Past and ongoing adaptive response of Fagus sylvatica along a short-scale climatic gradient

Sylvie Oddou-Muratorio

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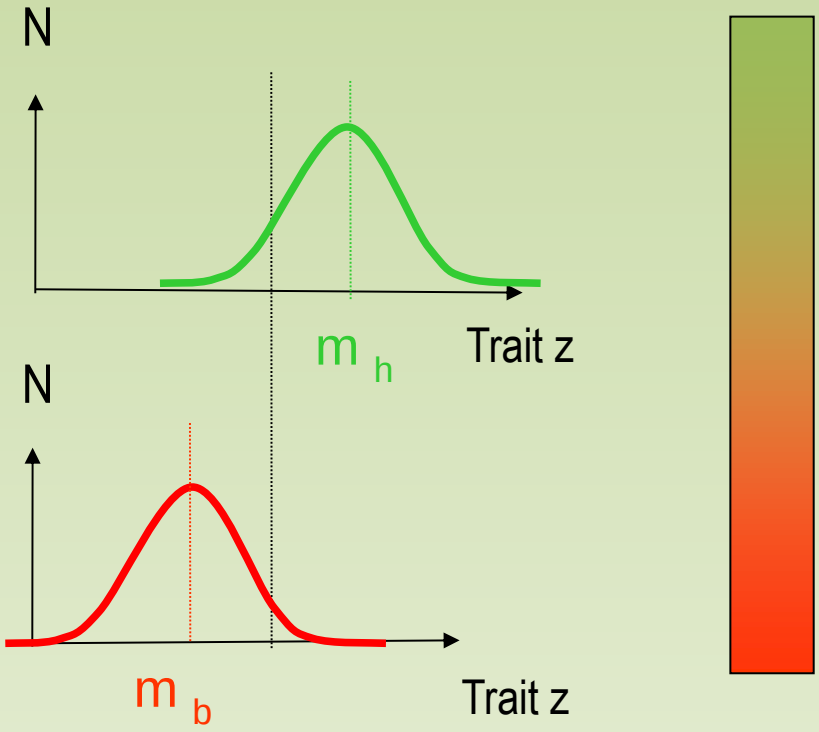
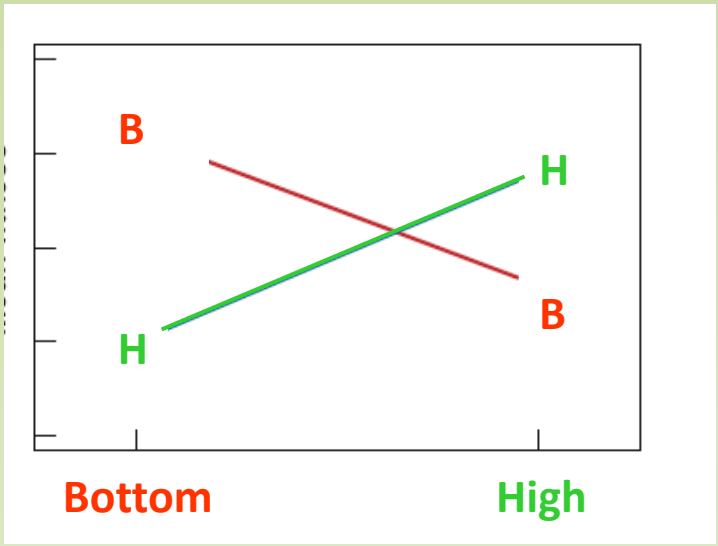
INRA
SCIENCE & IMPACT

Population adaptation to heterogeneous environment

Differentiation of adaptive trait *z*



Demonstration of local adaptation



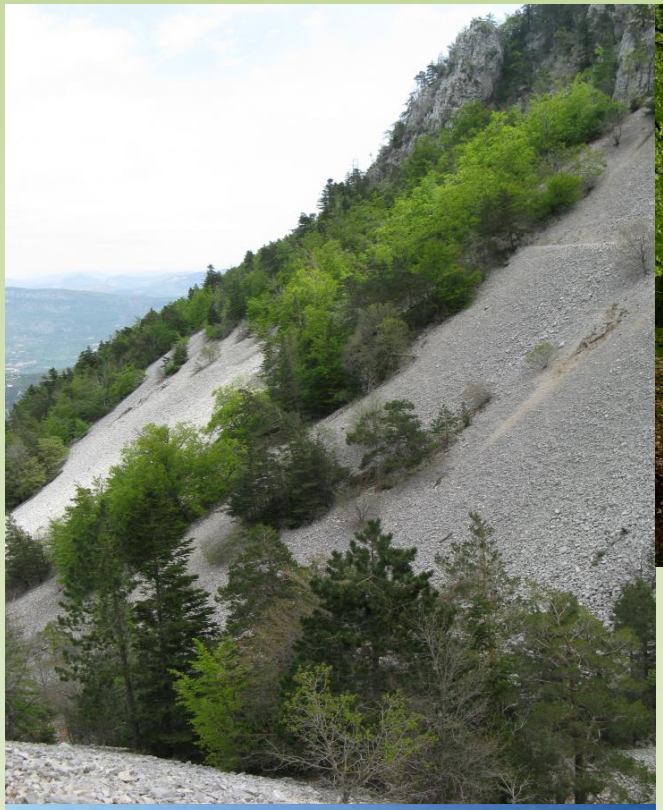
Transplantation site

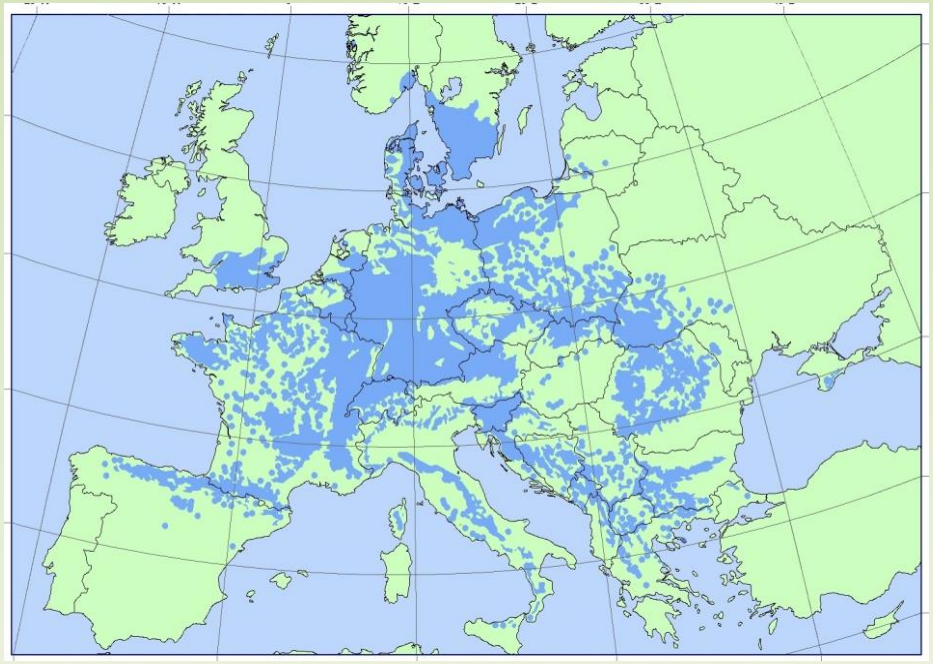
Kawecki et Ebert 2004

What are the rate and scale of adaptation?

How do existing patterns of local adaptation play on the future adaptive response?

Many forest trees spread over wide environmental gradients





Fagus sylvatica

Tree adaptation relies on specific life-history traits

Broad-sense adaptation

Phenotypic plasticity

Genetic adaptation

Important

LHT: longevity

Demonstration : Provenance tests

(Rehfeldt et al., 2002)

Supposed to be important

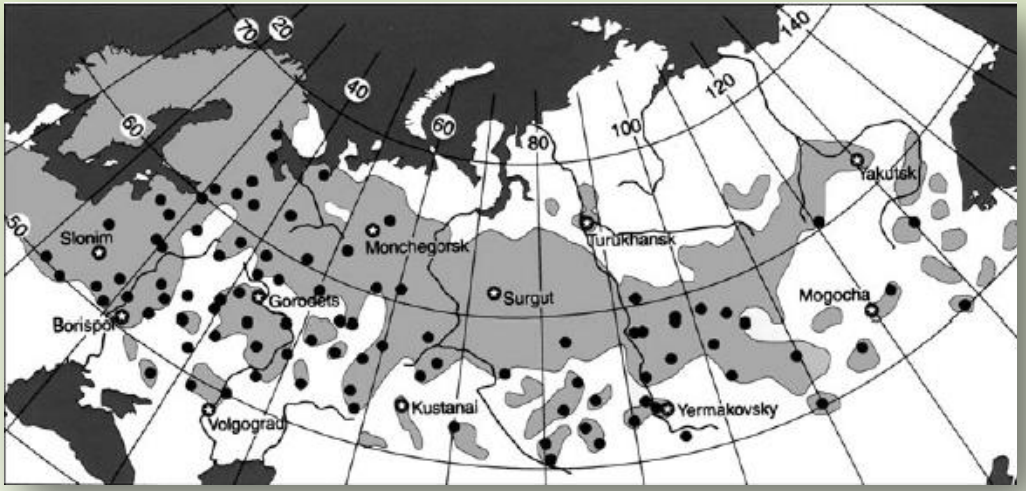
LHT: high fecundity + population size +gene flow

But…

Demonstration : (Provenance tests)

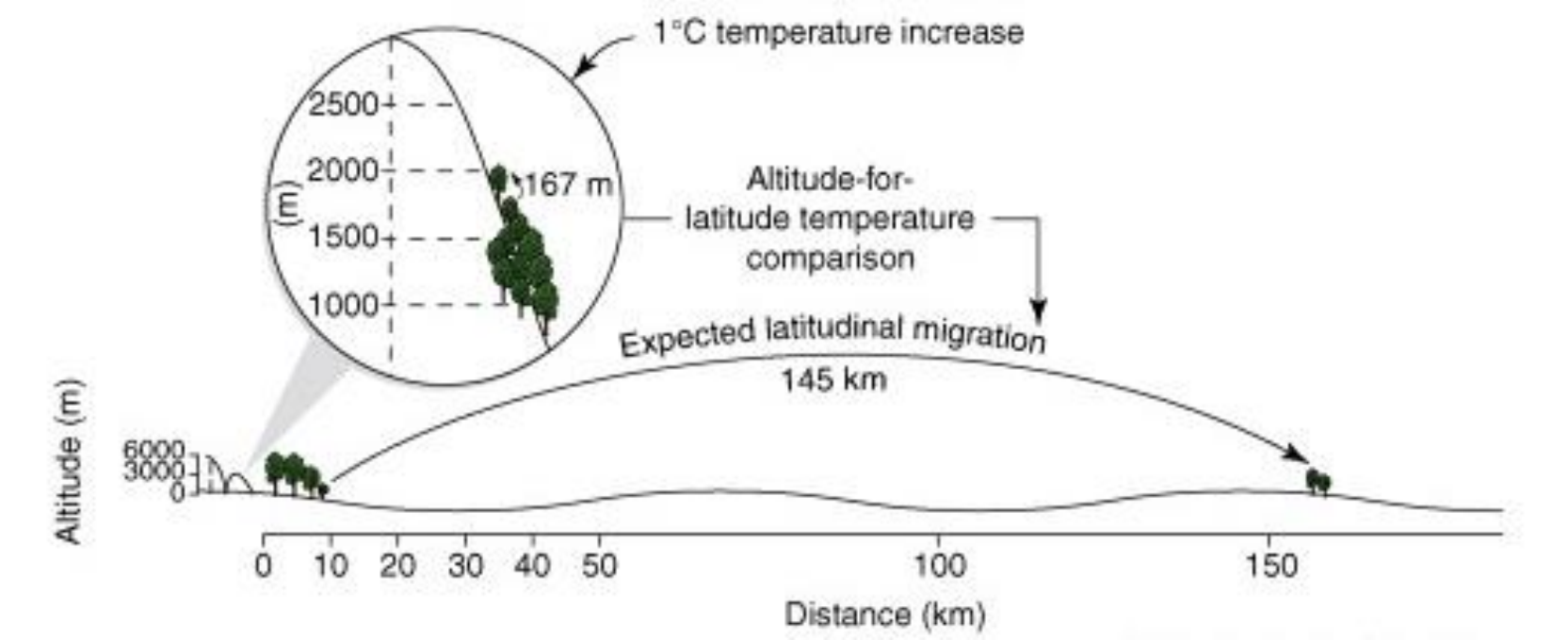
(Savolainen et al. 2007, Kremer et al. 2012)

Pinus sylvestris



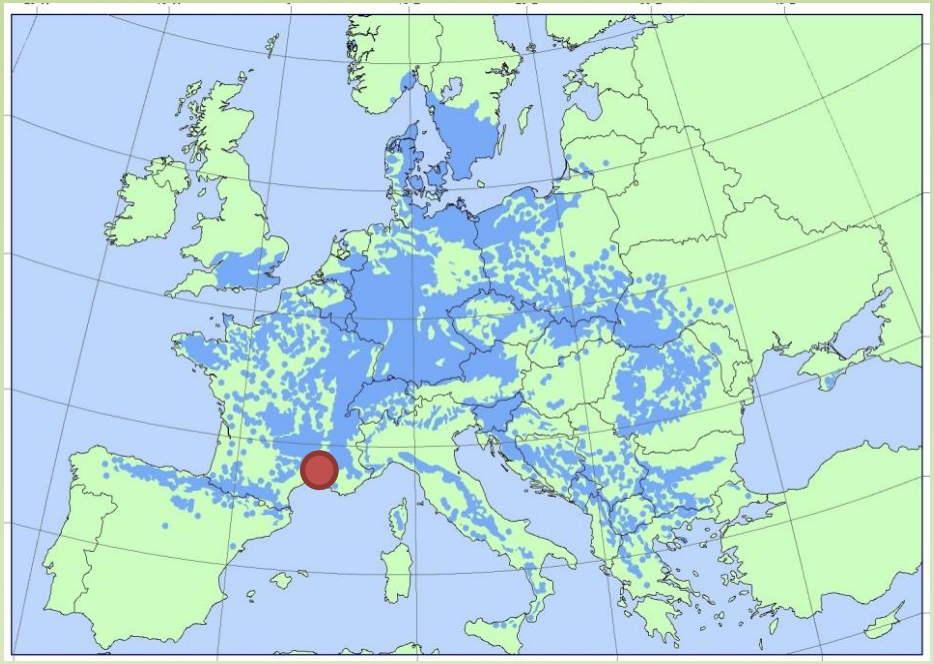
Altitudinal gradients to study adaptation

- Ideal experimental sites to study ongoing adaptation in face of gene flow
- Large environmental variations over short geographical distance



Jump et al. 2009

Adaptive response of Fagus sylvatica along a short-scale altitudinal gradient



LOCAL PATTERNS

Differentiation of adaptive traits

ECO-EVOLUTIVE PROCESSES

Gene flow
Genetic drift
Response to selection
Plasticity

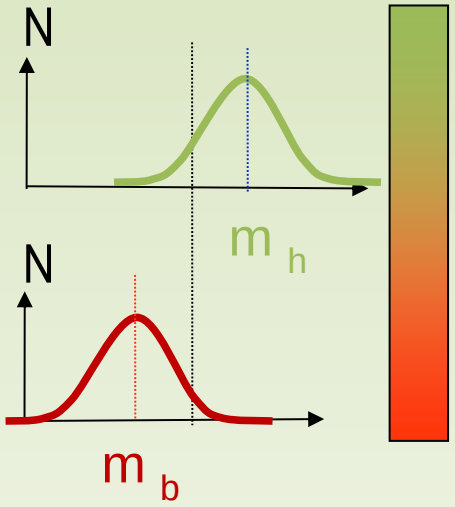
Signatures of selection on genetic differentiation of adaptive traits along an altitudinal gradient

Hypotheses on major constraints for beech :

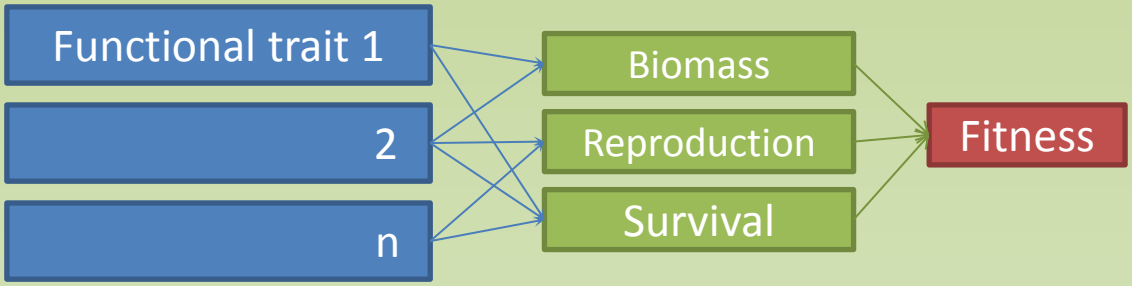
High elevation : Duration of vegetative season

Low elevation : water stress

Adaptive traits



Genetic differentiation of adaptive traits along an altitudinal gradient



FONCTIONAL TRAITS

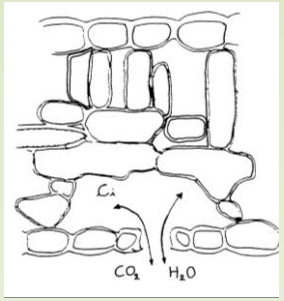
PLASTIC REPONSE ALONG VENTOUX ALTITUDINAL GRADIENT

Phenology

- Date of vegetative budburst — ↗ With elevation (6-12 days/km)
- Date of foliar senecence — ↘
- Duration of vegetation season — ↘

Foliar morphology

- Leaf Mass Area (LMA) ($g.m^{-2}$) — ↗



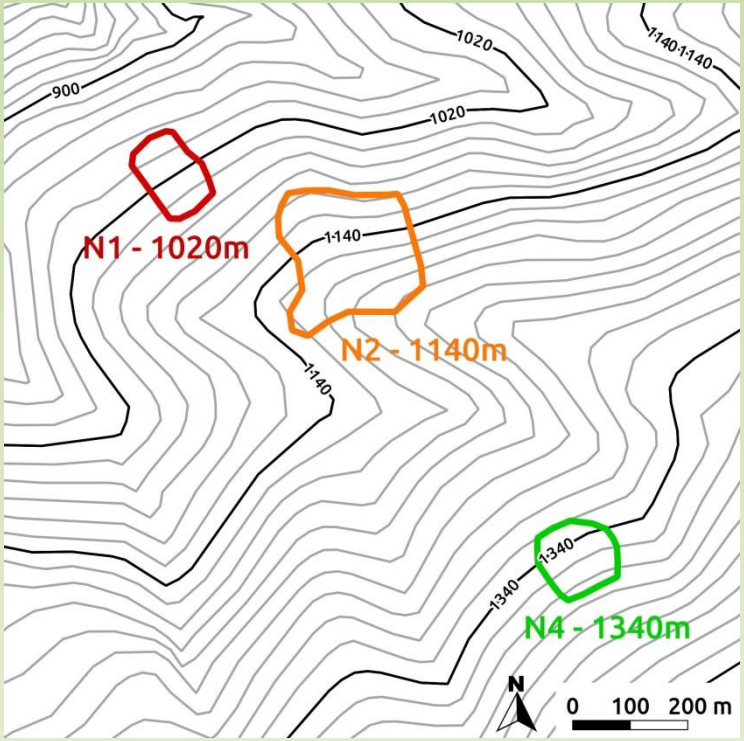
Foliar physiology

- Intrinsic water use efficiency (proxy =δ13C) — ↘
- Nitrogen content (%N) — Maximum at medium elevation
- Carbon content (%C) — -

PERFORMANCE TRAITS : growth, (reproduction) — Maximum at medium elevation

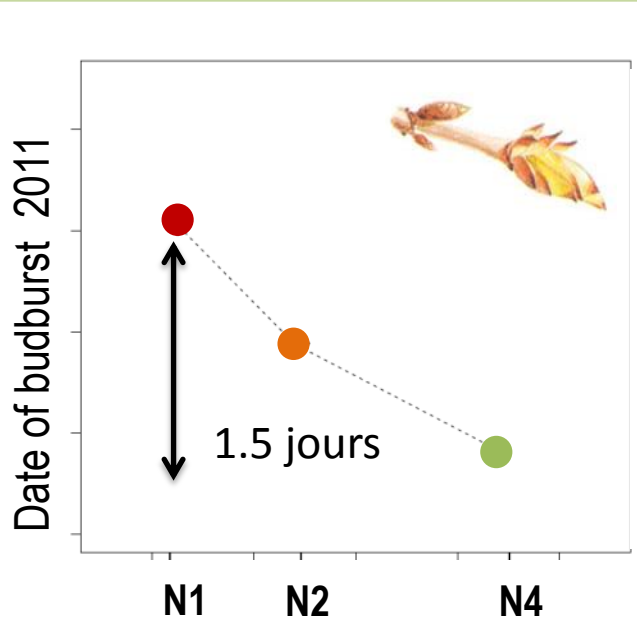
Genetic differentiation of adaptive traits along an altitudinal gradient

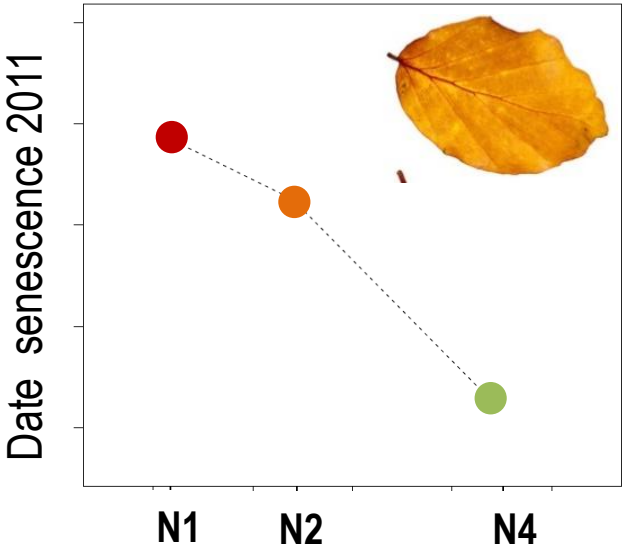
Progeny test, Aix en Provence

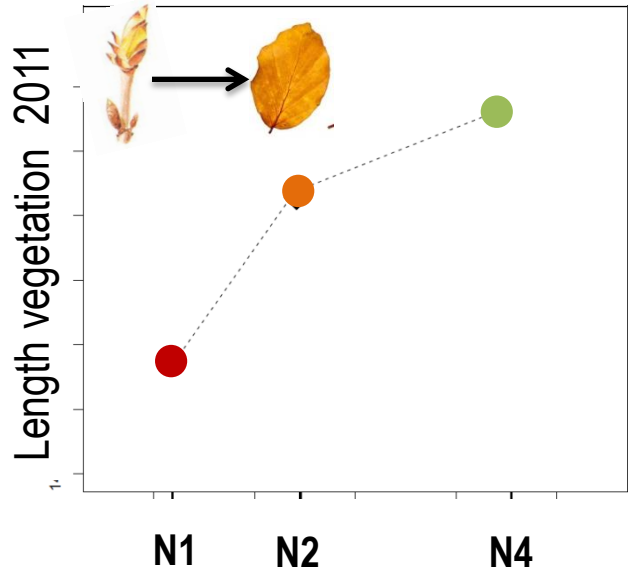


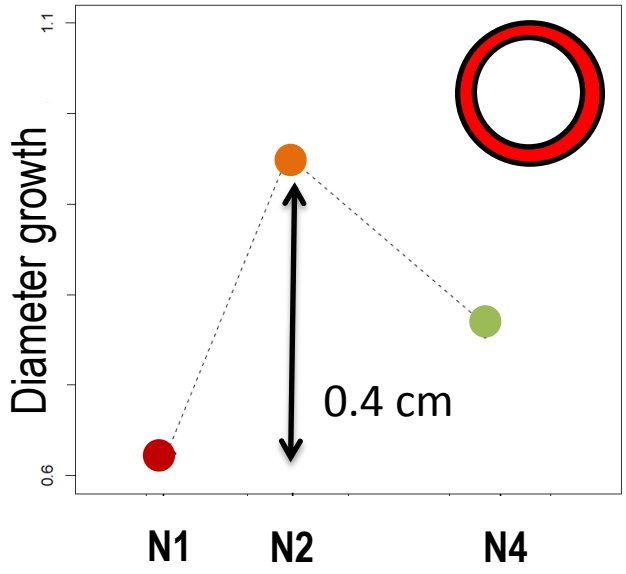
3 elevation ×20 mother-tree ×100 offspring ~5600 seedlings

Genetic differentiation of adaptive traits









- Genetic gradient for phenological traits
- No differentiation for traits expected to be related to water stress response
- Juvenile growth decreases at gradient borders
- Patterns resulting from selection (not from genetic drift , Ovaskainen et al. 2011)

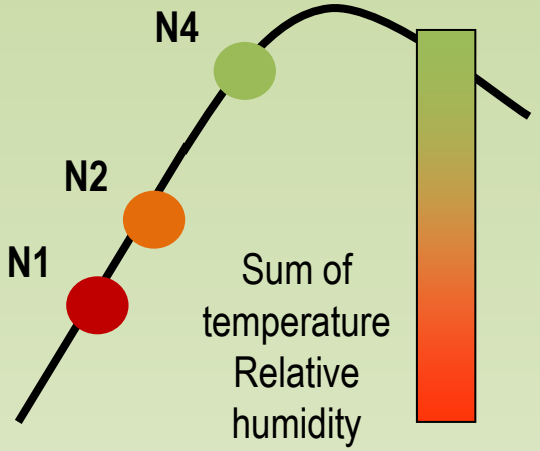
Gaüzère (2014)

Conclusion

Significant genetic differentiation despite the short scale (~1 km)

[Brousseau et al 2013, Audigeos et al. 2012]

[Vitasse et al. 2009, Gomory et Paule 2011]



….but a weak differentiation

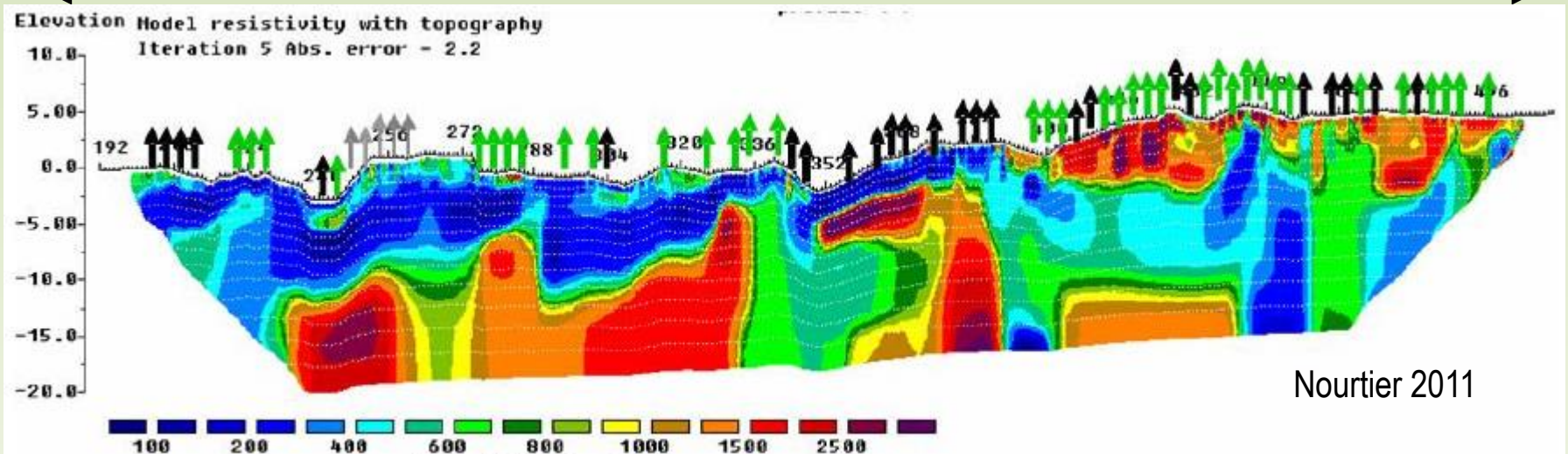
Altitudinal gradient + micro-local variation?

Recent recolonization of the altitudinal gradient

Management favoring asexual reproduction in beech

Local scale → gene flow/ genetic drift /selection ?

Variation of water availability along an isocline

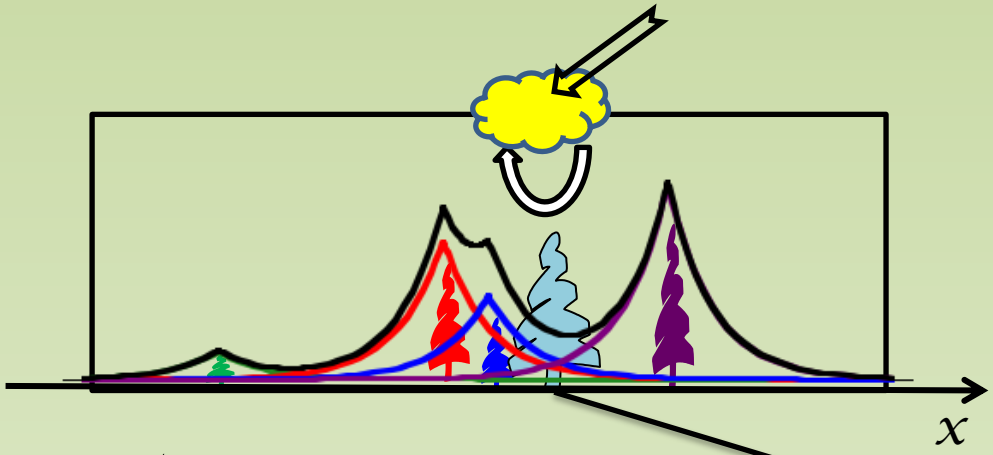


Nourtier 2011

Estimating dispersal and fecundity with the SEMM

Spatially Explicit Mating Model (SEMM)

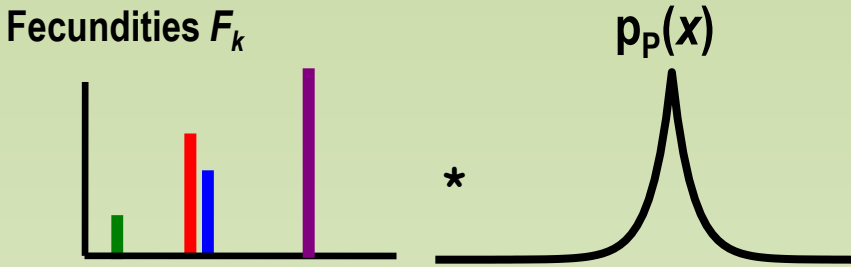
Oddou-Muratorio et al. 2005



Pollen migration (m_p)

Selfing (s)

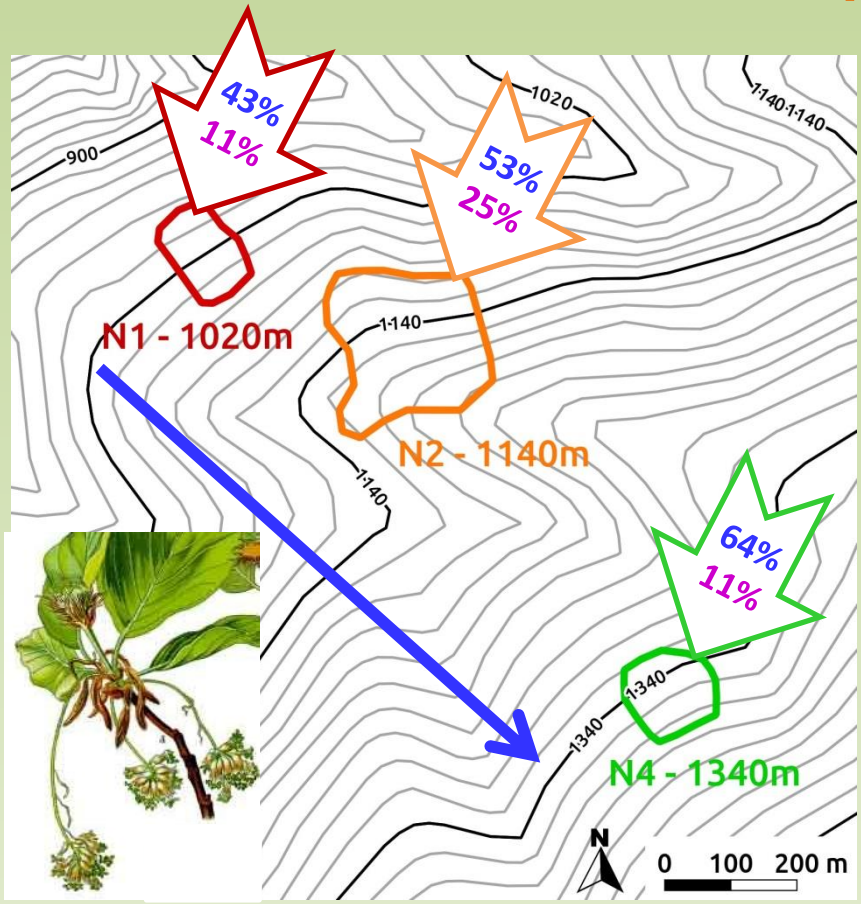
Polination by a local male



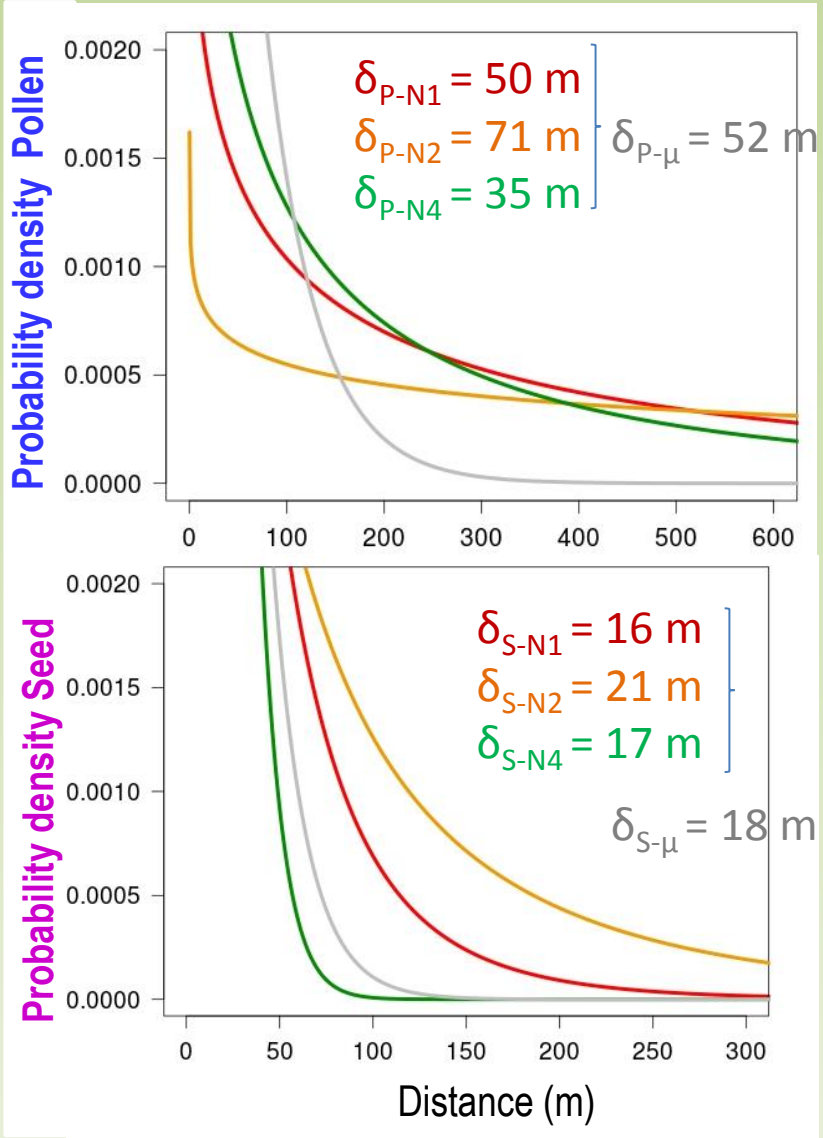
$$\pi_k(x) = \frac{F_k\, p_P(x - x_k)}{\sum_l F_l\, p_P(x - x_l)}$$

- Extension to {seed + pollen} * {dispersal + fecundity} estimates from established seedlings (Oddou-Muratorio & Klein 2008)
- Extension to individual fecundity estimates in a Bayesian framework (Klein et al. 2008)

Pollen and seed dispersal abilities (SEMM)



- Non negligible long distance dispersal
- Dispersal abilities pollen > seed
- Pollen immigration increases with elevation
- + Protogyny+ T° : directional gene flow



Bontemps et al. 2013, Gauzère et al. 2013

Variance of reproductive success and genetic drift

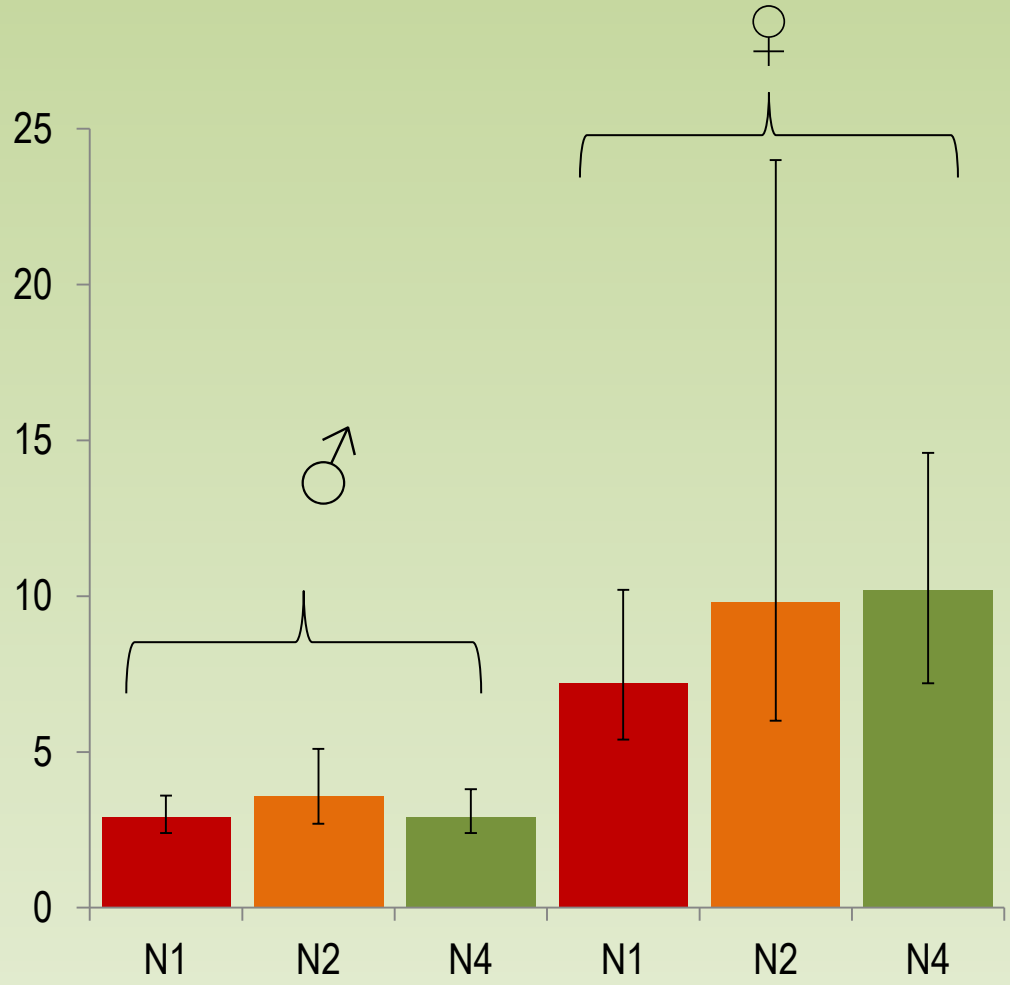
Observed adult density

↓

d_{obs}/d_e

↑

Effective adult density



- Variance of fecundities ♂< ♀ (SEMM, ongoing genetic drift)
- Historical effective population size N_e~2,000 individus (Lander et al. 2011) for N_{obs}~150,000 individus (Nobs/Ne~80)

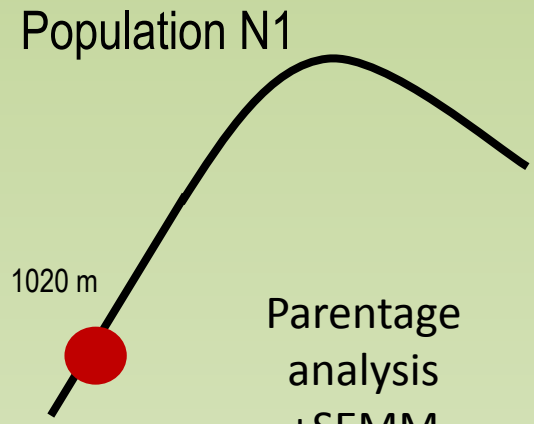
Bontemps et al. 2013, Gauzère et al. 2013

Potential response to selection

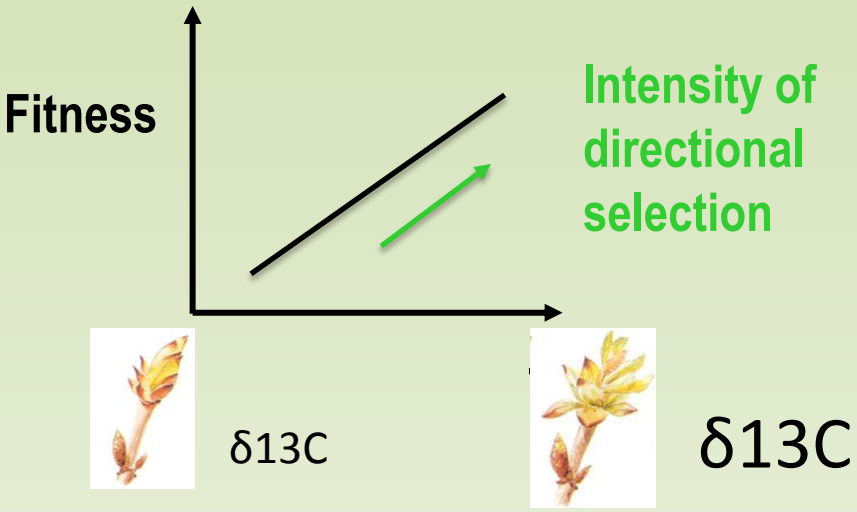
Response to natural selection

$R_z = VA.\beta = VP.h^2.\beta$

… (Lande et Arnold 1983)

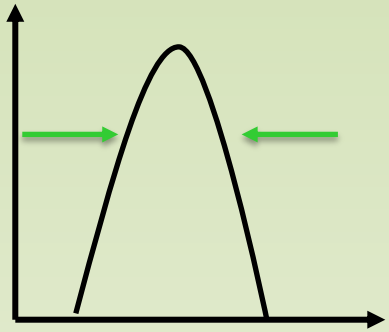


Linear term (β)



Intensity of directional selection

Quadratic term (γ)



Intensity of stabilizing/ disruptive sélection

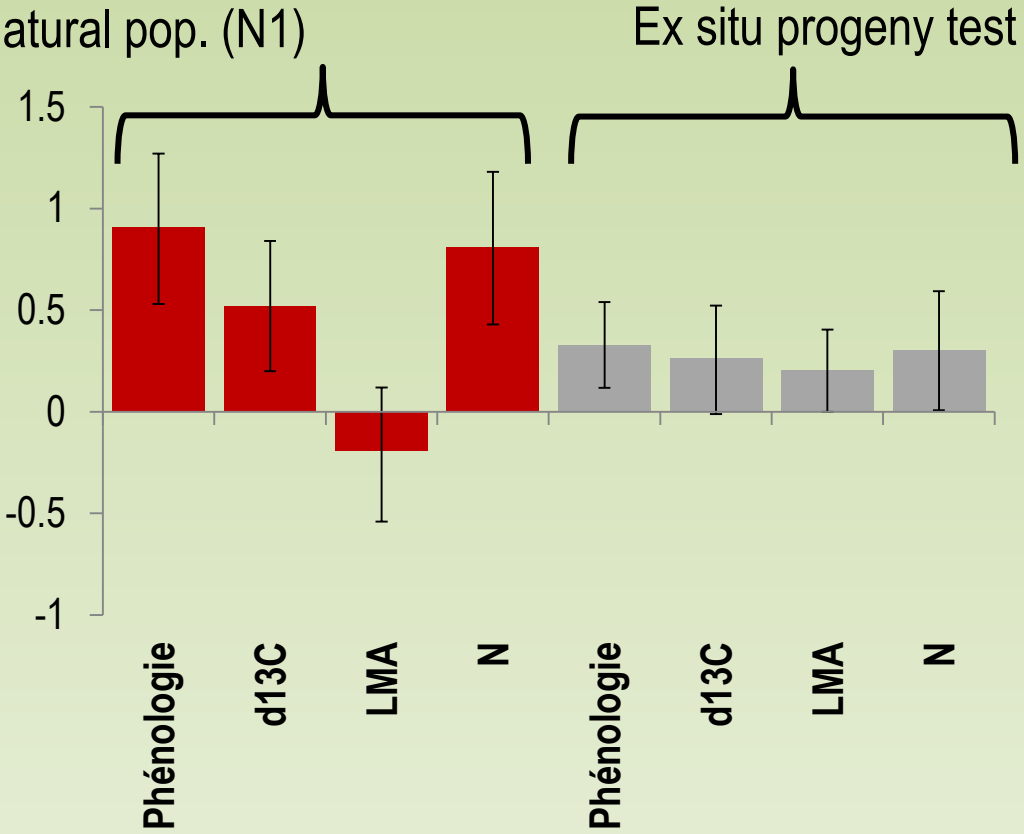
↳ Directional selection towards earliest budburst and higher Water Use Efficiency (δ13C)

↳ Stabilizing selection for LMA

Bontemps (2012)
Bontemps et al. in prep

Potential response to selection

Response to natural selection $R_z = VA.\beta = VP.h^2.\beta$



Ritland's method
Bontemps (2012)

Animal model
Gaüzère (2014)

↳ ~14 studied traits → most traits have significant h² + similar h² + Ritland's method OK

↳ Maternal effect : budburst phenology, growth, biomass (+LMA-N1)

Potential response to selection

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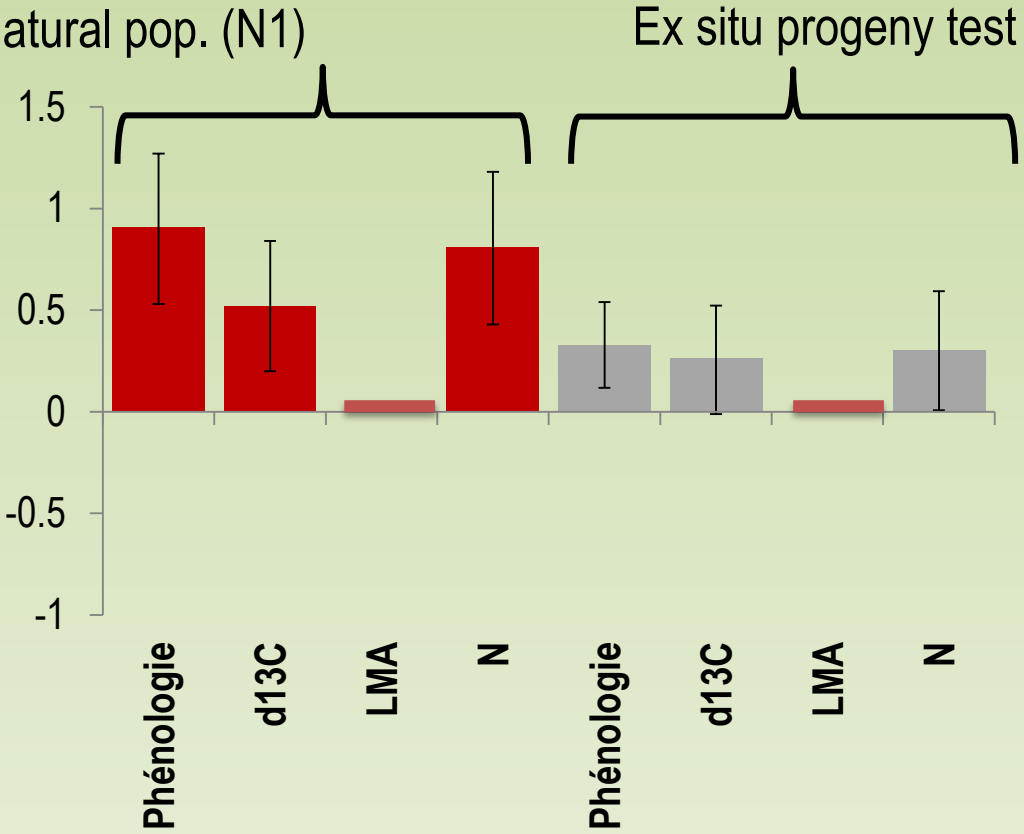

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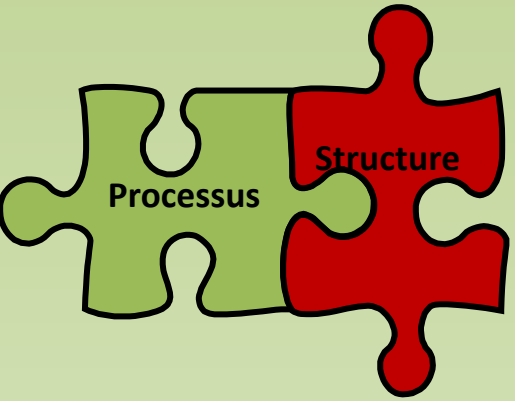
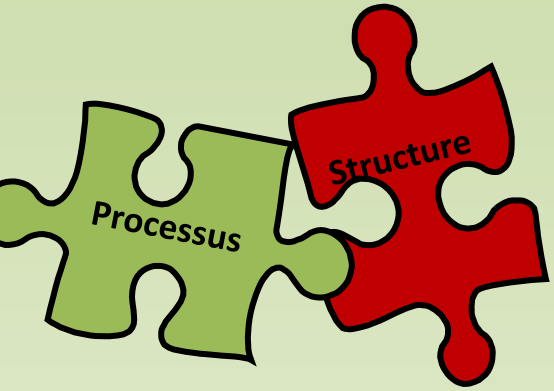
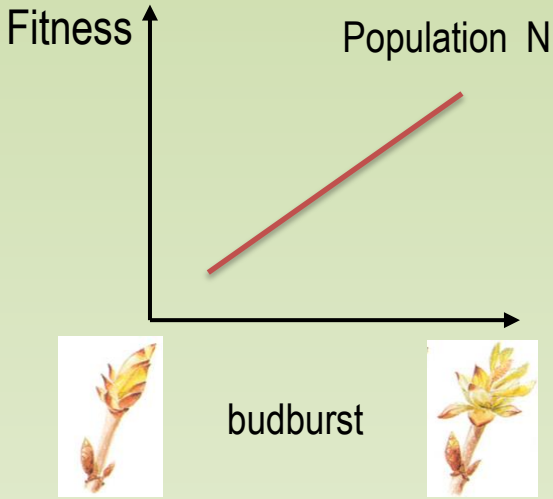
Conclusions

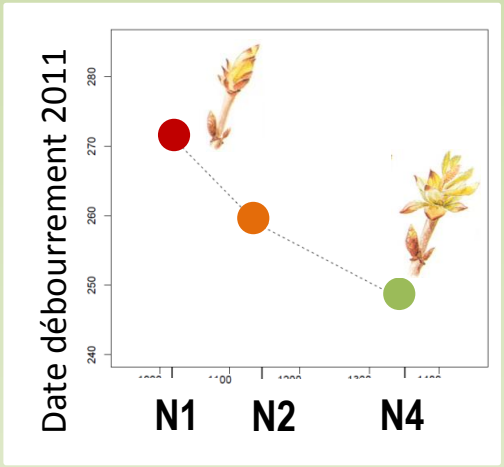


Overall consistency between processes et patterns of adaptive differentiation in the studied beech population

- Limited gene flow but non negligible LDD
- Reasonable effective population size
- Functional traits are variable, heritable and under selection







δ13C Efficiency δ13C

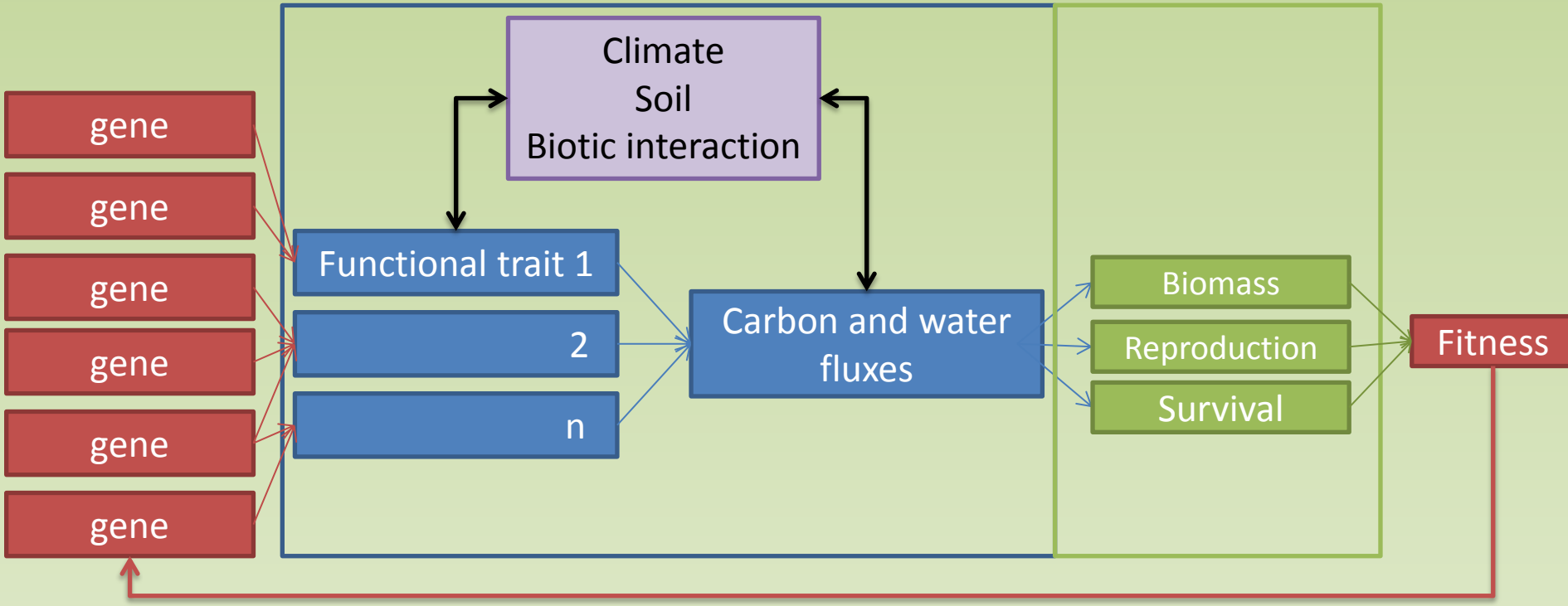
No adaptive differentiation

↳ No simple relationship between within-population evolutive processes and among-populations genetic divergence

↳ Need to account for multi-trait selection response

↳ Reciprocal transplants …

Conclusions: the interest of inter-disciplinary research



GENETICS ECOPHYSIOLOGY DYNAMICS GENETICS

Process-based approach of adaptation requires inter-disciplinary approaches
In situ and ex situ approaches are complementary

Many thanks to …

Aurore Bontemps

Aurore Bontemps, Julie Gaüzère, Etienne Klein, Hendrik Davi, François Lefèvre
Field team URFM (Nicolas Mariotte, William Brunetto) + UEFM (Frank Rei, Frédéric Jean, Jean Thévenet, Mehdi Pringarbe, Norbert Turion, Olivier Gilg)
State nursery in Aix en Provence (Patrice Brahic, Marie de Castro)

Julie Gaüzère

LINKTREE

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