Influence of climate change on the natural distribution of tree species. Diaporama
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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
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 °C 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)
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,
• 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.
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.
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°C (*likely* range is 1.1°C to 2.9°C),

and for high scenario (A1FI) is 4.0°C (*likely* range is 2.4°C to 6.4°C).
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°C) and rainfall (0.1 to 0.3 mm/day)!
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
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**

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

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

*Quercus petraea*

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**

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.).
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

Marginal stands: autochthony is not always best
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? **Plasticity and its limitations**
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
An ecological crisis can rapidly trigger adaptation through selection. An example with bud set in a Scandinavian common garden.
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.
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

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?

European oak isochronal pollen map (www.pierroton.inra.fr/Fairoak/)
Diffusion model taking into account genetic diversity data and rare long distance events can explain why Holocene recolonization was so fast.

Simple diffusion model $N(0, \text{sd} = 250 \text{ m})$  
$\Rightarrow$ recolonization speed $= 100 \text{ m} / \text{year}$

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

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

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).

Abies alba median dispersal distance < 20 m
Some limitations to long distance dispersal:  
Is long distance dispersal (estimated from paleo-records) enough to track climate change?

“… the \textit{(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)

\[ \text{==> 2000 years needed to reach 2090 conditions!!} \]

\[ \text{and … current landscape structure prohibits long distance dispersal!} \]
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.
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.
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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Peripheral type</th>
<th>% variation compared to central</th>
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</thead>
<tbody>
<tr>
<td>A</td>
<td>disjunct</td>
<td>96.3</td>
</tr>
<tr>
<td></td>
<td>marginal</td>
<td>98.1</td>
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<tr>
<td>P</td>
<td>disjunct</td>
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<td></td>
<td>marginal</td>
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<tr>
<td>$H_e$</td>
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<td>$H_0$</td>
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<td>89.6</td>
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<tr>
<td></td>
<td>marginal</td>
<td>96.0</td>
</tr>
</tbody>
</table>

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

California conditions: Top Height class 25%
Site Index (100 years) = 48 m

Juvenile Fitness Index

Population

Alaska conditions: Top Height class 40%
Site Index (100 years) = 33 m

Adaptation to northern environment

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.
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

Distance in meters

Sagnard et al 2007, unpublished
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)

<table>
<thead>
<tr>
<th>Dispersal function parameters</th>
<th>Number of adult trees</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02</td>
<td>2 4 9 16 25 49</td>
</tr>
<tr>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>0.104</td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
</tr>
</tbody>
</table>

- Im/ 0-7.5m < 0.01
- 0.01 > Im/ 0-7.5m > 0.05 (non significant)
- 0.05 > Im/ 0-7.5m > 0.1 (significant)
- Im/ 0-7.5m > 0.1 (highly significant)

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!