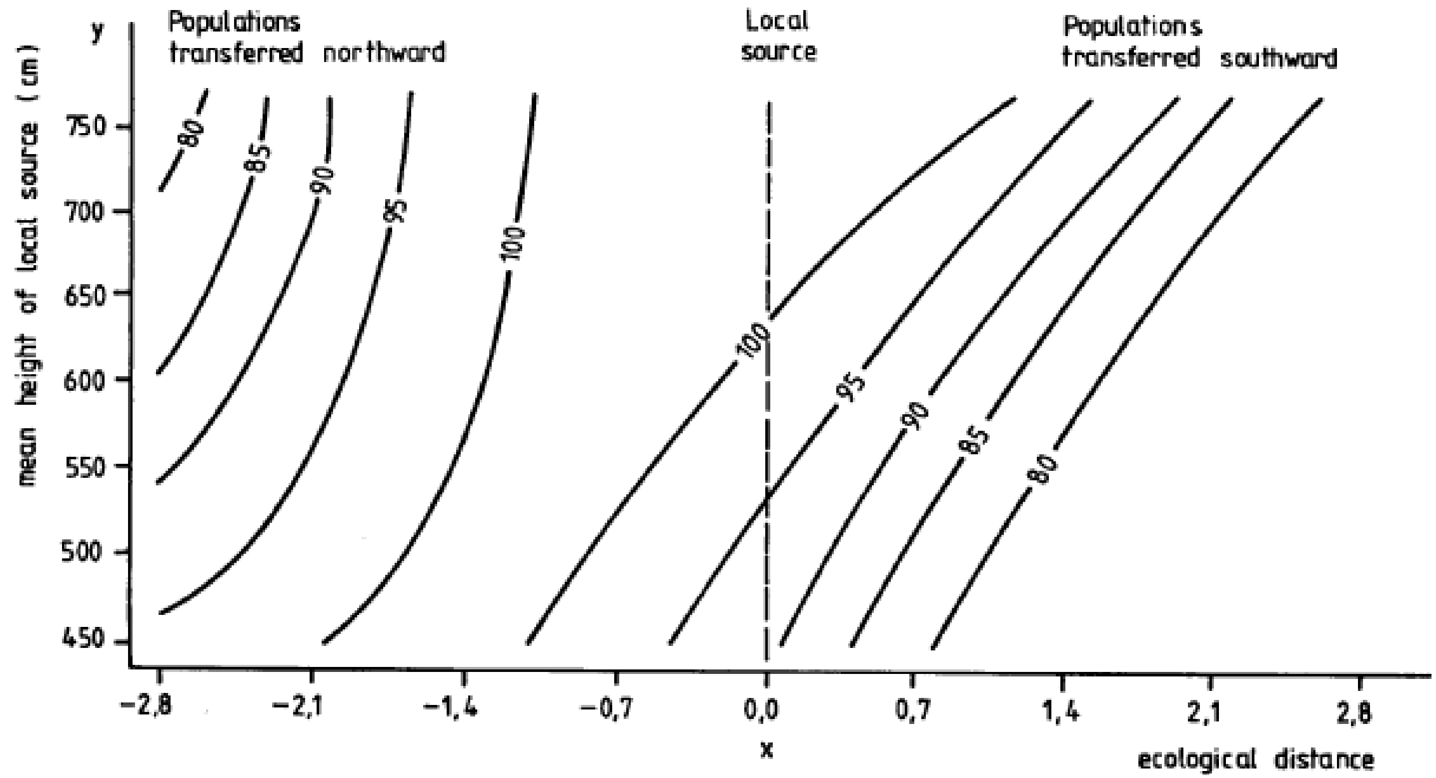
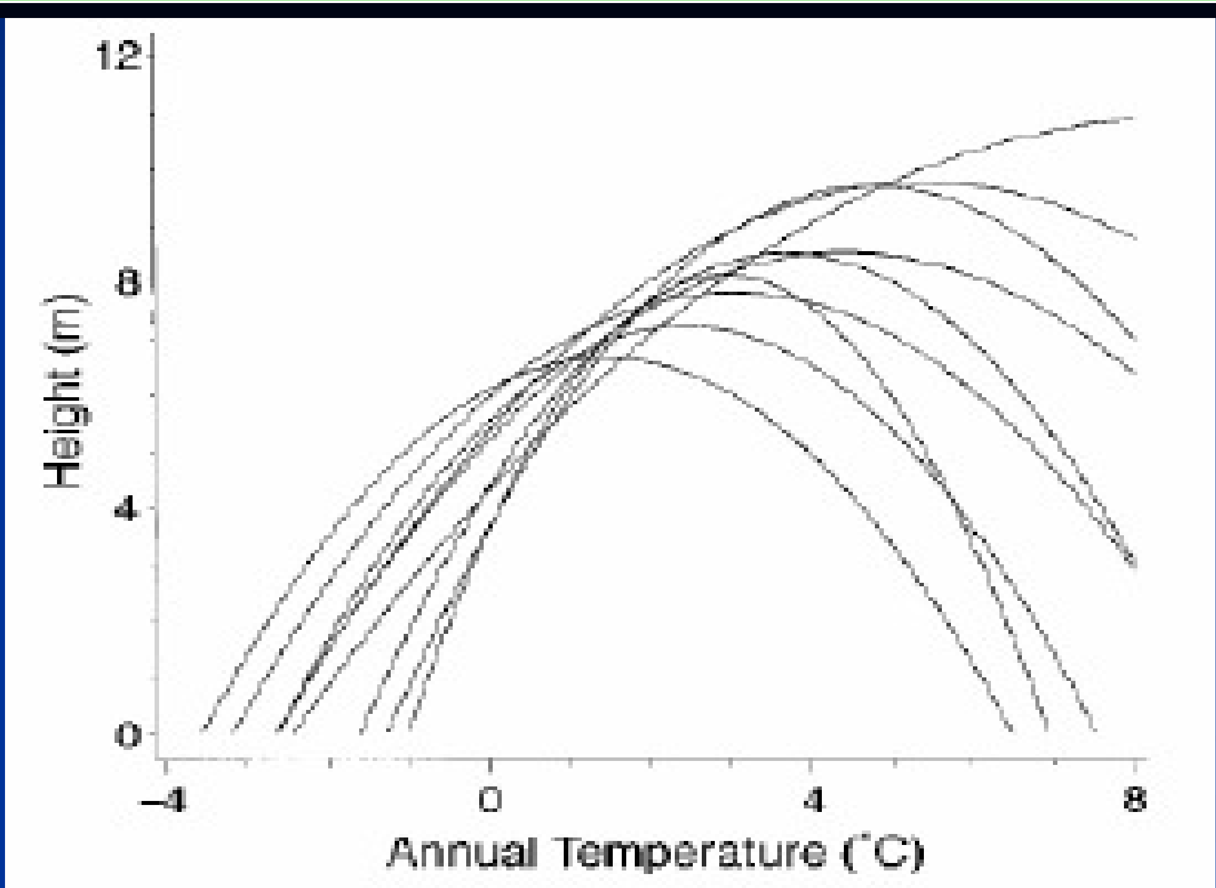


Figure 2. — Contour plot of the relative source heights (calculated from 6 Ontario tests) expressed as percents of the local height. Excessively transferred sources exhibiting marked growth depression were excluded.

Pinus banksiana (Matyas and Yeatman, 1992, Silvae genetica)

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

***Plasticity** and its limitations*

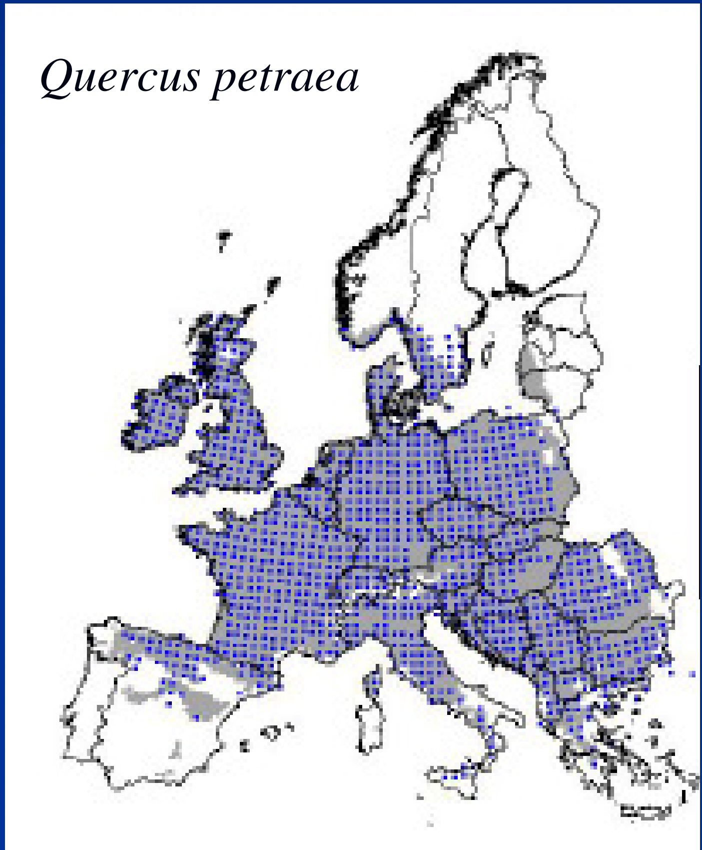


Response functions, 9 populations, *Pinus contorta*, Rehfeldt et al. 1999, Ecological Monographs

Current forest tree populations demonstrate phenotypic plasticity to increasing temperature in forests trees… **up to a certain point !!**

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

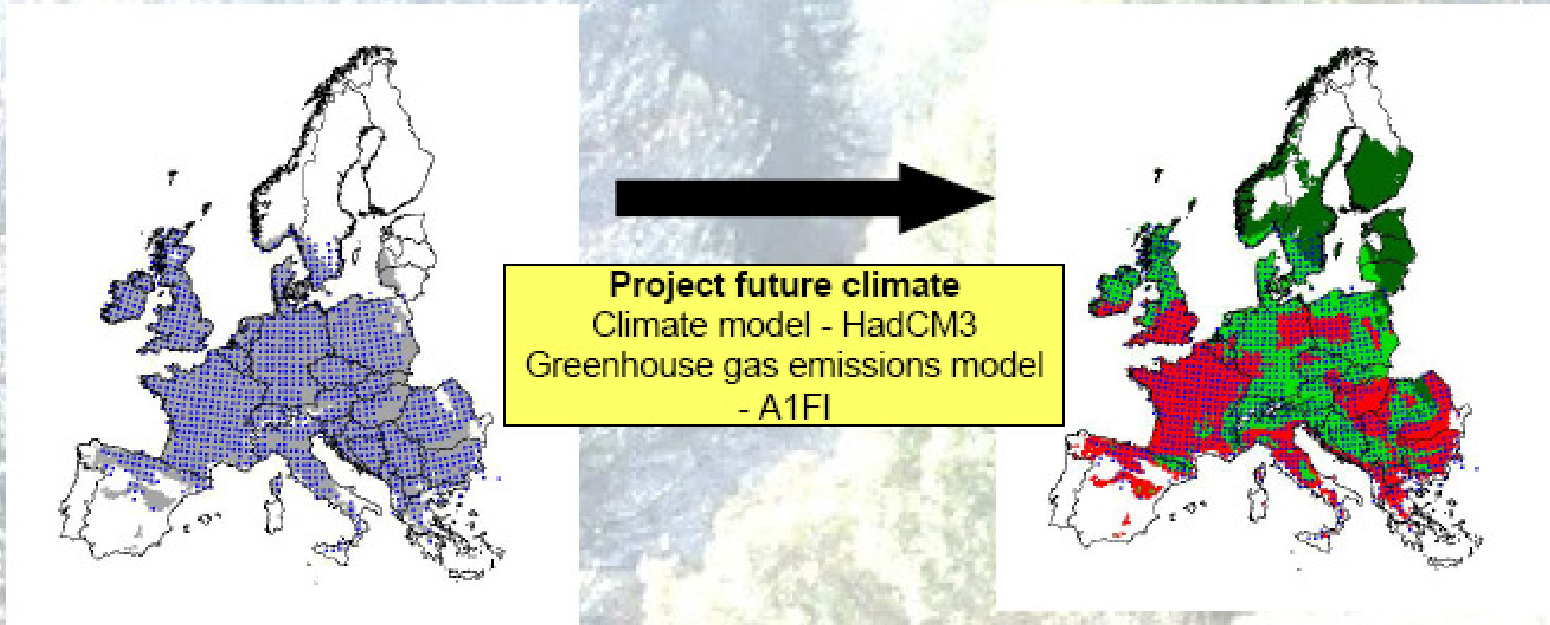
Plasticity and its limitations



Phenotypic plasticity (among other factors) determines the ecological niche and the geographic distribution of a species

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Plasticity *and its limitations*



Current Distribution
simulated using BIOMOD

- **Observation**
- **Simulation**

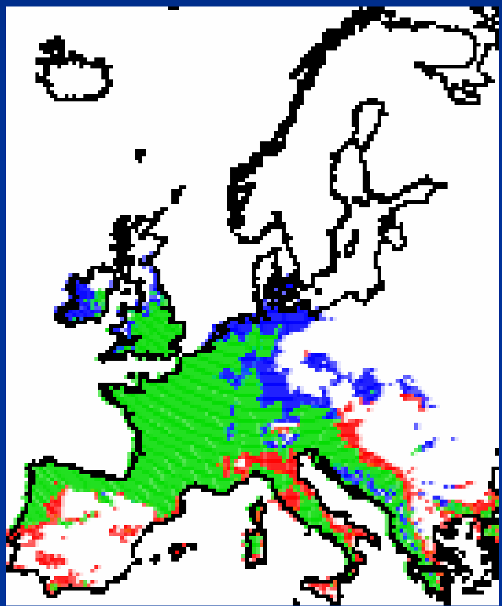
Future Distribution: 2080
simulated using BIOMOD

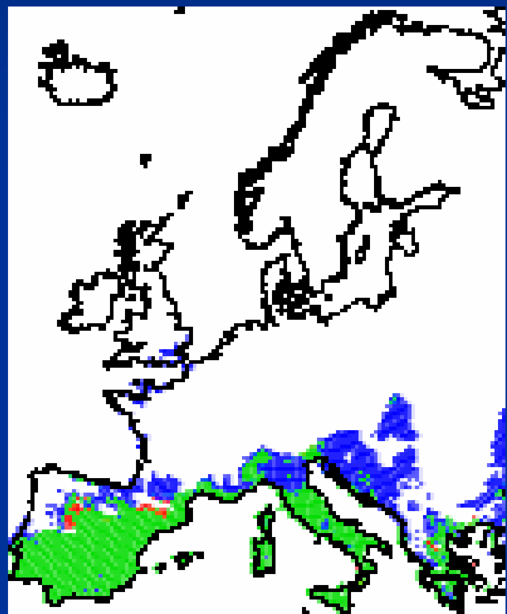
- **Loss of habitat**
- **Stable habitat**
- **Gain of habitat**

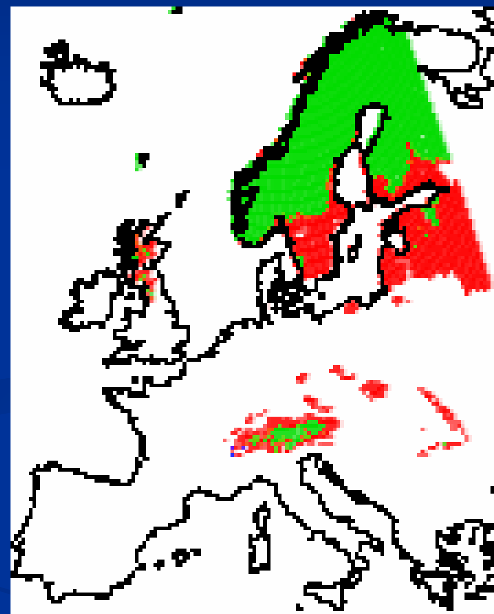
Quercus petraea, Thuiller GCB 2003, Thuiller et al. PNAS 2005

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Plasticity and its limitations



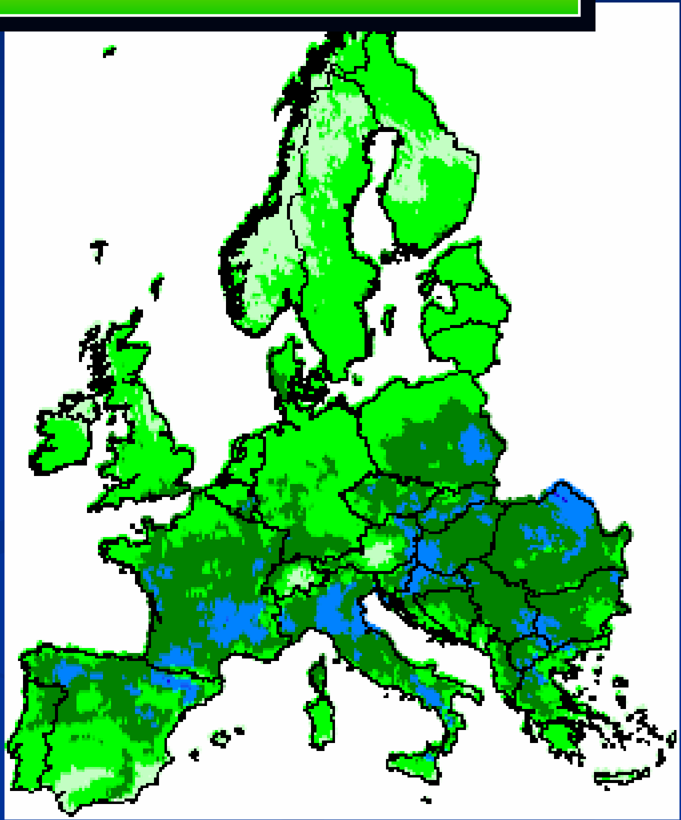


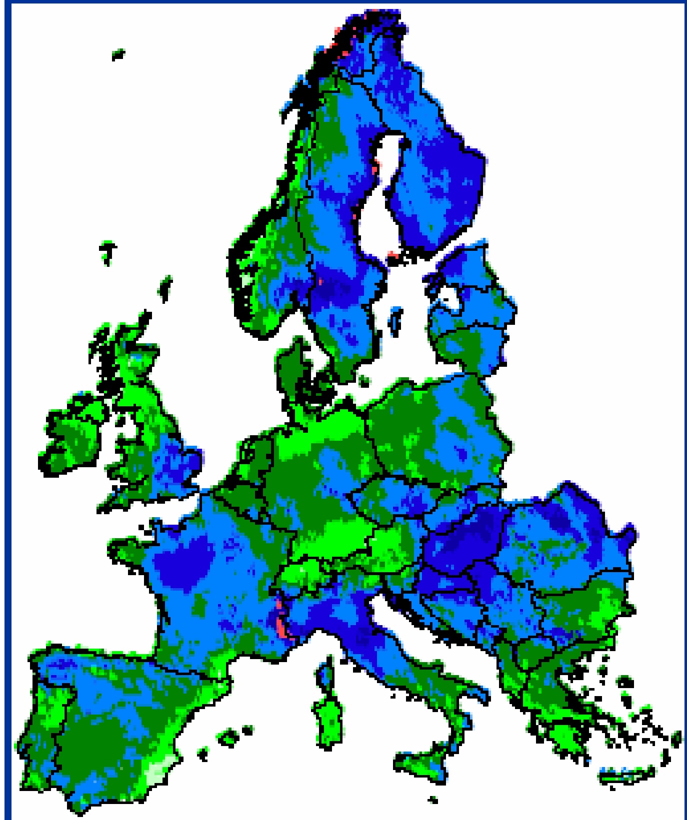


Comparison of current and projected (2050) distributions of *C. sativa*, *P. halepensis* and *B. nana*: Green = favorable habitat now and in 2050, blue = favorable habitat in 2050 (but not now), red = favorable habitat now but not in 2050. (Thuiller 2003)

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

***Plasticity** and its limitations*



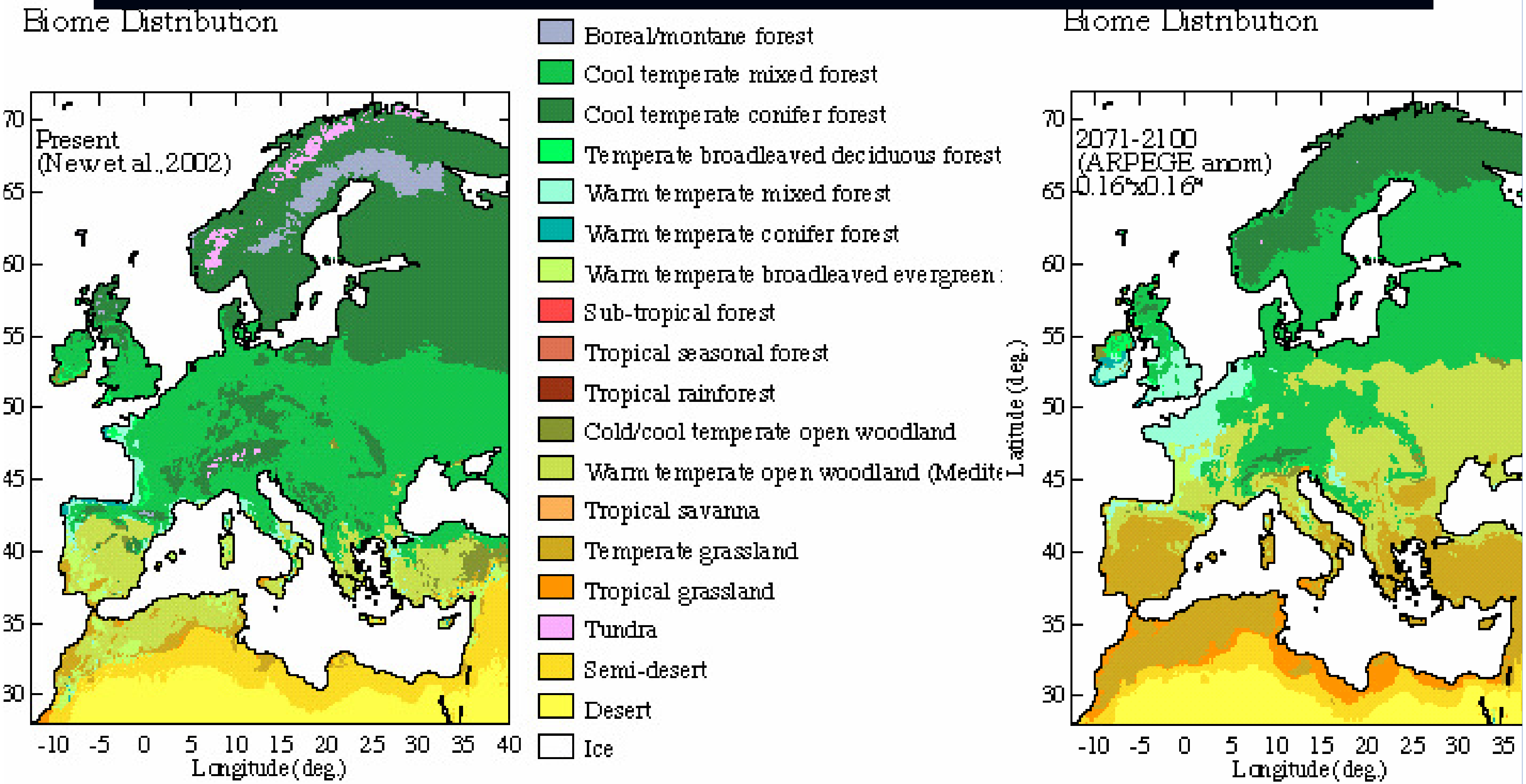


	0 - 10 %
	10 - 20 %
	20 - 30 %
	30 - 40 %
	40 - 50 %
	50 - 60 %
	60 - 70 %
	70 - 80 %
	80 - 90 %
	90 - 100 %

Modeled species extinction (top) and colonization (bottom) rate by pixel for 2013 species across Europe under A1 scenario (Thuiller 2003)

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

***Plasticity** and its limitations*



Distribution of European biomes for the climatic conditions of years 1961-1990 (left) and years 2071-2100 (right) under a mild scenario. (From Chuine et al.).

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Plasticity and its limitations

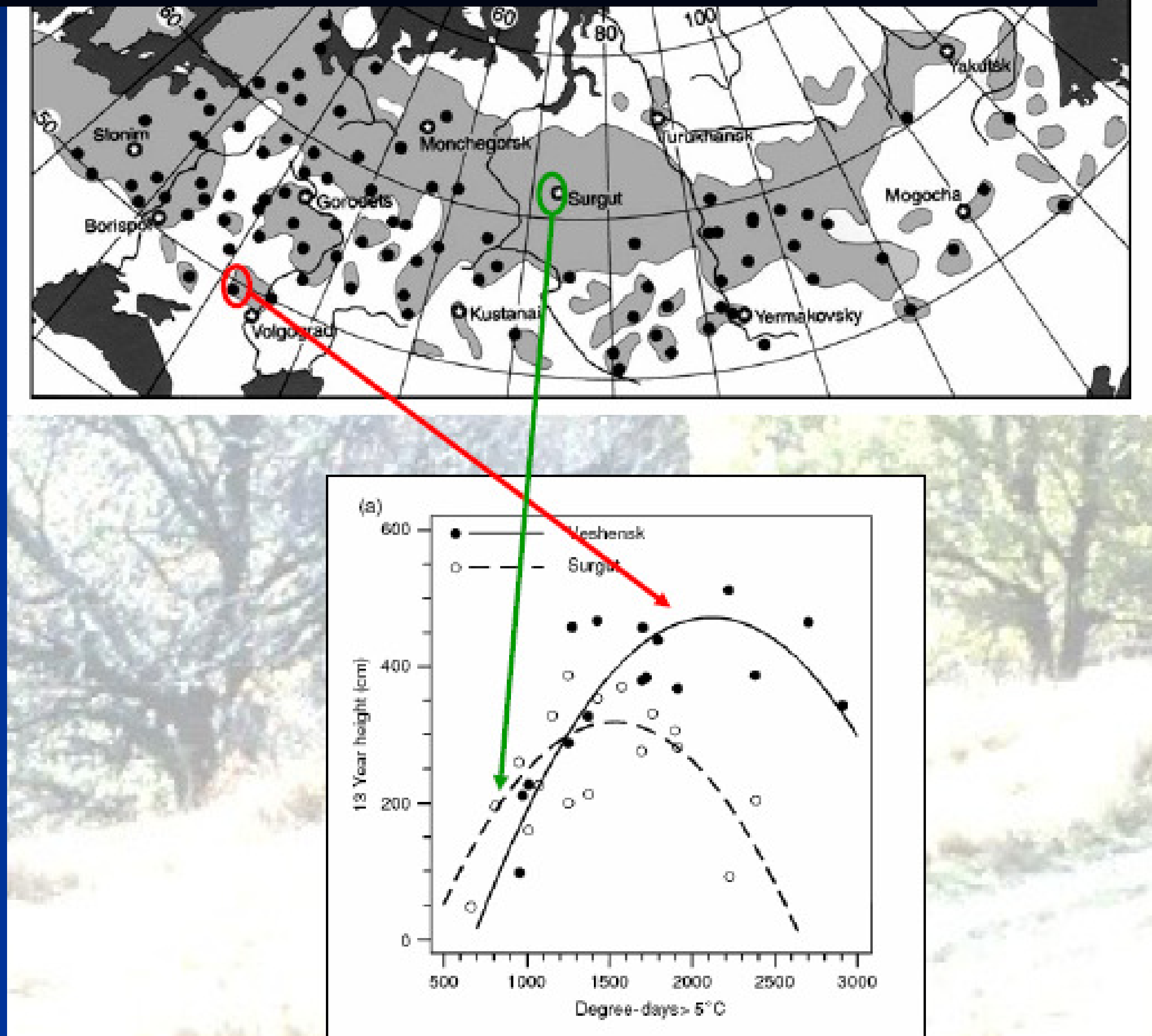
Marginal stands: autochthony is not always best

Abies alba dieback after the 2003 summer heat wave, southern France (Mont Ventoux, elevation 1200 m).

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Plasticity ***and its limitations***

Southern provenances of *P. sylvestris* show a better response to increased temperature than northern ones (Rehfeldt et al. 2001, Climatic Change).



What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Adaptation

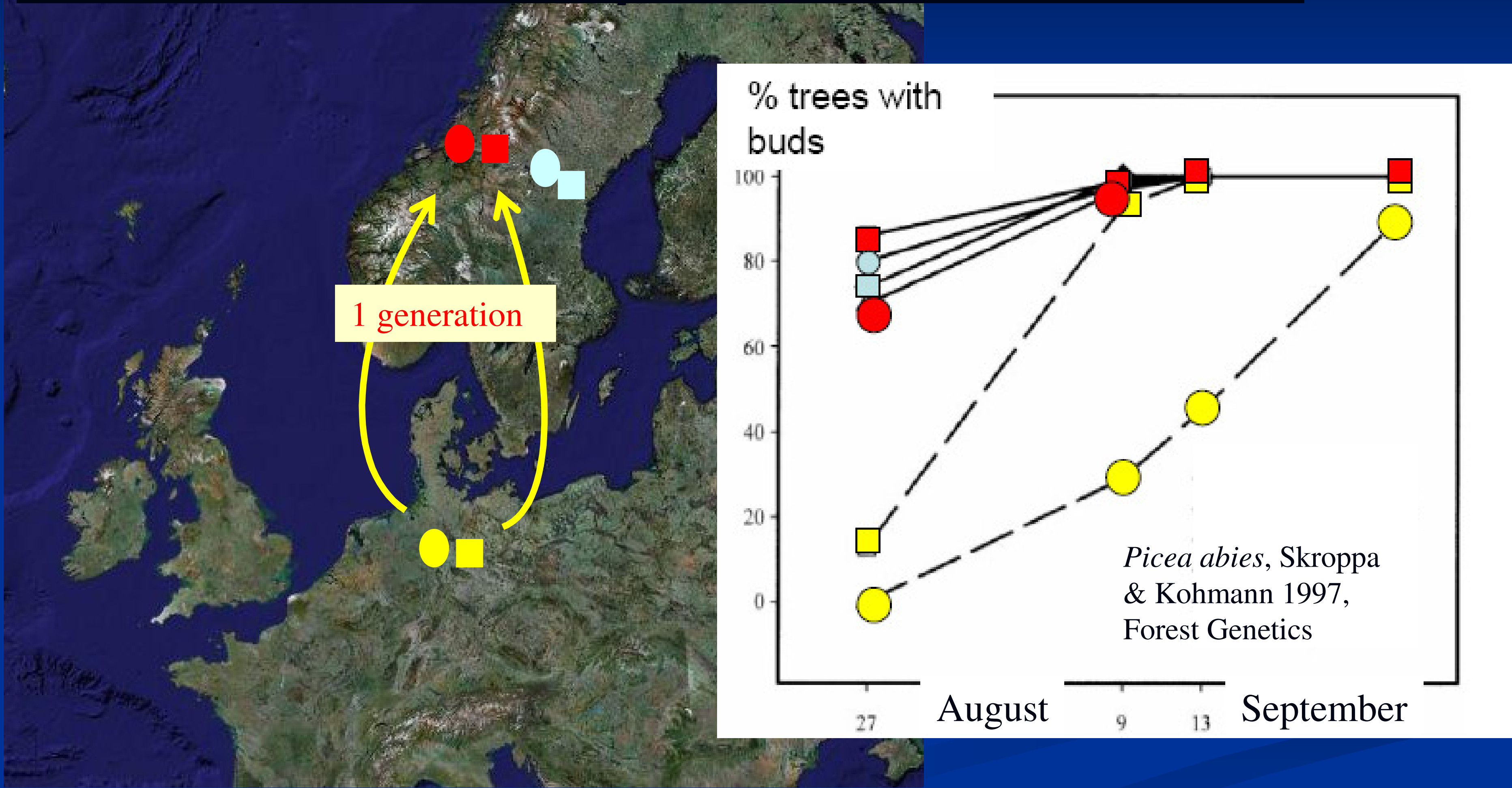
Forest trees:

- are very variable in their genetic diversity
- show altitudinal and latitudinal clines of adaptation for many traits

i.e. there is hope for adaptation when the environment changes

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

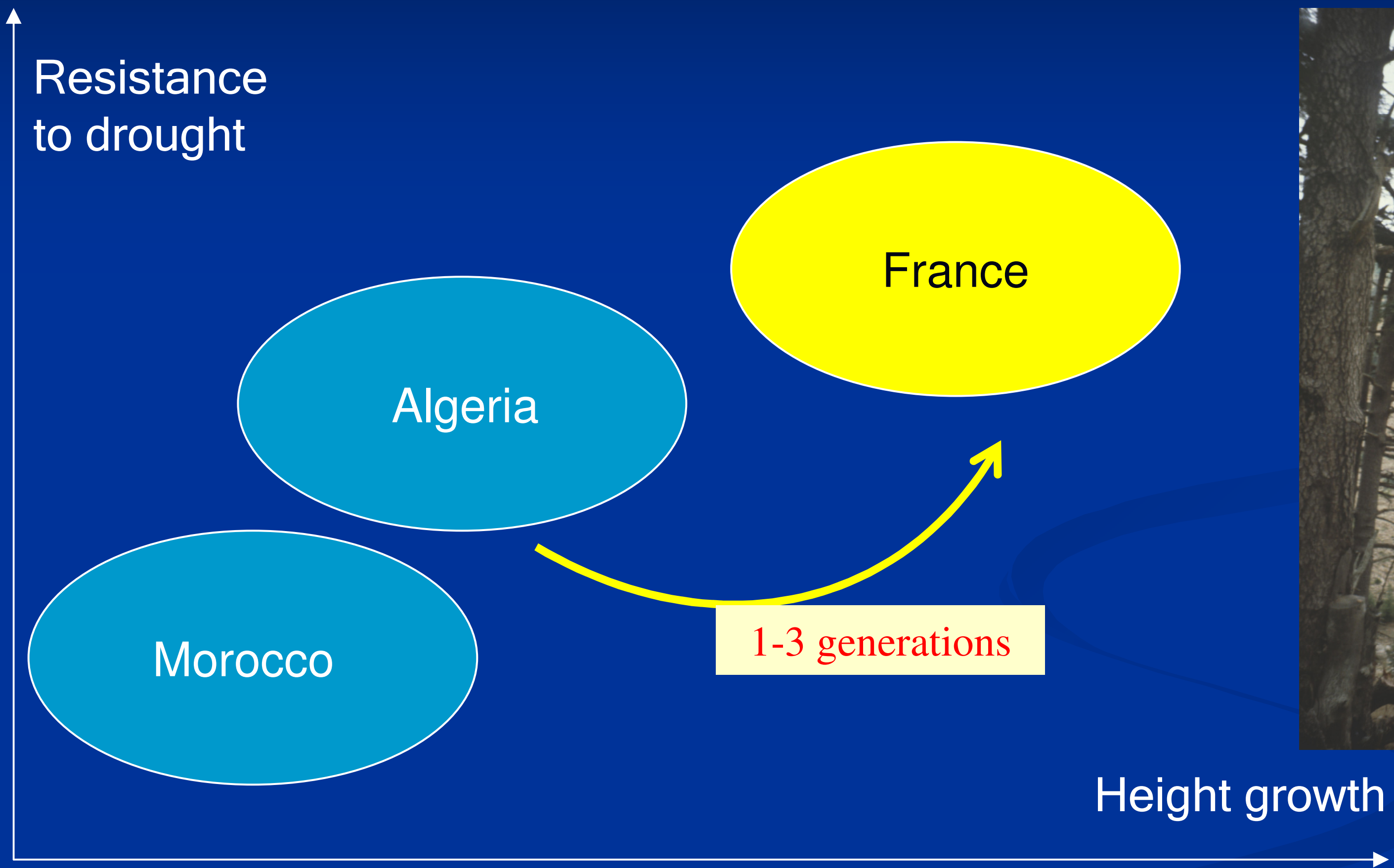
Adaptation



An ecological crisis can rapidly trigger adaptation through selection.
An example with bud set in a Scandinavian common garden.

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Adaptation



An ecological crisis can rapidly trigger adaptation through selection and strong bottlenecks. An example with two fitness related traits in French *Cedrus atlantica* common gardens.

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?
Adaptation *is possible, but at which costs?*

- Although very genetically diverse, several tree genera went extinct in Europe because of climate change during the Pleistocene (glacial / interglacial cycles): *Taxodium*, *Sequoia*, *Cedrus*, ...

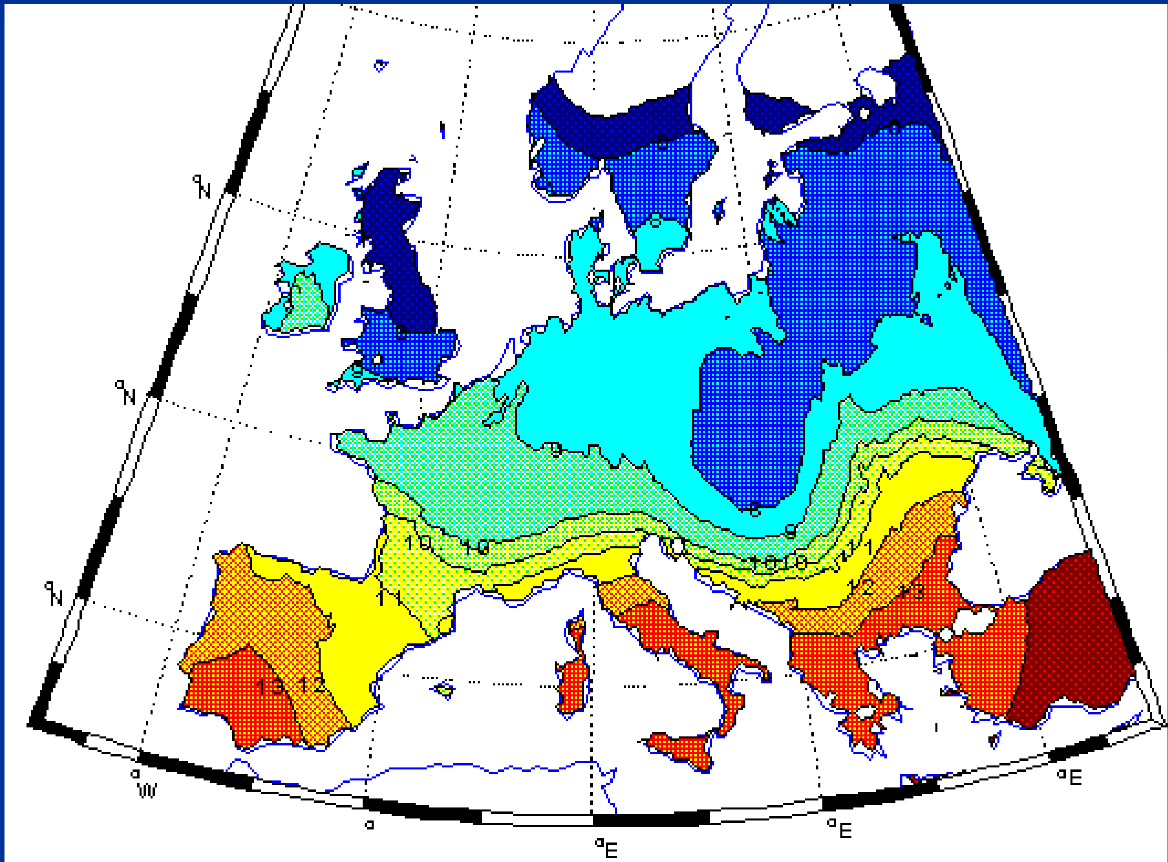
- Genetic variability of different traits may be inversely correlated. Fitness related traits may involve many low effect genes.

- A need for 1 to 12 generations to accommodate for climate change (Rehfeld et al. 2002 Global Change Biology) in *Pinus sylvestris* depending on location ==> 50 to 1000 years!

- Marginal populations (the "founder" populations under climate change) are less variable and under more severe threats than core populations.

What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Long distance dispersal



European oak isochronal pollen map (www.pierroton.inra.fr/Fairoak/)

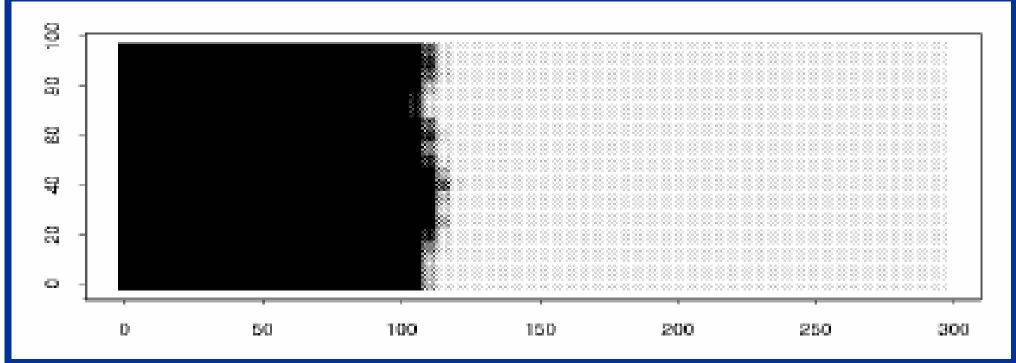
Fossil pollen data show a rapid habitat recolonization of tree species across Europe after the last Ice Age (up to 500 m per year on average during the last 12 000 years)

… is this realistic?
… is this enough?

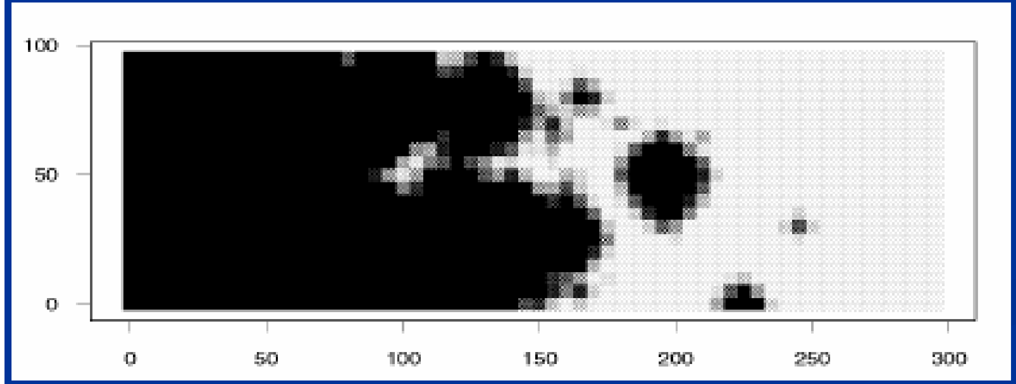
What will happen to trees that are present in the areas where ecological conditions are no longer optimal?

Long distance dispersal.

Diffusion model taking into account genetic diversity data and rare long distance events can explain why Holocene recolonization was so fast.



Simple diffusion model N (0, sd = 250 m)
==> **recolonization speed = 100 m / year**



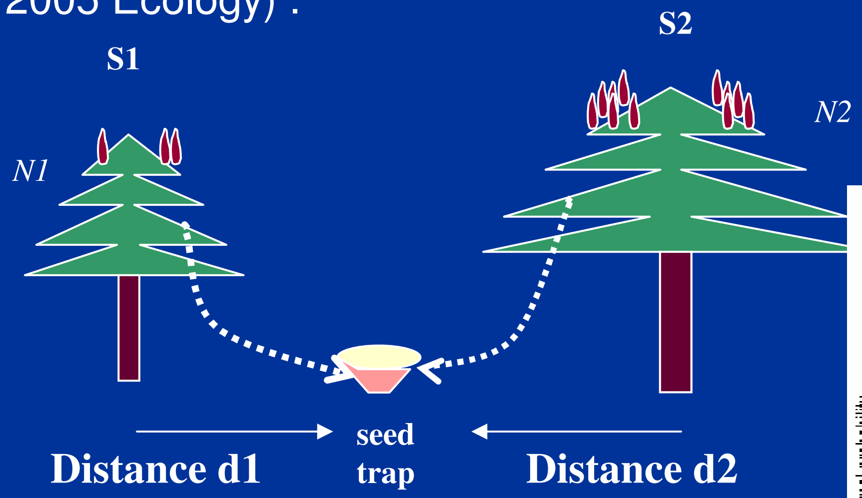
Simple diffusion model N (0, sd = 250 m)
+ rare long distance dispersal
$5*10^{-6}$ N (0, sd = 50 km)
==> **recolonization speed = 400 m / year**

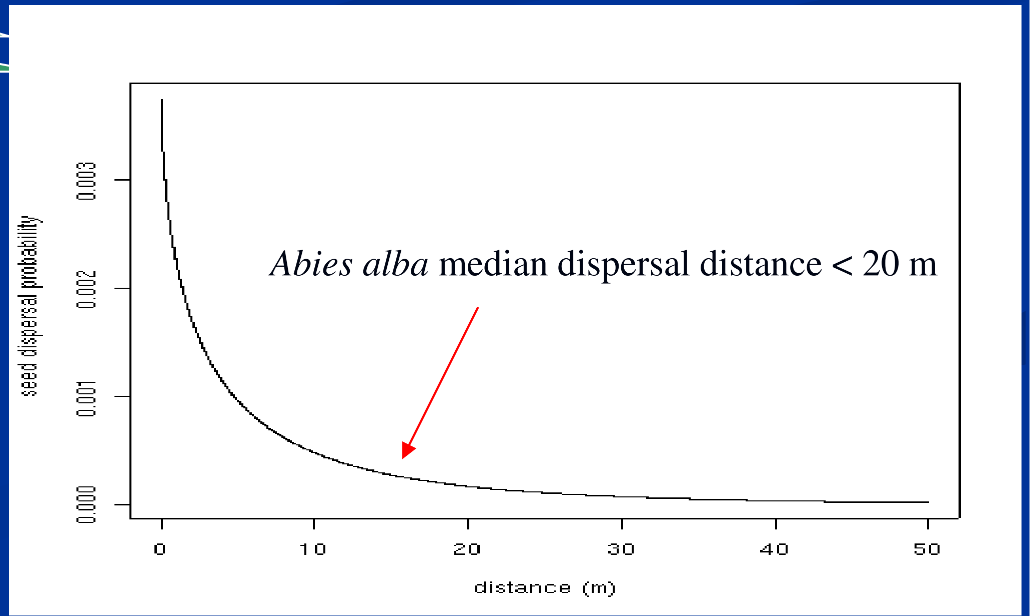
Le Corre et al., 1997. Genetical research

Some limitations to long distance dispersal: Are paleo-ecological estimates of long distance dispersal realistic?

… Current experimental data indicate that most dispersal occurs at short distances (Sagnard et al 2007, Ecological Modelling).

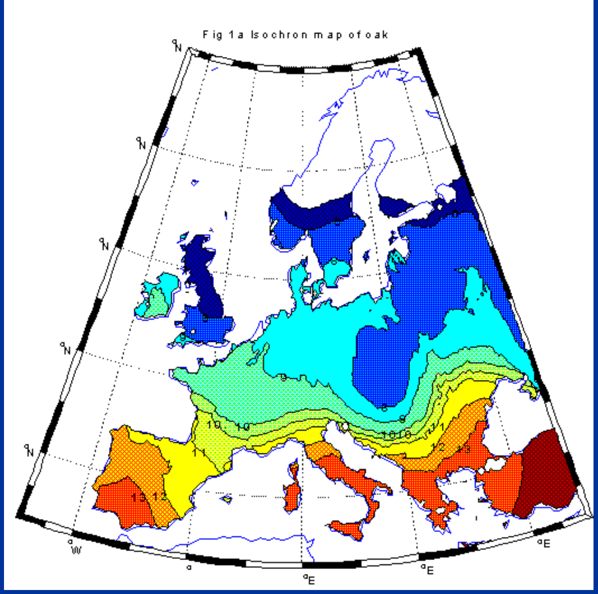
… Cryptic refugia may have been underestimated (McLachlan et al, 2005 Ecology) .





Some limitations to long distance dispersal: Is long distance dispersal (estimated from paleo-records) enough to track climate change?

"… the (*Pinus sylvestris*) genotypes best suited to the climate of 2090 currently exist at large distances (>1000 km) from the site of their future optima" (Rehfeld et al. 2002 Global Change Biology)



==> 2000 years needed to reach 2090 conditions!!

and …

current landscape structure prohibits long distance dispersal!

What will happen to trees and forest ecosystems?

Clearly, trees can

- acclimatize,
- adapt,
- move …

… but only up to a certain limit!

And this is where scientific and management challenges remain.

What can be done to protect our forest ecosystems and resources against climate change?
- Research -

✓ Research has to better understand the effects of climate (and global) change on tree diversity, physiology, ecosystem functioning, in interaction with social sciences, etc.

==> Process based modelling; effects of extreme events; multi-scale, multidisciplinary projects on biodiversity organization, multi-criteria long term breeding programs

What can be done to protect our forest ecosystems and resources against climate change?
- Policy making and management -

✓ Public awareness needs to be raised on climate change and its effects on forest ecosystems and resources:

==> one of the goals of collaborative networks such as Euforgen.

A need for a better integration of all conservation (genes, species, habitat conservation) networks. Too often is conservation limited in scope.

What can be done to protect our forest ecosystems and resources against climate change?
- Policy making and management -

✓ The "forest community" needs to ask itself the question: "what can I do with already existing knowledge and uncertainties ?"

==> managing to increase evolutionary potential as an everyday practice

What can be done to protect our forest ecosystems and resources against climate change?
- Policy making and management -

1- Make sure marginal and disjunct areas (where ecological conditions are already severe and selection already at work) are included within conservation networks and research plans.

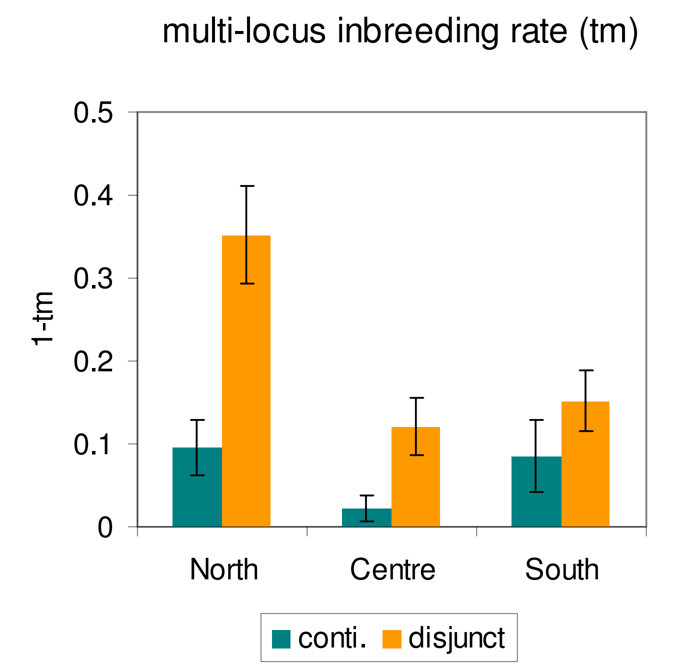
Extirpate / transfer populations most at risk.

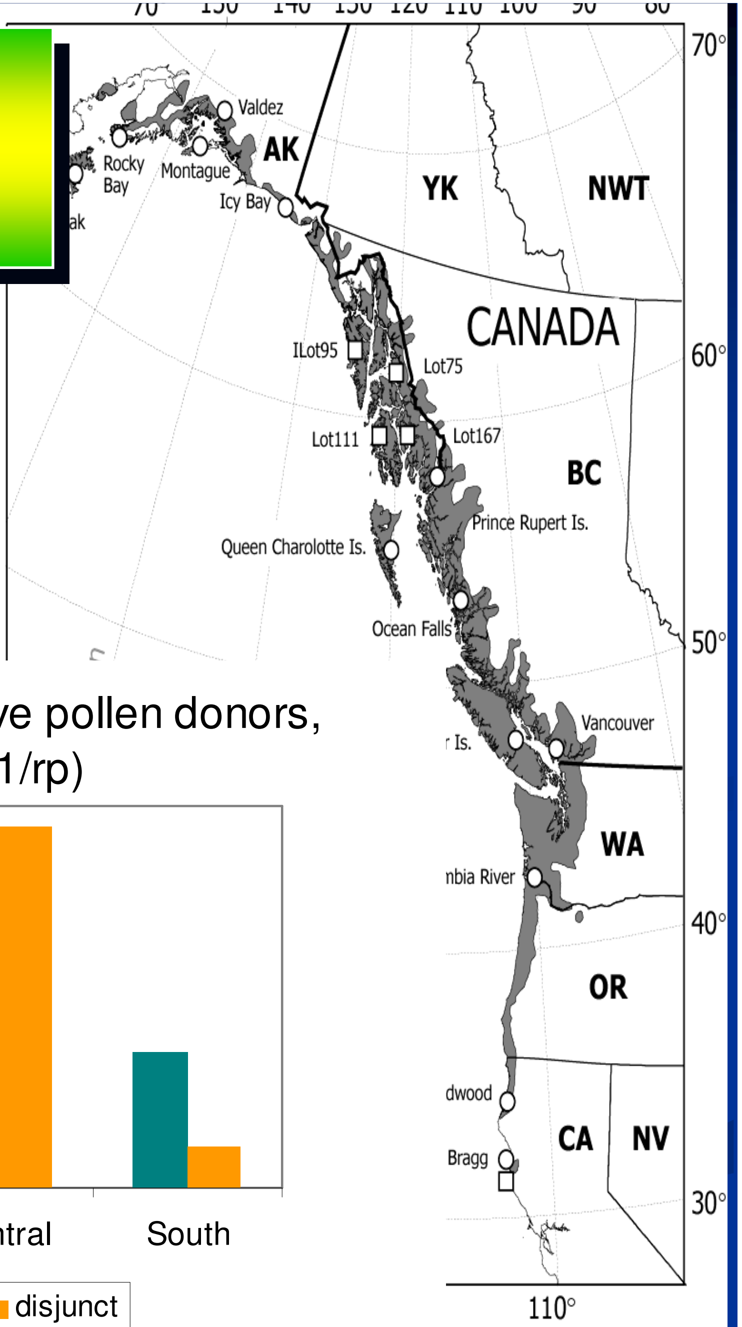
Variation in peripheral compared to central populations

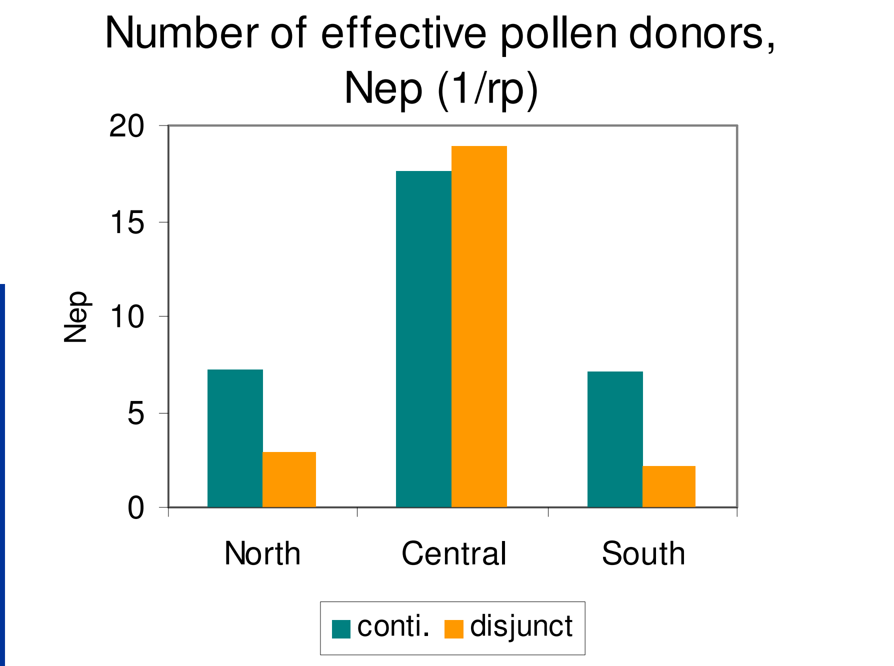
Parameter	Peripheral type	% variation compared to central
A	disjunct	96.3
	marginal	98.1
P	disjunct	90.6
	marginal	98.2
H_e	disjunct	92.4
	marginal	96.5
H_o	disjunct	89.6
	marginal	96.0

Aitken & Fady, unpublished

Core-peripheral structure in Sitka spruce



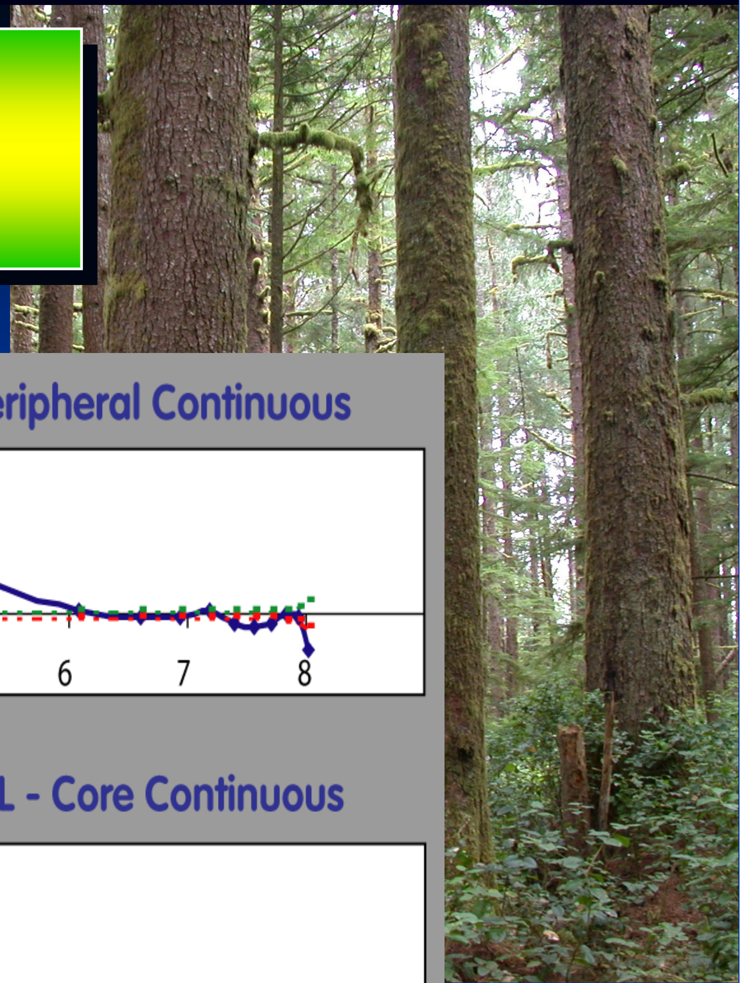


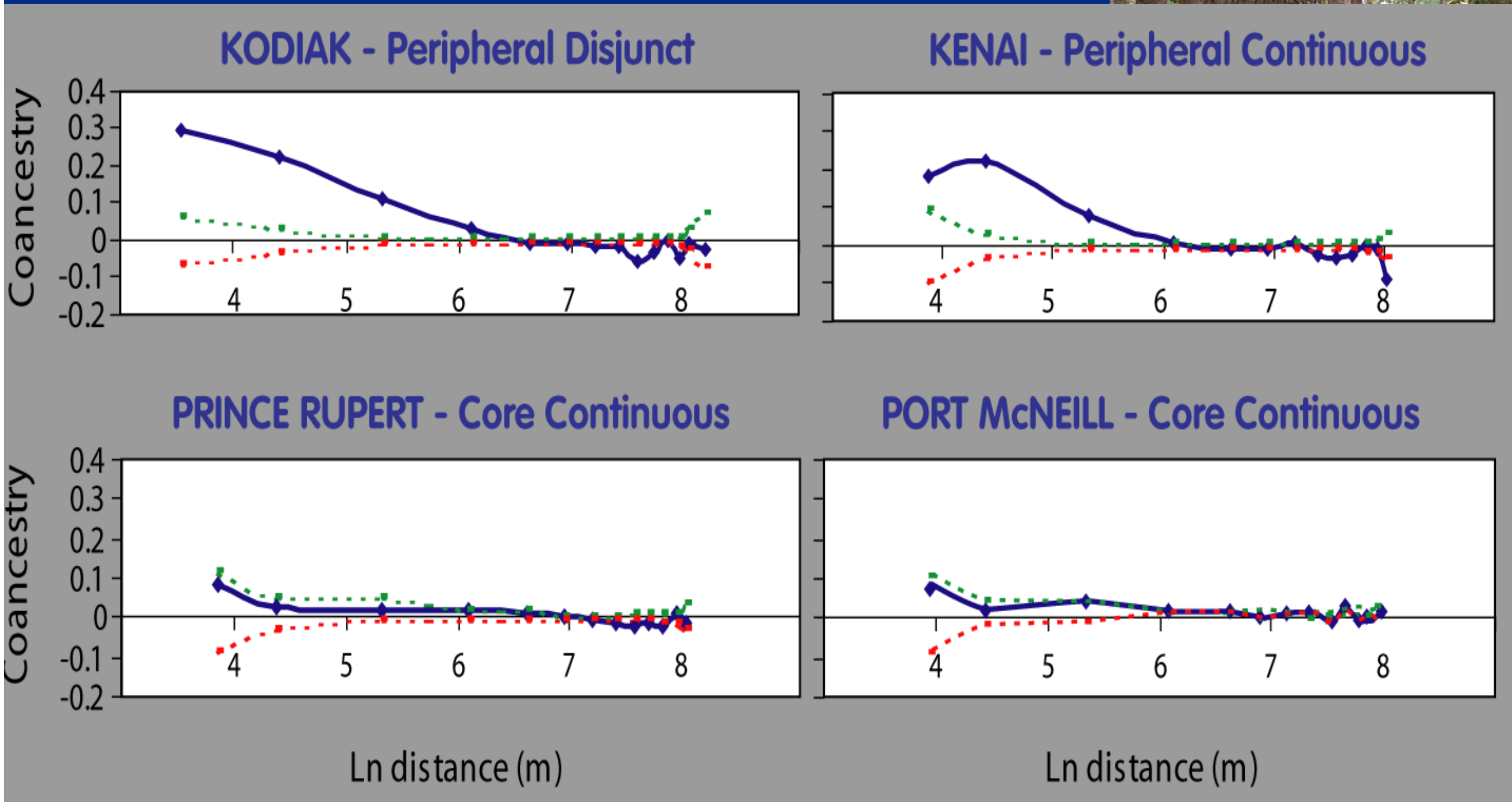


Peripheral populations show higher selfing and less effective males than core populations

Mimura and Aitken. Am. J. Bot. 2007

Core-peripheral structure in Sitka spruce

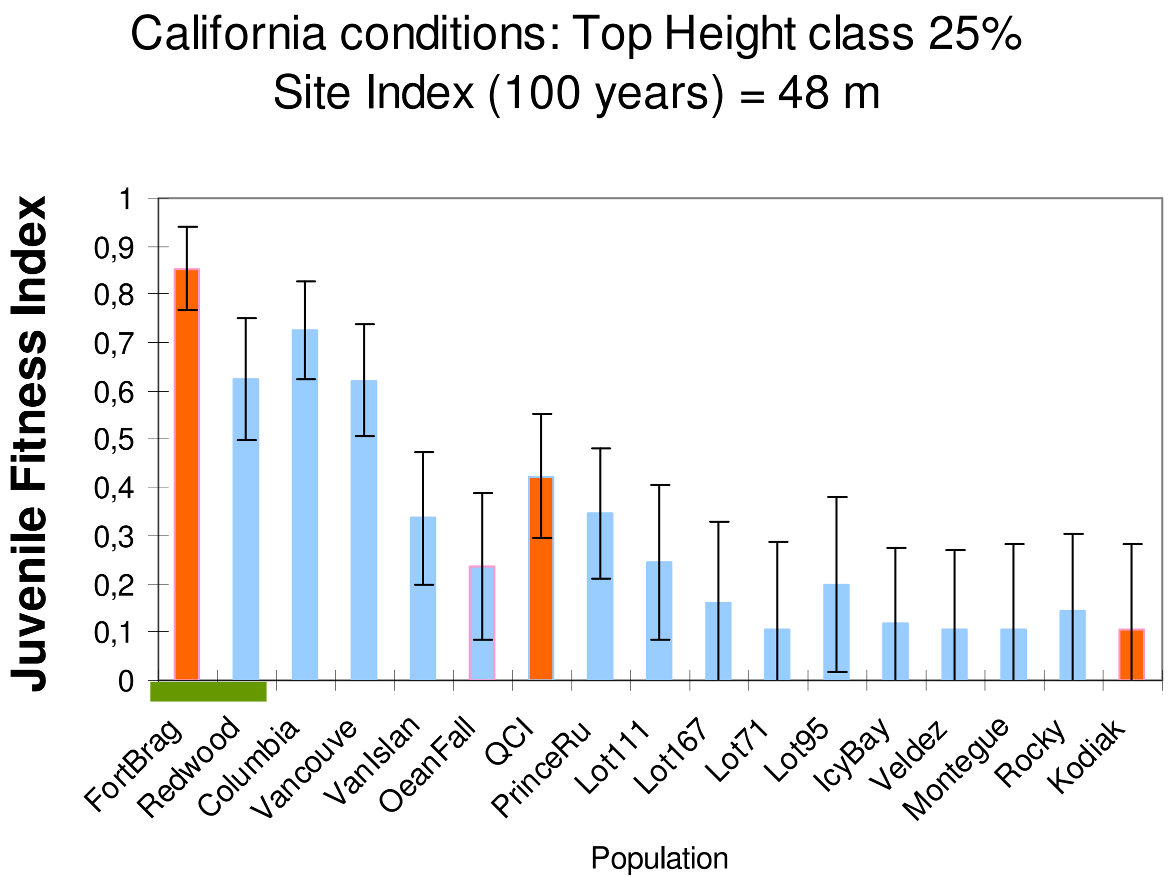


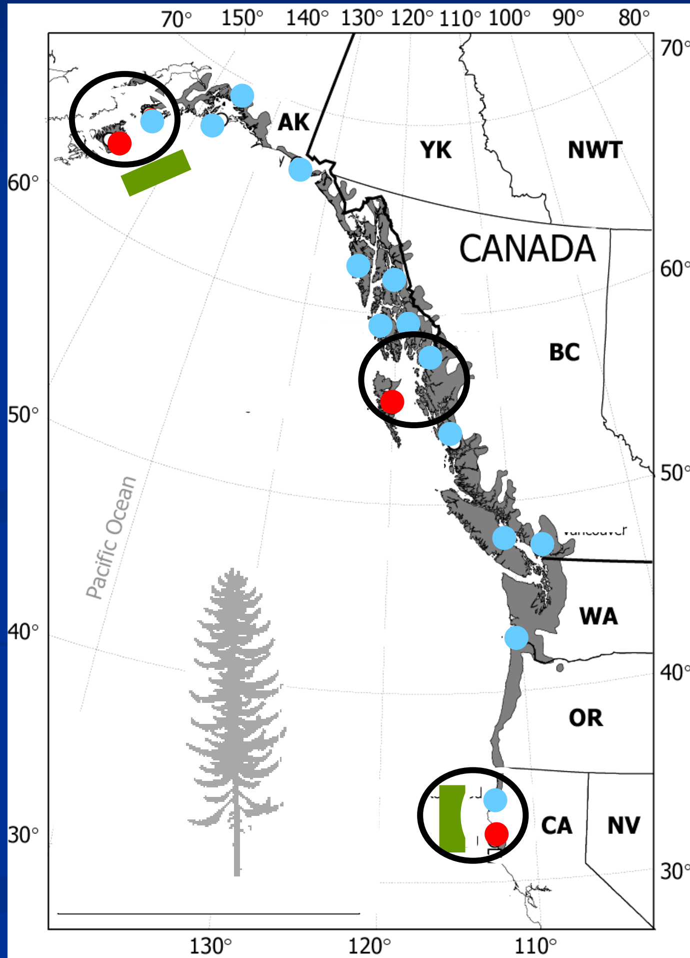


Peripheral populations have stronger spatial genetic structure than core populations

Gapare and Aitken. Mol. Ecol. 2005

Adaptation to southern environment



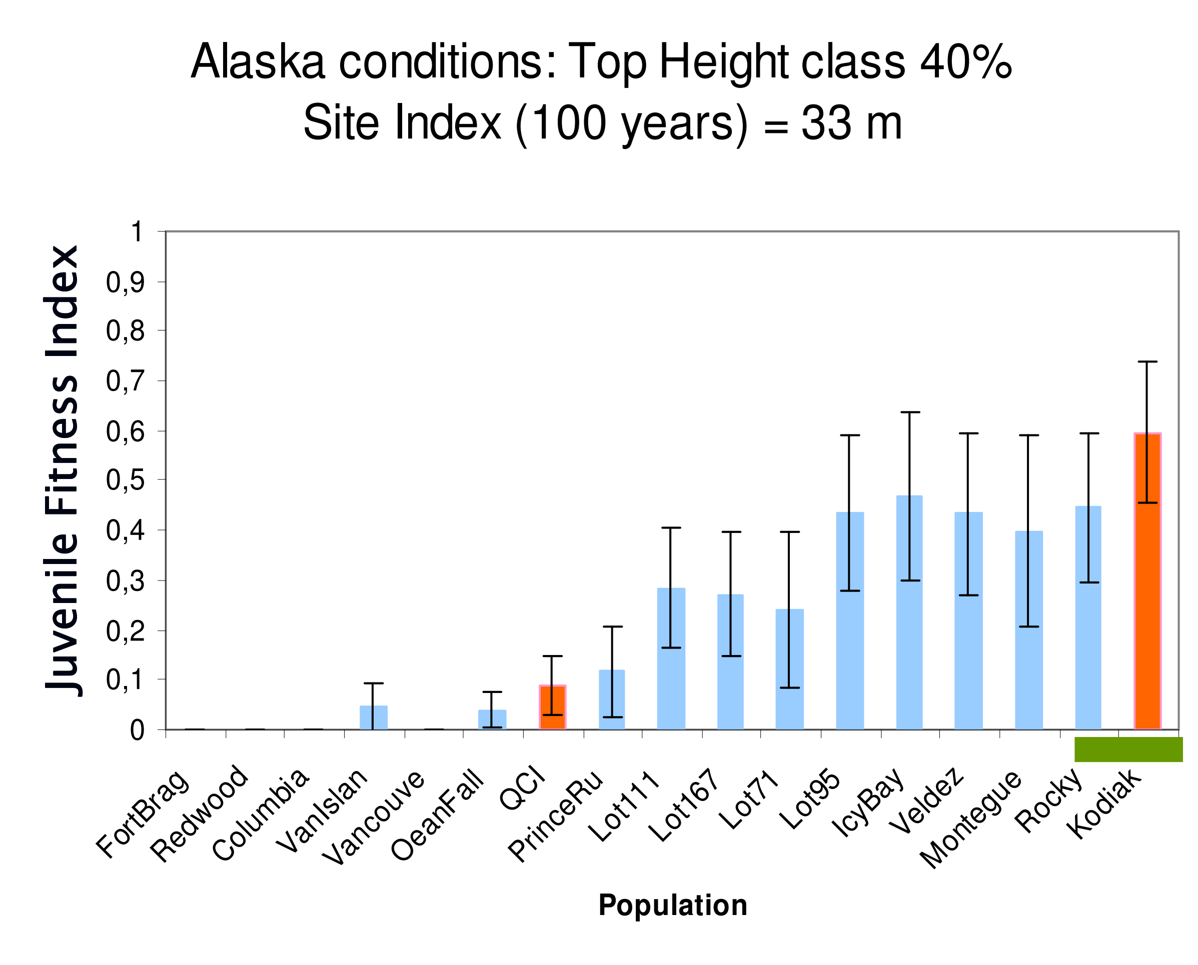


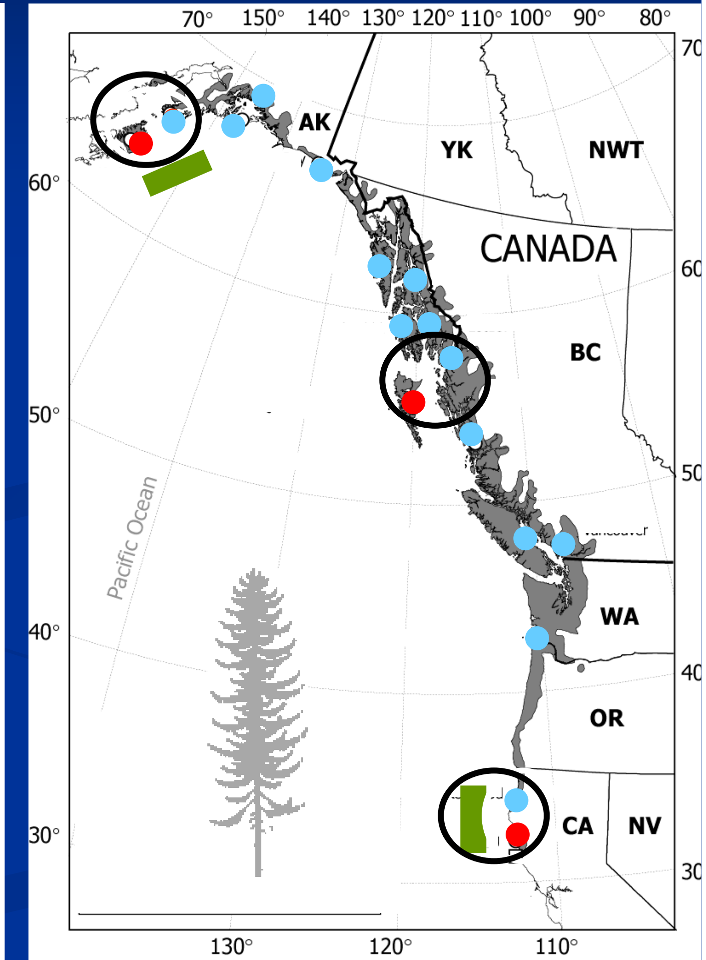
Chamber conditions

Isolated-continuous pop. pair

Mimura & Aitken. Heredity, 2007. Evolution, in press.

Adaptation to northern environment





Chamber conditions

Isolated-continuous pop. pair

Mimura & Aitken. Heredity, 2007. Evolution, in press.

Variation in peripheral compared to central populations

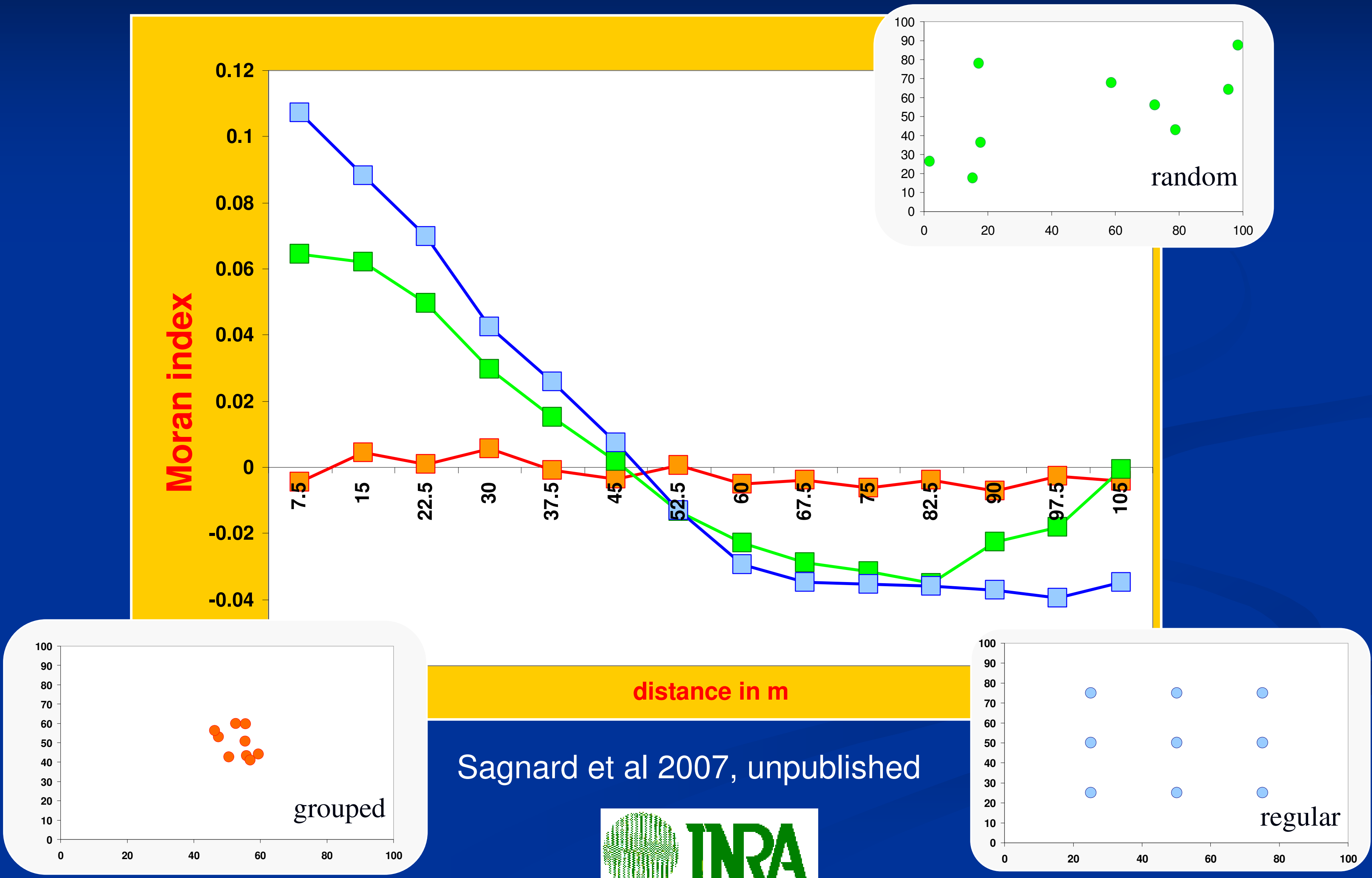
- Genetic diversity of peripheral populations remains high although they have slightly lower levels of genetic diversity than core populations due to limited gene flow and drift,
- Peripheral populations contain original genetic resources valuable for breeding (e.g. genotypes adapted to new climatic conditions), thus should be high priority for conservation,
- Disjunct, peripheral populations have higher fitness than continuous, peripheral populations. They are likely to have extreme phenotypes not found in other populations across the range.

What can be done to protect our forest ecosystems and resources against climate change?
- Management -

2- Diversify management systems within the same climatic zone / forest area to facilitate and promote evolutionary mechanisms:

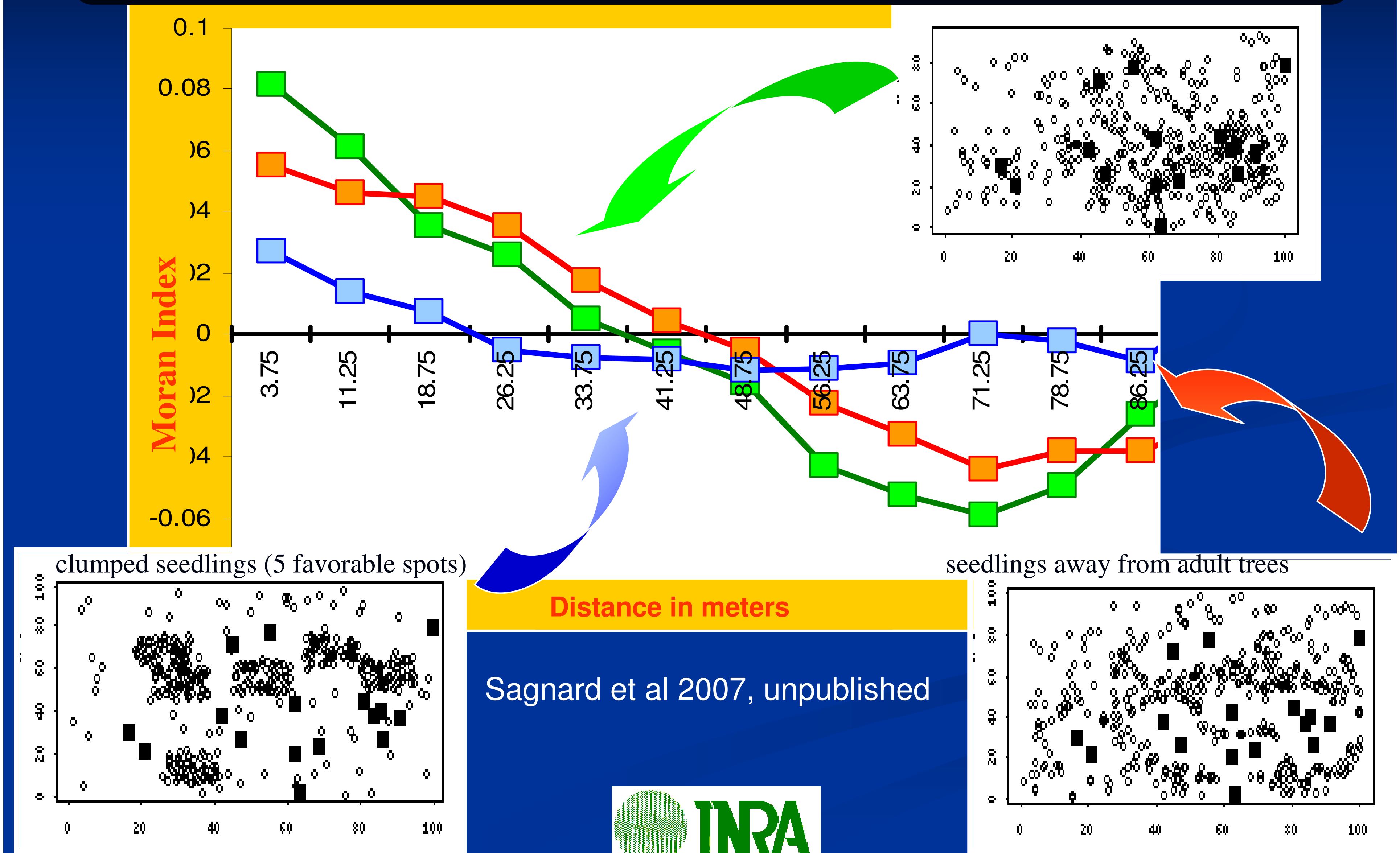
- *e.g.* increase plantation density,
- *e.g.* avoid fragmentation, too small populations,
- *e.g.* multi species management (mixed forests),
- *e.g.* variable densities (mosaic type structures) …

Effect of the spatial distribution of adult trees on the spatial genetic structure of their seedlings



Sagnard et al 2007, unpublished

Effect of the spatial distribution of seedlings on their spatial genetic structure



Sagnard et al 2007, unpublished

What can be done to protect our forest ecosystems and resources against climate change?
- Management -

3- Use proper Forest Reproductive Material (FRM).

- the cheapest FRM is not necessarily the best. Do not plant in marginal areas.

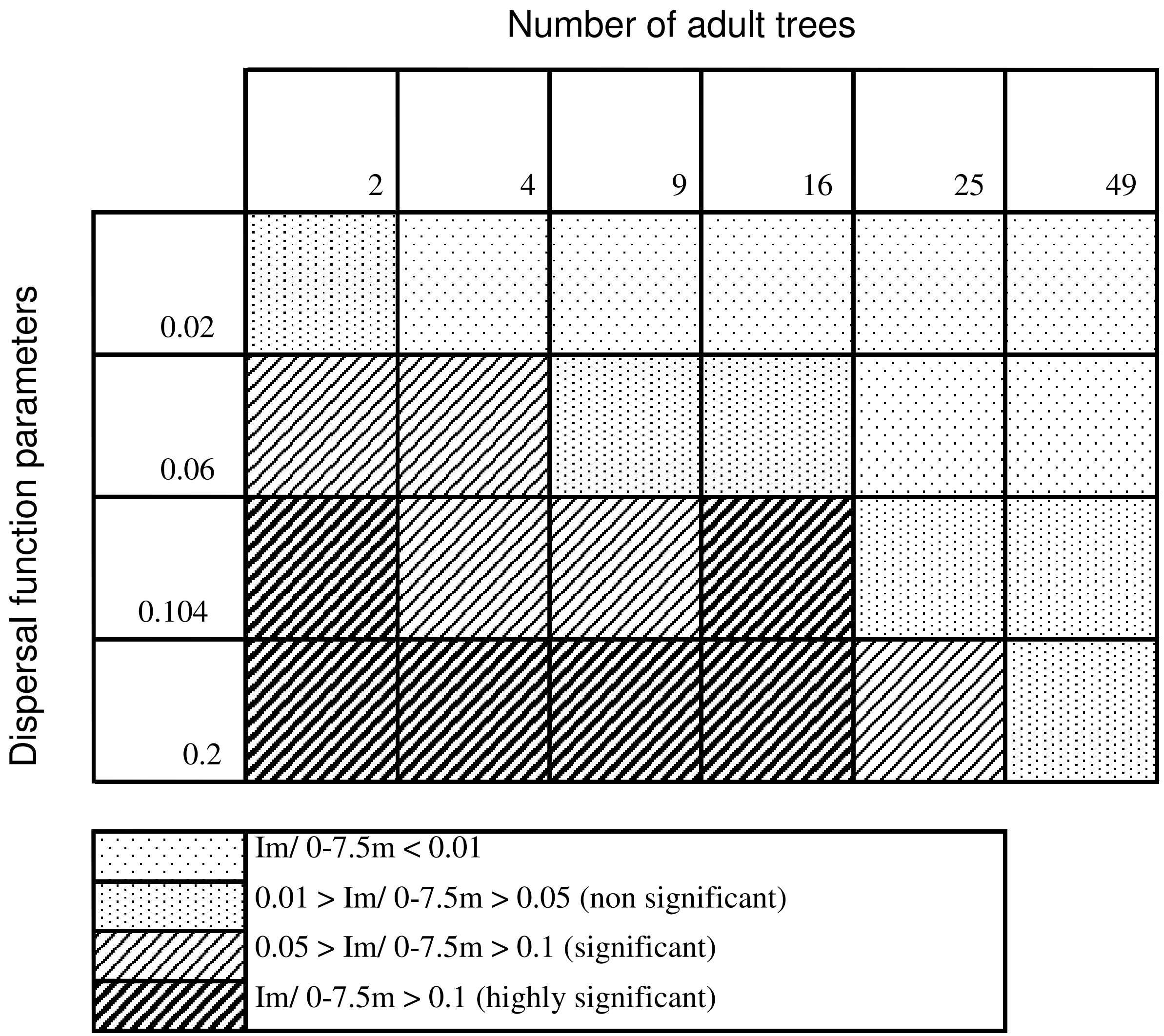
- change seed collection practice. Seed lots should be made of at least 20 trees per populations or a mix of trees from several populations within one region of provenance. Enough genetic diversity for selection to work on is crucial!

Effect of adult seed tree number and dispersal distance on genetic diversity in seedlings at short distance (= seed lots)

Dispersal parameter:

0.104 = Abies alba

0.2 = gravity dispersed species



Sagnard et al. in prep

What can be done to protect our forest ecosystems and resources against climate change?
- Management -

4- Follow plantation guidelines and seed transfer rules, but:

- Include southern / heat resistant / high phenotypic plasticity FRM in a-forestation / reforestation projects?

- Plant outside current distribution area (*e.g.* beyond current northern limits)?

- Promote hybridization (within and among natural and exotic species)?

- Ask the question “should I plant anything at all or should I promote natural regeneration?”

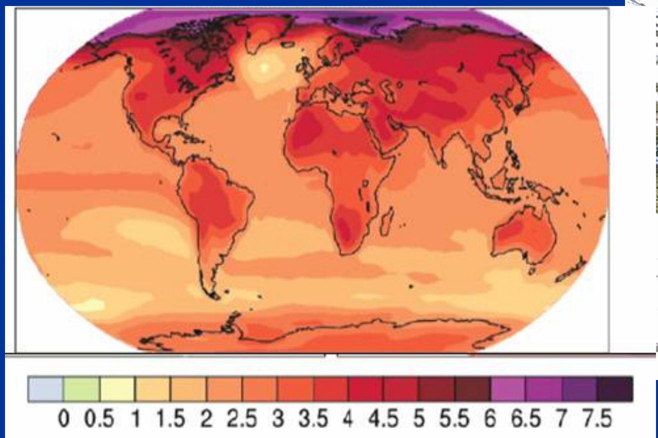
What can be done to protect our forest ecosystems and resources against climate change? - Management -

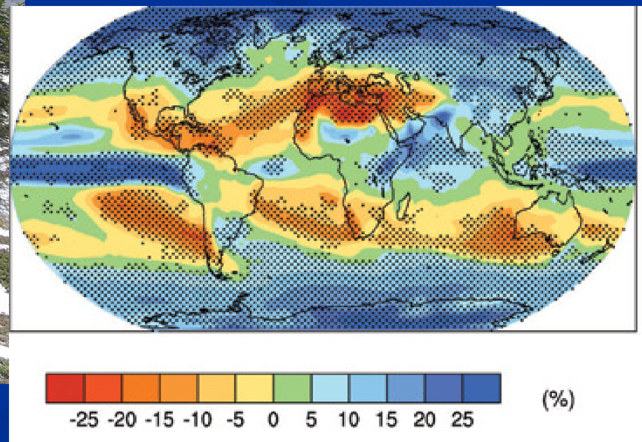
We have some tools …

… and we should use them !

Influence of climate change on the natural distribution of tree species.

Thank you for your attention !





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