# How will *Fagus sylvatica* L. respond to climate change? Modelling its geographic distribution and adaptive potential.

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with sheets from: Gert-Jan Nabuurs, Thomas Gieseke, Andreas Bolte

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## Outline

- issues addressed in this presentation
- background
  - distribution Fagus sylvatica
  - projected climate change
- models
  - methodology
  - results
- conclusions & recommendations

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## Structure – modeling section

| 1. Species area models | 2. Genetic models |
|---|---|
| A. statistical niche-based modeling (Wilfried Thuiller) → | A. landscape scale: EcoGene (Bernd Degen), applied to centre of distribution range |
| B. process-based modeling: LPJ-Guess (Thomas Hickler, Martin Sykes) → | B. stand scale: ForGEM (Koen Kramer + collegues), applied to NW- and S- edge of distribution range |

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## Issues

1. What is the likely effect of climate change on the geographic distribution of Fagus sylvatica?
2. Which factors are mainly responsible for this change?
   - growing season duration
   - water availability
   - frost
3. Is there sufficient adaptive potential?

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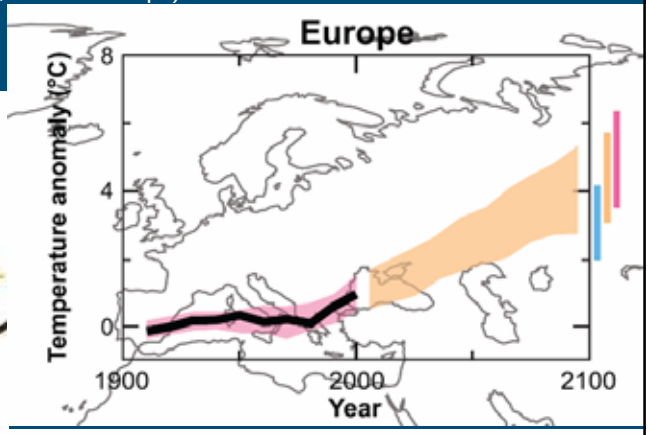
## Distribution of Fagus sylvatica L.

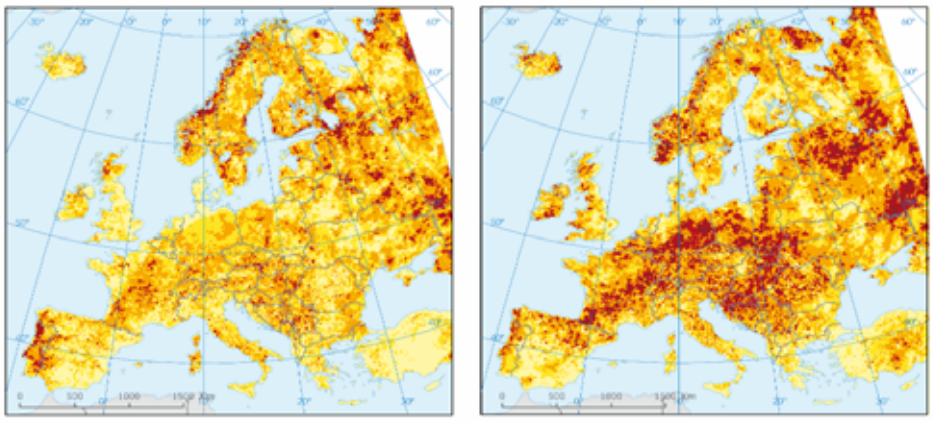
## Projected climate change in Europe

- Temperature: +2.0 ° C to +6.2 ° C (min. SRES B2 to max. A2 scenario)
- More extremes: more frequent and intensive heat waves and droughts (Mediterranean area, Central Europe)




Source: Christensen et al., 2007 (IPCC report)

## Projection of heat waves



**Heat wave frequency for the periods 1961–1990 (left) and 2071–2100 (right)**
Based on the IPCC-SRES A2 emission scenario and the DMI climate model

Source: EEA, 2007

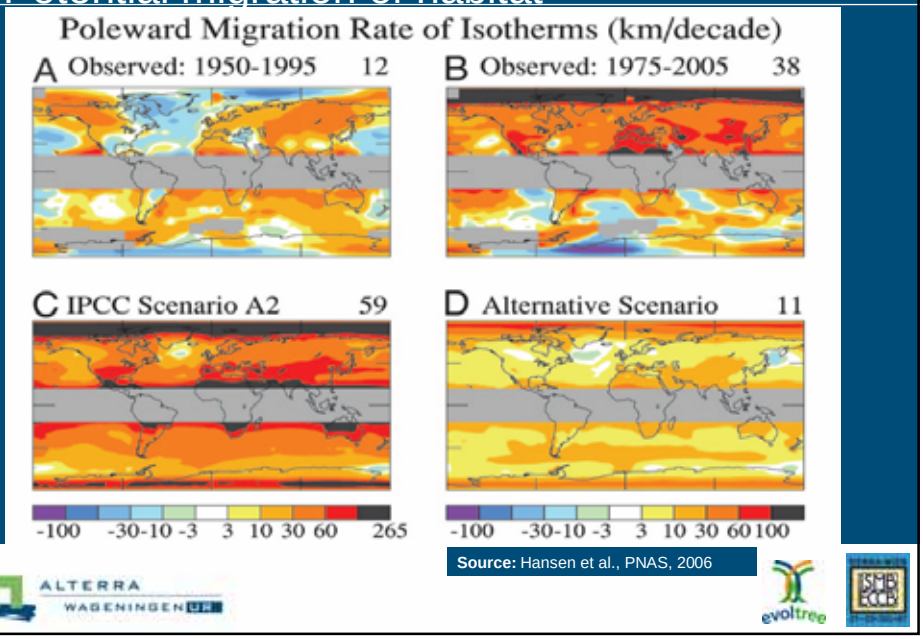
Frequency of heat wave events of 7 days or longer

< 1 | 1 | 2–3 | 4–5 | 6–7 | 8–9 | ≥ 10 | Outside report coverage

**Note:** The A2 baseline scenario in combination with the Danish regional climate model.

**Source:** Indicator elaboration: R. Hiederer, European Commission DG Joint Research Centre, Institute for Environment and Sustainability, 2007.
Data: PRUDENCE Project 12km HIRHAM4, Danish Climate Centre, 2006.

## Potential migration of habitat




**Source:** Hansen et al., PNAS, 2006

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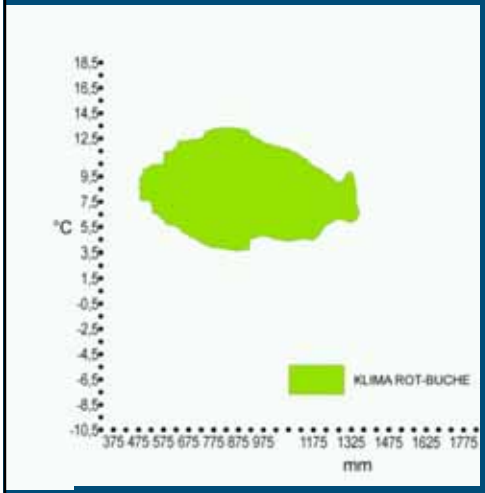
## 1A. Species area models : Statistical modeling




Minimum requirements beech:

-Precipitation : about 500 mm p.a.; 250 mm from May to September

-July mean temperature < 19°C

- < 141 frost days

- January mean temperature > – 3°C

- more than 217 days with a daily mean temperature > 7°C (growing season)

(Bolte et al, 2007)

Climate envelope Fagus sylvatica (Kölling et al. 2007)

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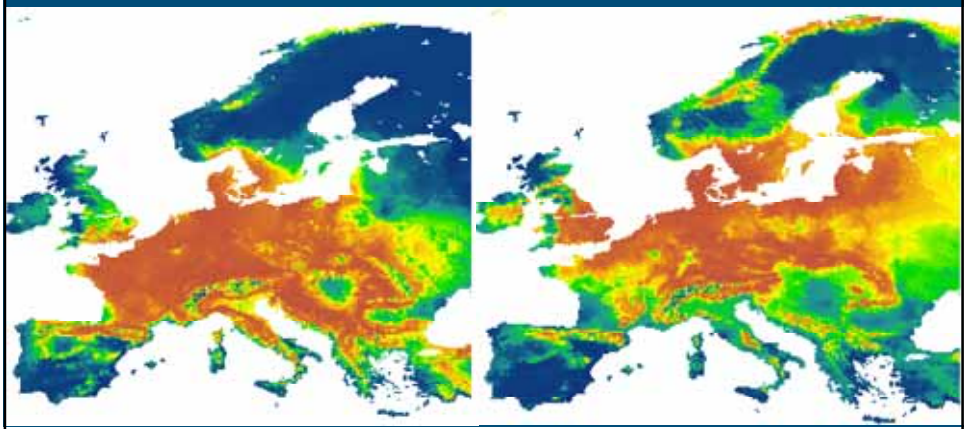
## 1A. Results statistical species area modeling

current climate A2 (~B1)-scenario:



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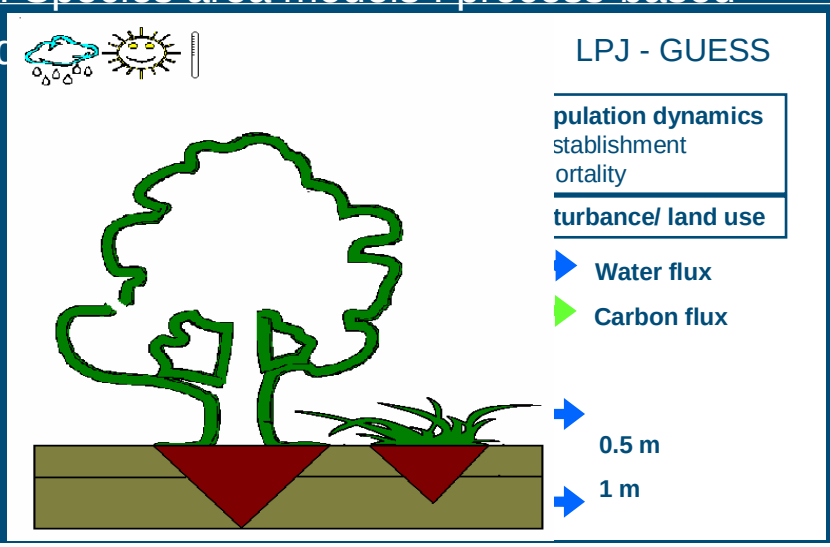
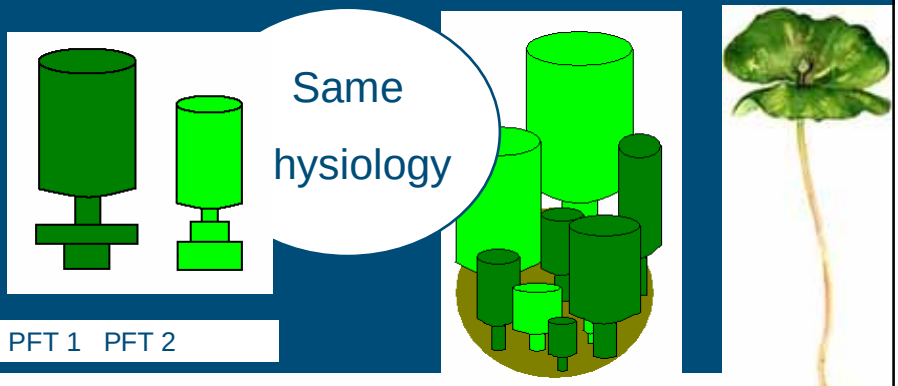
## 1B. Species area models : process-based mod




Smith, B., I. C. Prentice, and M. T. Sykes. 2001. *Global Ecology & Biogeography* **10**:621-637.
www.nateko.lu.se/embers: about 30 publications, e.g. Hickler, T., B. Smith, M. T. Sykes, et al. 2004. *Ecology* **85**:519-530.

Combines two formerly separated models:
Lund-Potsdam-Jena (LPJ) Dynamic Global Vegetation Model + General Ecosystem Simulator (GUESS)

| LPJ | GUESS |
|---|---|
| • Average individuals | • Age classes |
| • No age classes | • Gap dynamics |



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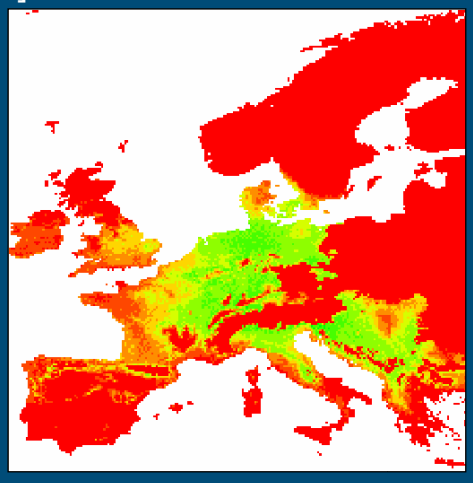
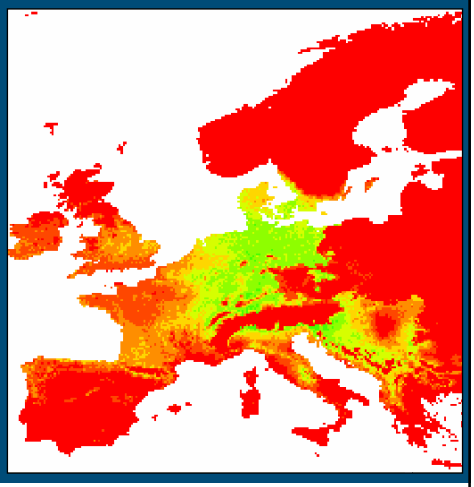
## 1B. Results p-b species area model: leaf area index [0 .. 4]

current



A2 scenario



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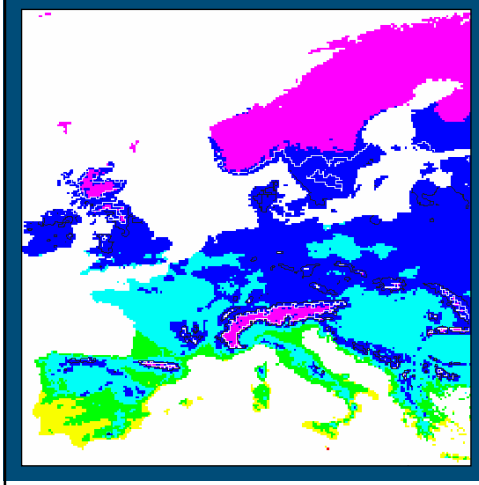
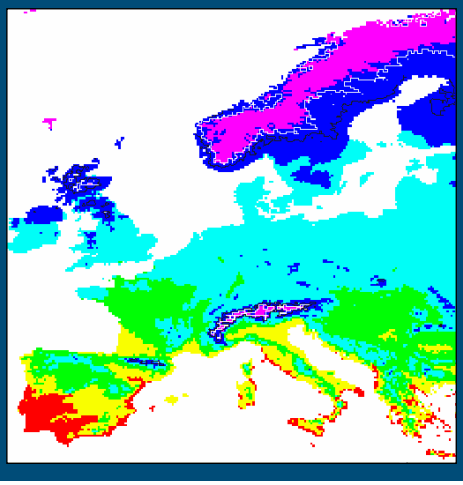
## growing degrees [0 .. 6000]

current



A2 scenario



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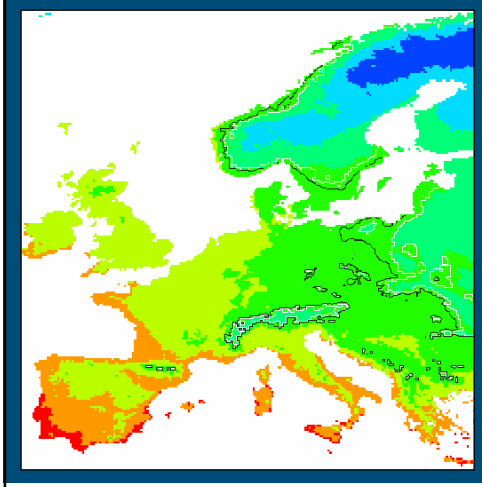
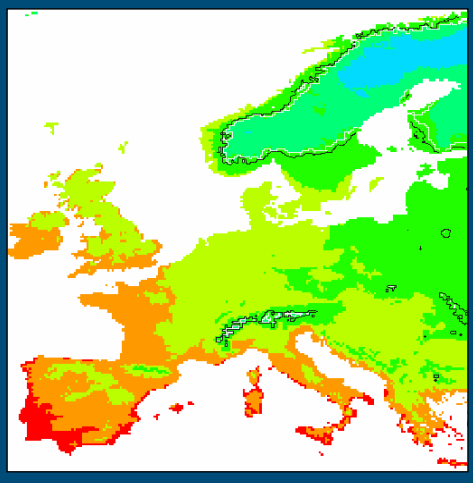
## minimum temperature [-30 .. 15]

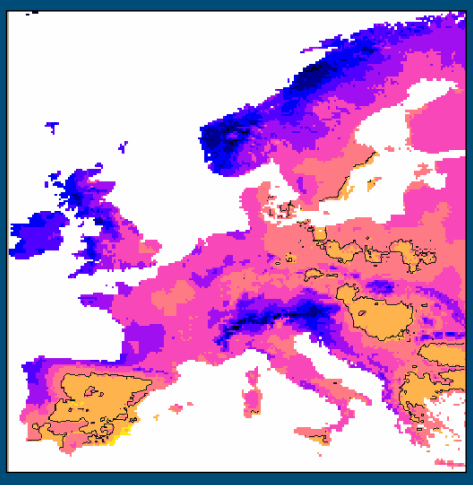
current A2 scenario

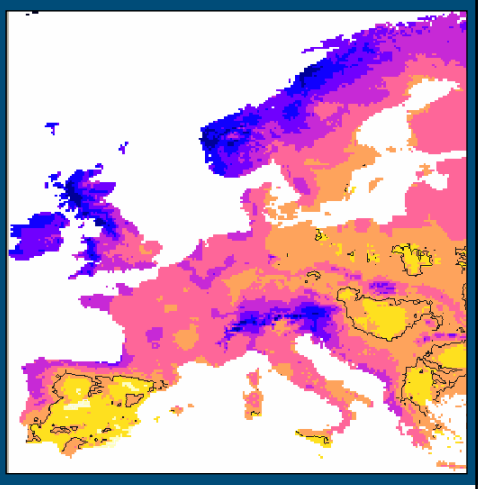




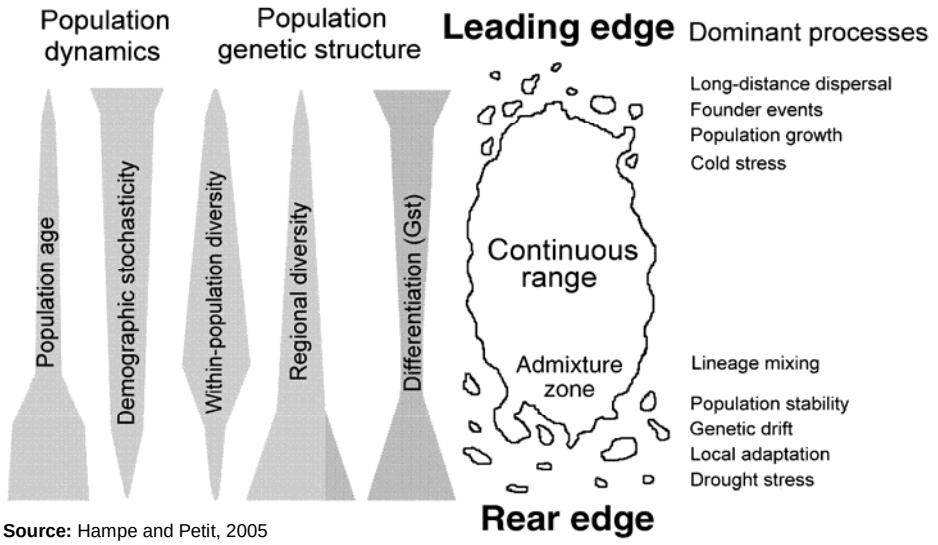
## relative water availability top 0.5m [0 .. 1]

current A2 scenario



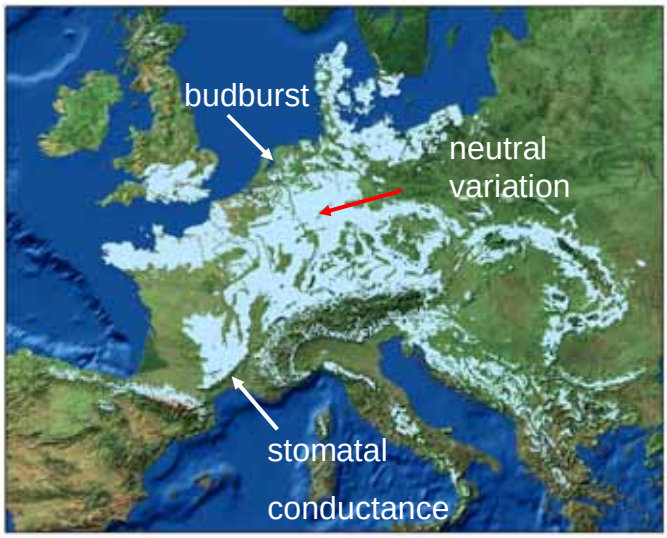


## Is there sufficient adaptive potential?




**Source:** Hampe and Petit, 2005

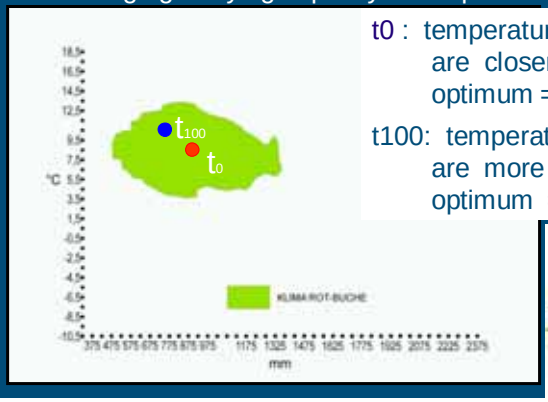
## 2. Genetic modeling



## 2A. Landscape level genetic modeling: Eco-Gene

Scenario on changing temperature and precipitation

=> changing carrying capacity for a species




t0 : temperature and percipitation
are closer to the species
optimum => higher carrying capacity

t100: temperature and percipitation
are more distant to the species
optimum => lower carrying capacity

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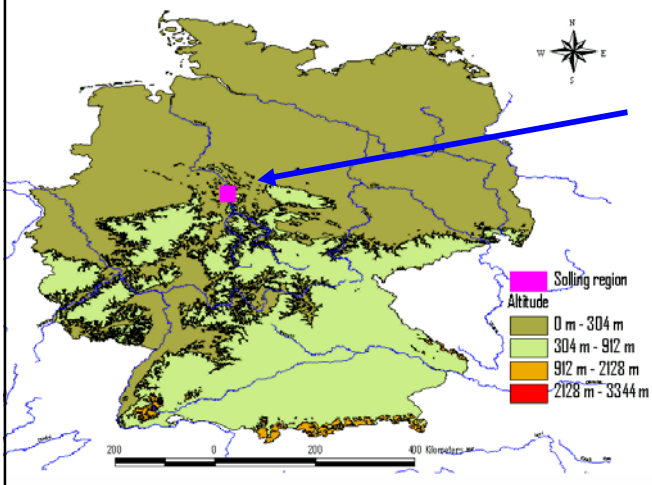
## study site




Simulations were done using landscape information of a 10km by 10km area of the Solling region in Germany

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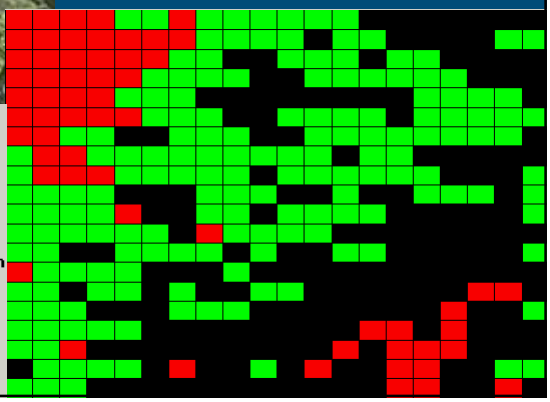
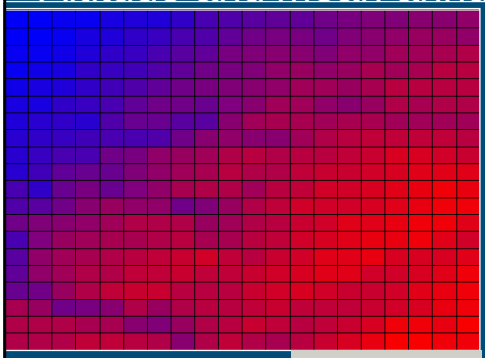
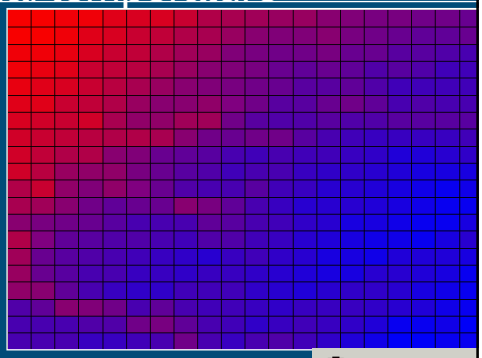
## The data set “Solling”

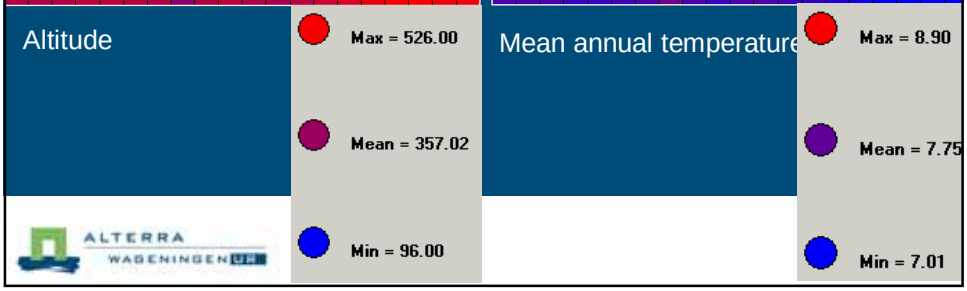
Landscape information is integrated into the model



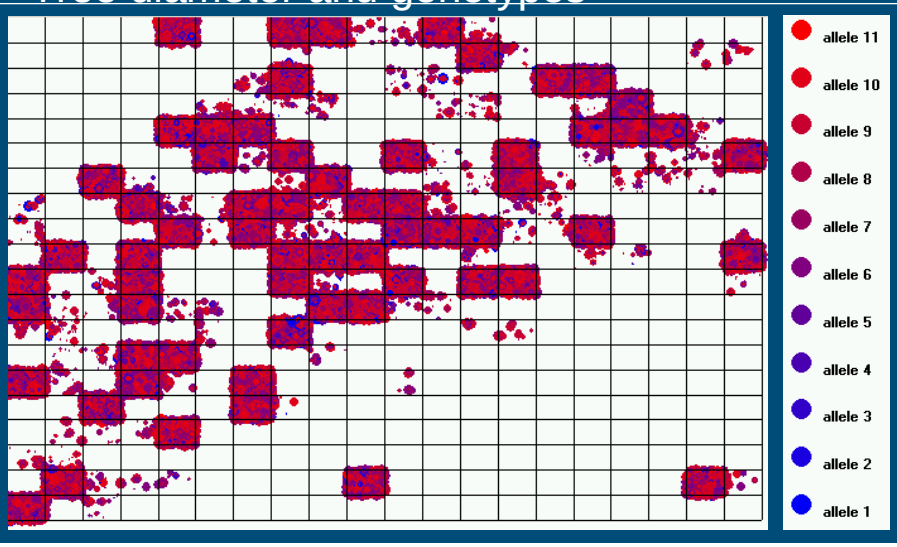

## Altitude and mean annual temperature







## Tree diameter and genotypes




## Scenarios – 100yr

- Scenario A.
  - constant mean temperature
  - mean annual rainfall average 1950-2000
- Scenario B.
  - linear increasing temperature of 2C°
  - linear **de**-creasing annual rainfall by 20%
- Scenario C.
  - linear increasing temperature of 2C°
  - linear **in**-creasing annual rainfall by 20%

## Effect of scenarios on carrying capacity

**Total number of reproductive trees of *Fagus sylvatica***

| | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| **Year 1** | 130,204 | 130,204 | 130,204 |
| **Year 100** | 128,770 | 111,498 | 127,755 |

**Total number of reproductive trees of *Picea abies***

| | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| **Year 1** | 120,808 | 120,808 | 120,808 |
| **Year 100** | 117,576 | 19,515 | 5,606 |

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## 2A. Results landscape level genetic modeling

**Mean effective number of alleles for *Fagus sylvatica***

| | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| **Year 1** | 1.47 | 1.47 | 1.47 |
| **Year 100** | 1.46 | 1.46 | 1.46 |

**Mean effective number of alleles for *Picea abies***

| | Scenario A | Scenario B | Scenario C |
|---|---|---|---|
| **Year 1** | 2.87 | 2.87 | 2.87 |
| **Year 100** | 2.87 | 2.85 | 2.83 |

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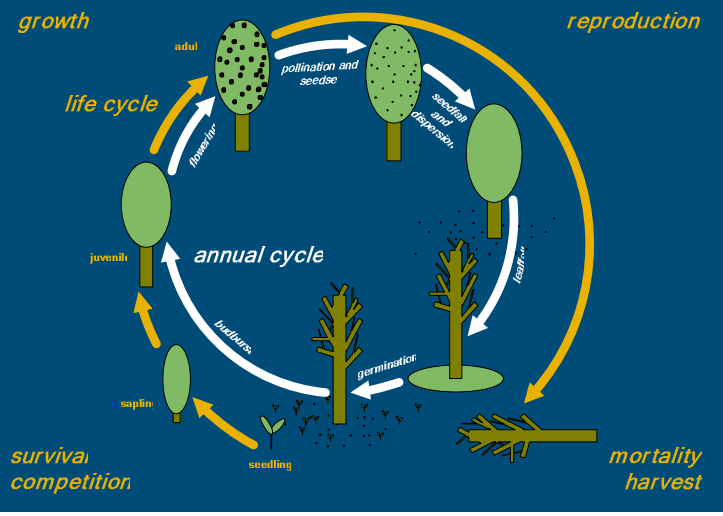
## 2B. Genetic modelling stand scale: ForGEM



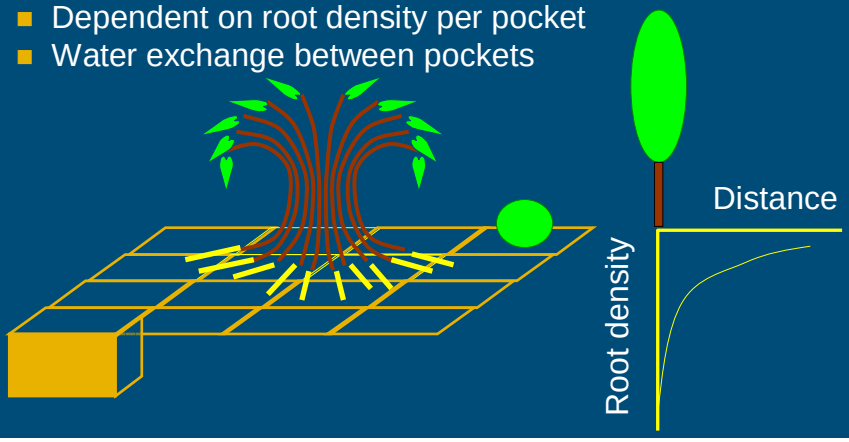

Kramer et al. 2008

## Physical environment: light interception

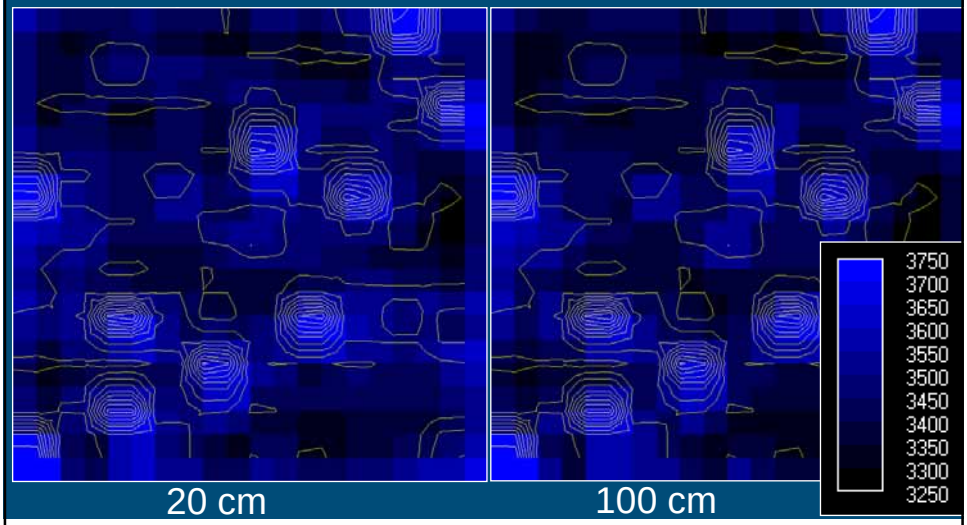
- Ray tracing or gap model
- Gap model for seedling and ray tracing for ‘adults’
- Purpose: amount of energy intercepted by the plant

## Physical environment: water availability

- Gas exchange (e.g. temp, humidity, radiation) => water need
- Dependent on root density per pocket
- Water exchange between pockets



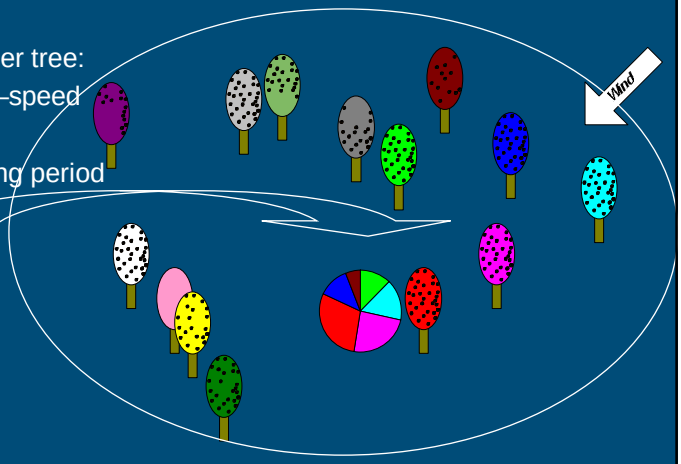

## Water content at different depth (g H2O /



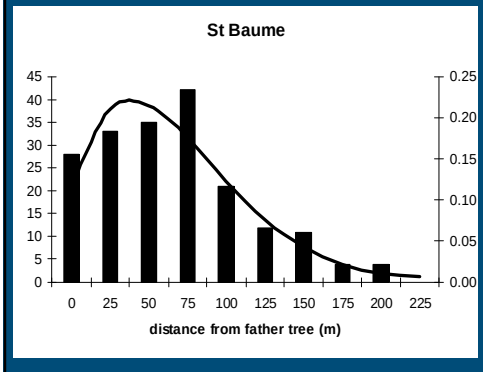
## Pollination

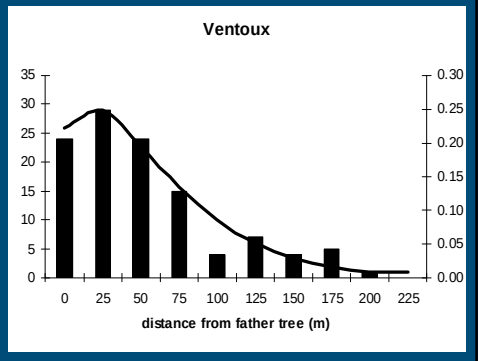
Fraction pollen at mother tree:

- Wind direction and –speed
- Number of flowers
- Overlapping flowering period
- Self pollination
- Pollen from outside
- Compatibility



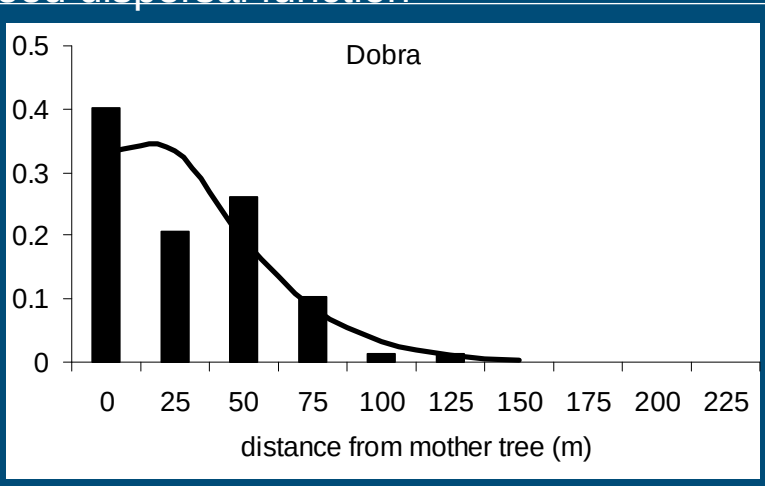

## Pollen dispersal curve



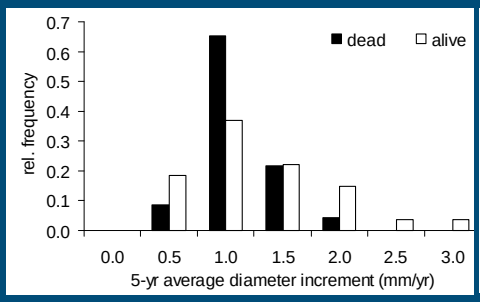

- Observed and estimated pollen dispersal curve in France.

## Seed dispersal function

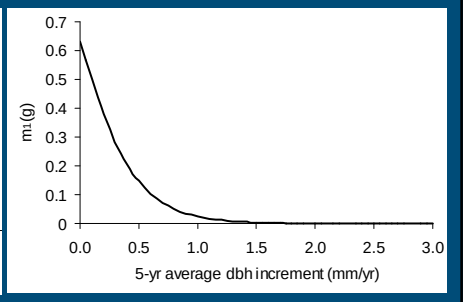



- Observed and estimated seed dispersal curve in Austria

## Mortality / fitness




Observed distribution of diameter increment of currently living and currently dead trees

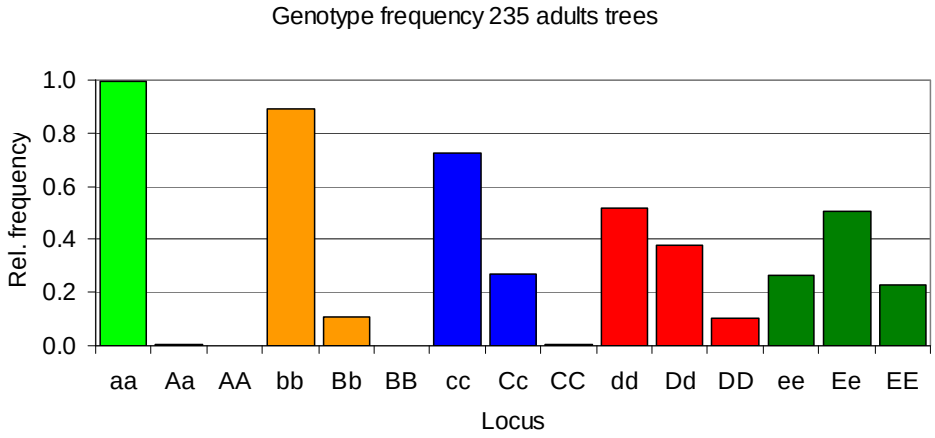



Derived probability of annual mortality depending on growth (Kobe & Pacala)

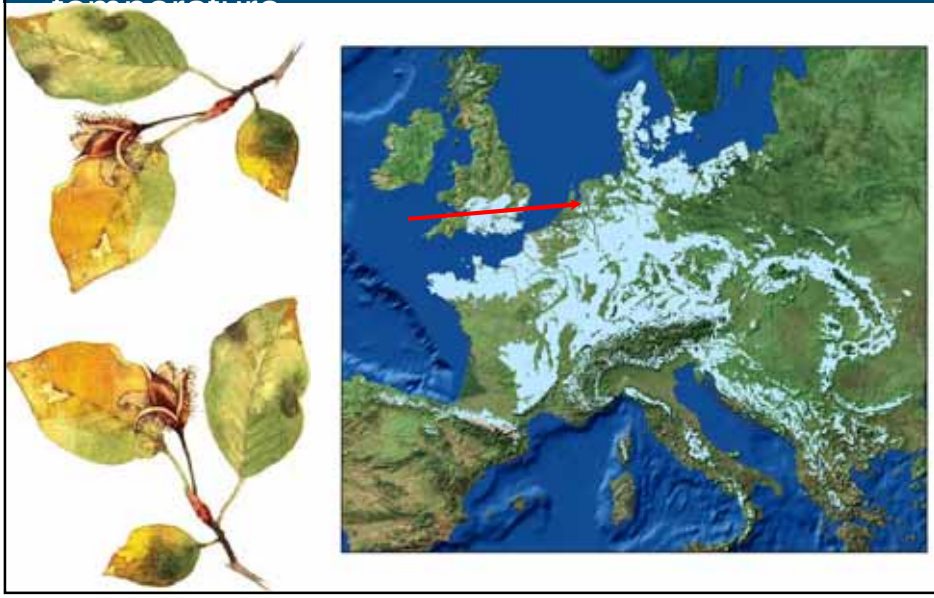
observations: Nico van Kappel

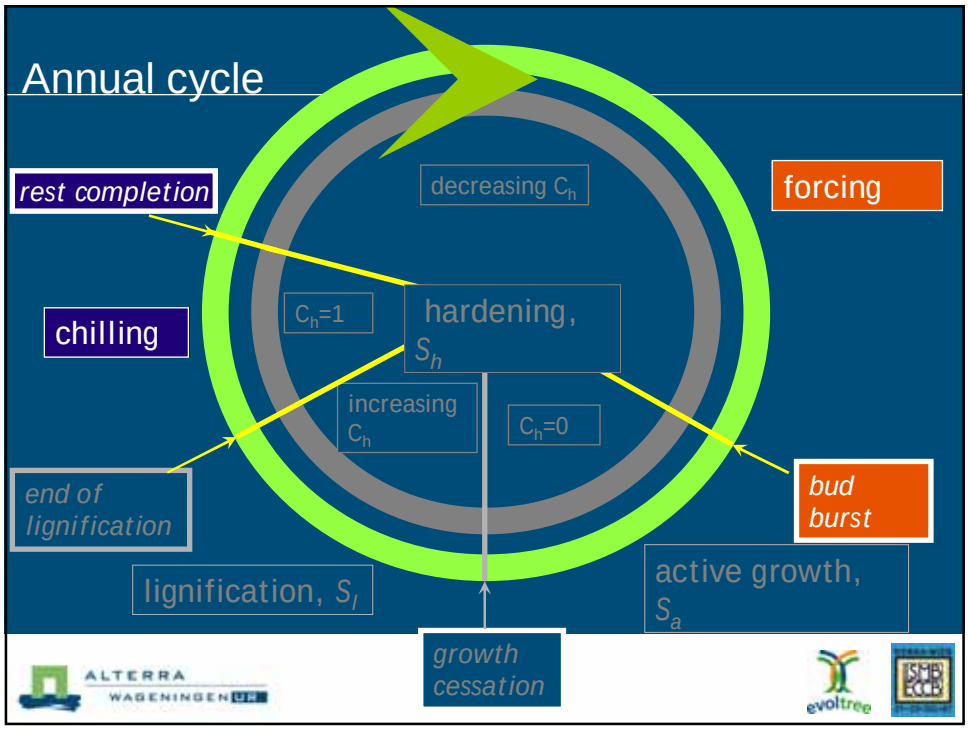
## linking genotype to phenotype

- obtain total variance and initial heritability of a particular model parameter
- assign effect to each allele
- add all values together over 10 loci
- add environmental deviate

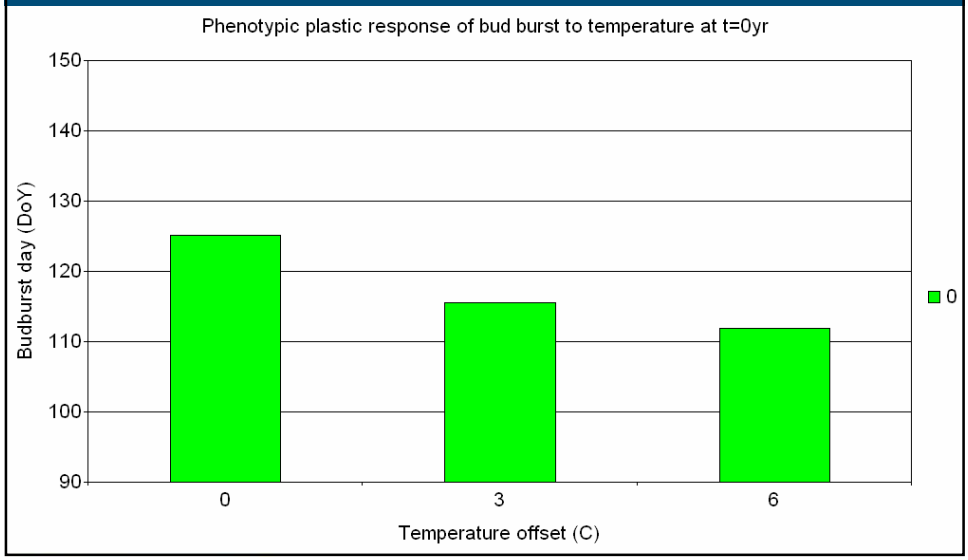



## Adaptive response of bud burst to temperature

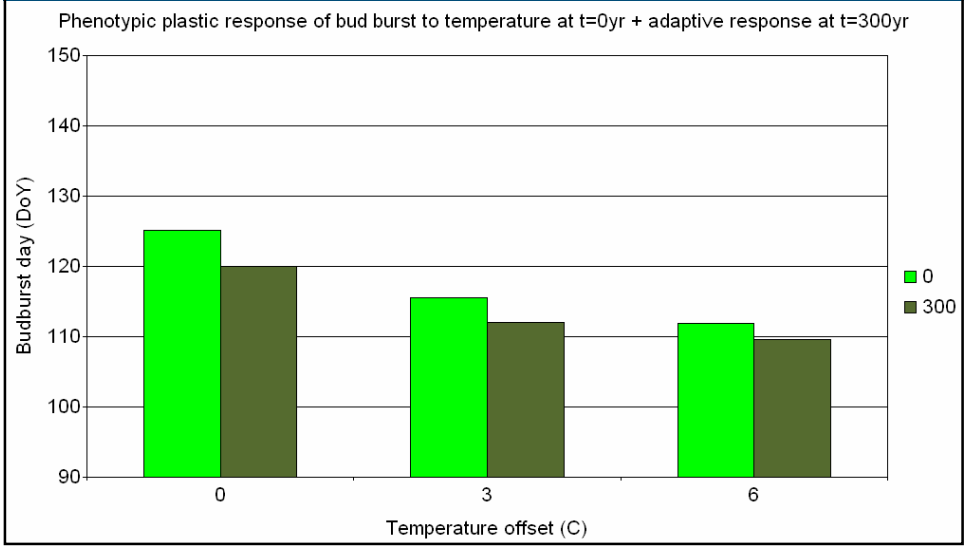




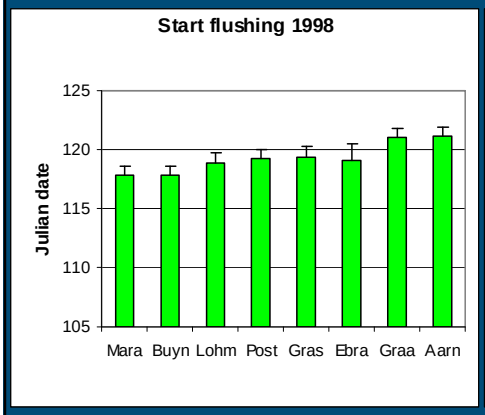

## Response of bud burst to temperature

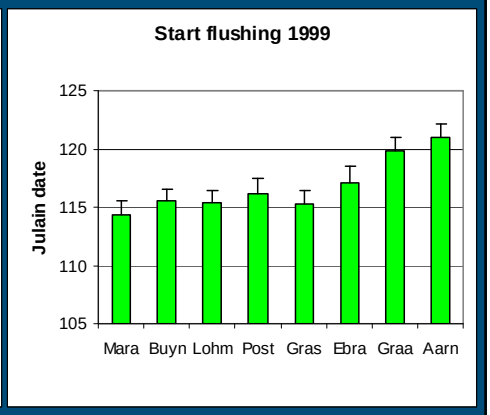


## Response of bud burst to temperature



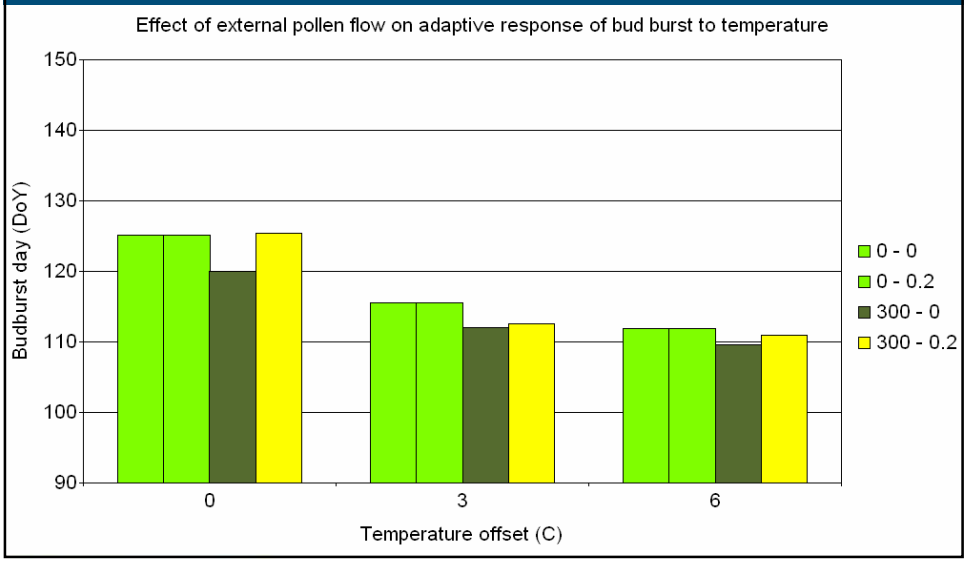

## comparison simulated adaptive response with differences in bud burst between provenances



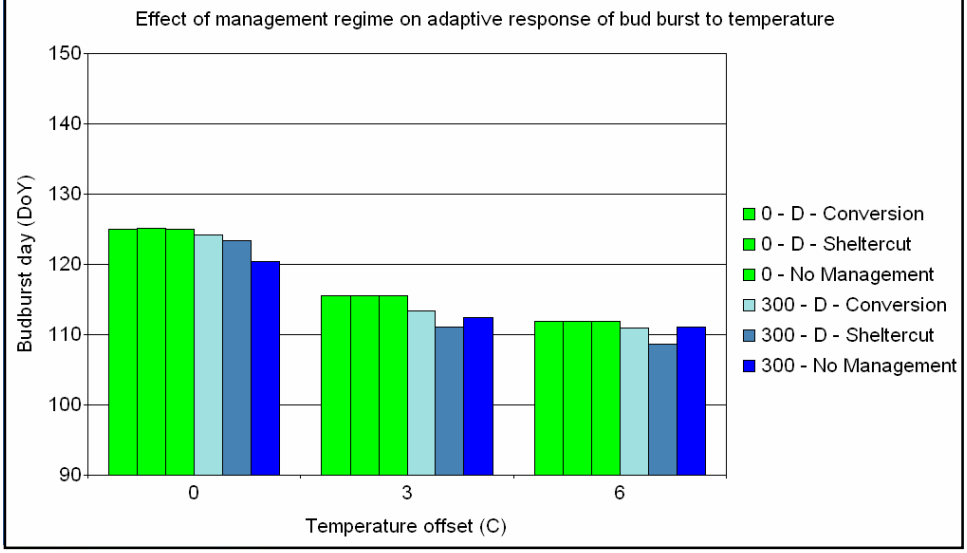




EU-FRRB – Georg von Wuelisch

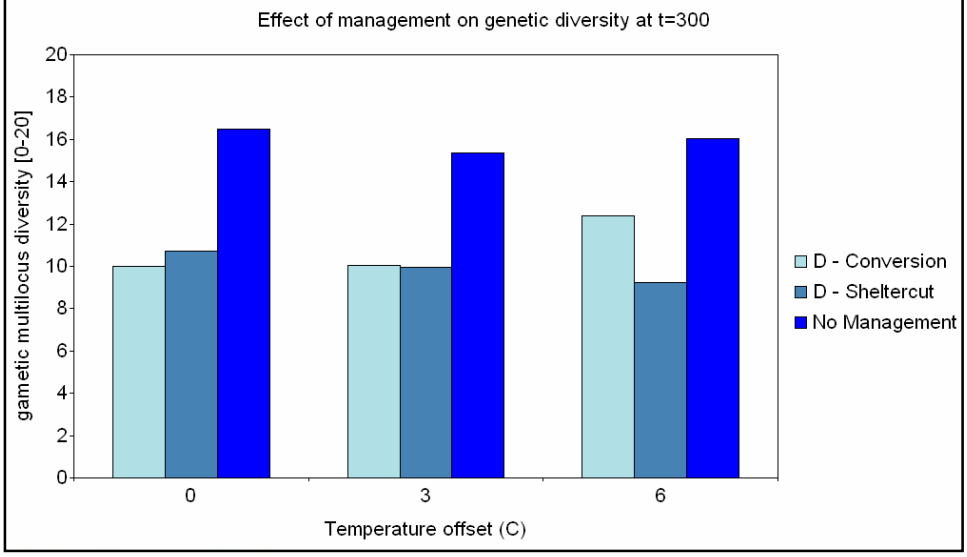
## Interaction temperature - pollen flow



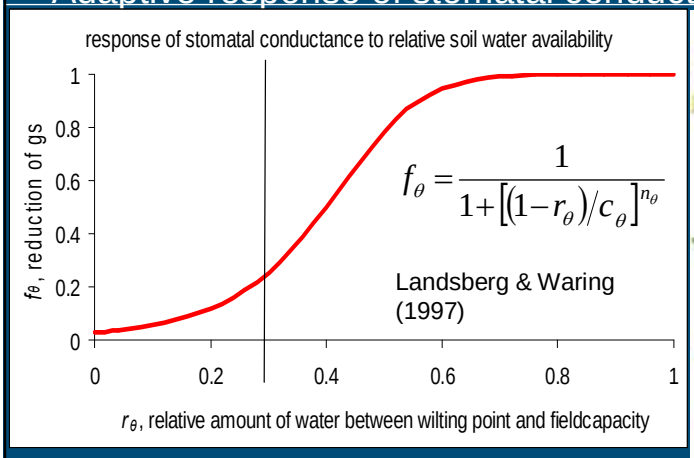

## Interaction temperature - forest management



## Management and genetic diversity




## Adaptive response of stomatal conductance to



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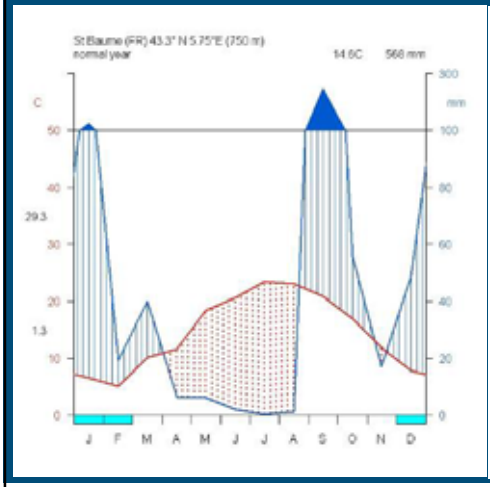
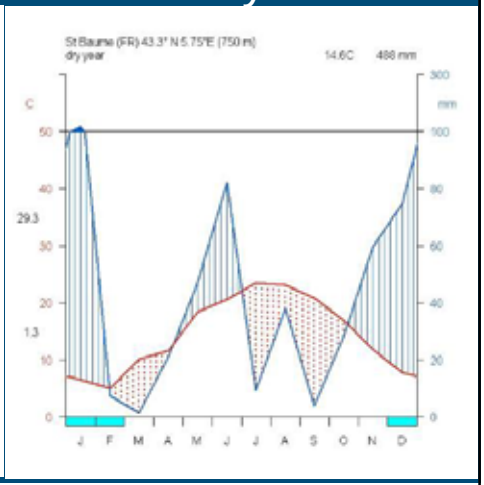
## Climate scenarios for adaptive response of conductance

normal




dry

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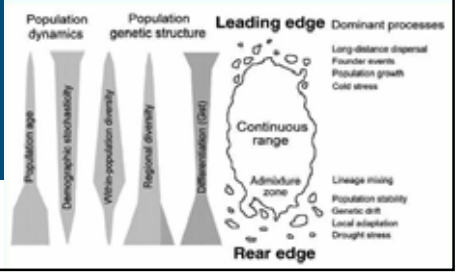
## Preliminary results adaptive response of conductance

(no replica's)

| | nature oriented | shelter cut | conversion |
|---|---|---|---|
| dry | † | † | † |
| normal | too limited regeneration for adaptive response -> aging population | | |

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## Conclusions

- What is the likely effect of climate change on the geographic distribution of Fagus sylvatica?
  - -> potential for expansion in leading edge
  - -> reduction of area at rear edge
  - -> consistent results between statistical- and process-based models
  - -> rate of change uncertain
    - quality climate change scenario
    - quality models

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## Conclusions

- Which factors are mainly responsible for this change?
  - -> leading edge: growing season duration / temperature / frost all improve
  - -> rear edge: reduced water availability

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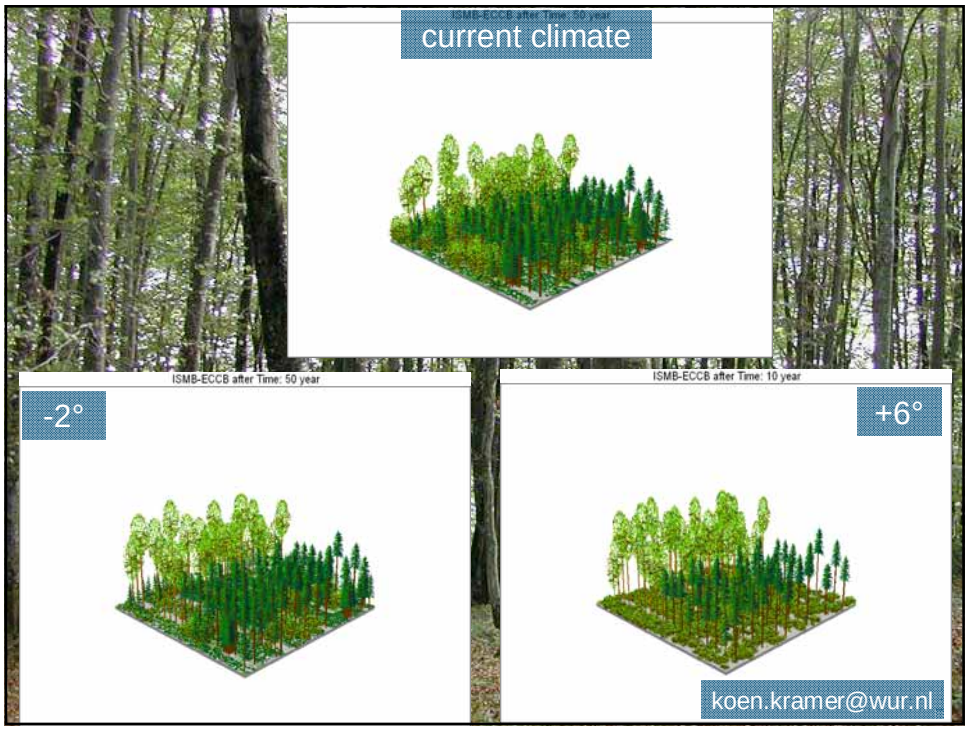
## Conclusions

- Is the adaptive response sufficient?
  - leading edge - bud burst- growing season probably yes
  - centre - neutral variation probably yes
  - rear edge - conductance- water availability most likely no

## Consequences for practical forestry

- leading edge of distribution
  - allow for expansion
- rear edge of distribution
  - take advantage of any regeneration
  - promote frequent regeneration events
  - nature oriented system not the best choice to promote adaptive response to climate change: too few regeneration events


current climate
ISMB-ECCB after Time: 50 year
-2°
ISMB-ECCB after Time: 10 year
+6°
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