Adaptive silviculture regarding climate change: the geneticist's view

Francois Lefèvre, Thomas Boivin, Aurore Bontemps, Francois Courbet, Hendrik Davi, Bruno Fady, Julie Gauzere, Cindy Gidoin, Marion Durand, Marie-Joe Karam, et al.

Adaptive silviculture regarding climate change: the geneticist's view

or

Facing the complexity of evolutionary processes to design adaptive forestry practices

F. Lefèvre, T. Boivin, A. Bontemps, F. Courbet, H. Davi, B. Fady, J. Gaüzere, C. Gidoin, M. Gillmann, M.J. Karam, E. Klein, H. Lalagüe, S. Oddou-Muratorio, C. Pichot.

INRA, Avignon (URFM)

MENU

Appetizer

evidence of high evolutionary potential
and limits to adaptation

Main course, sweet and sour style

a global frame for the complexity of evolutionary processes, potential impacts of forestry practices

Dessert of the moment

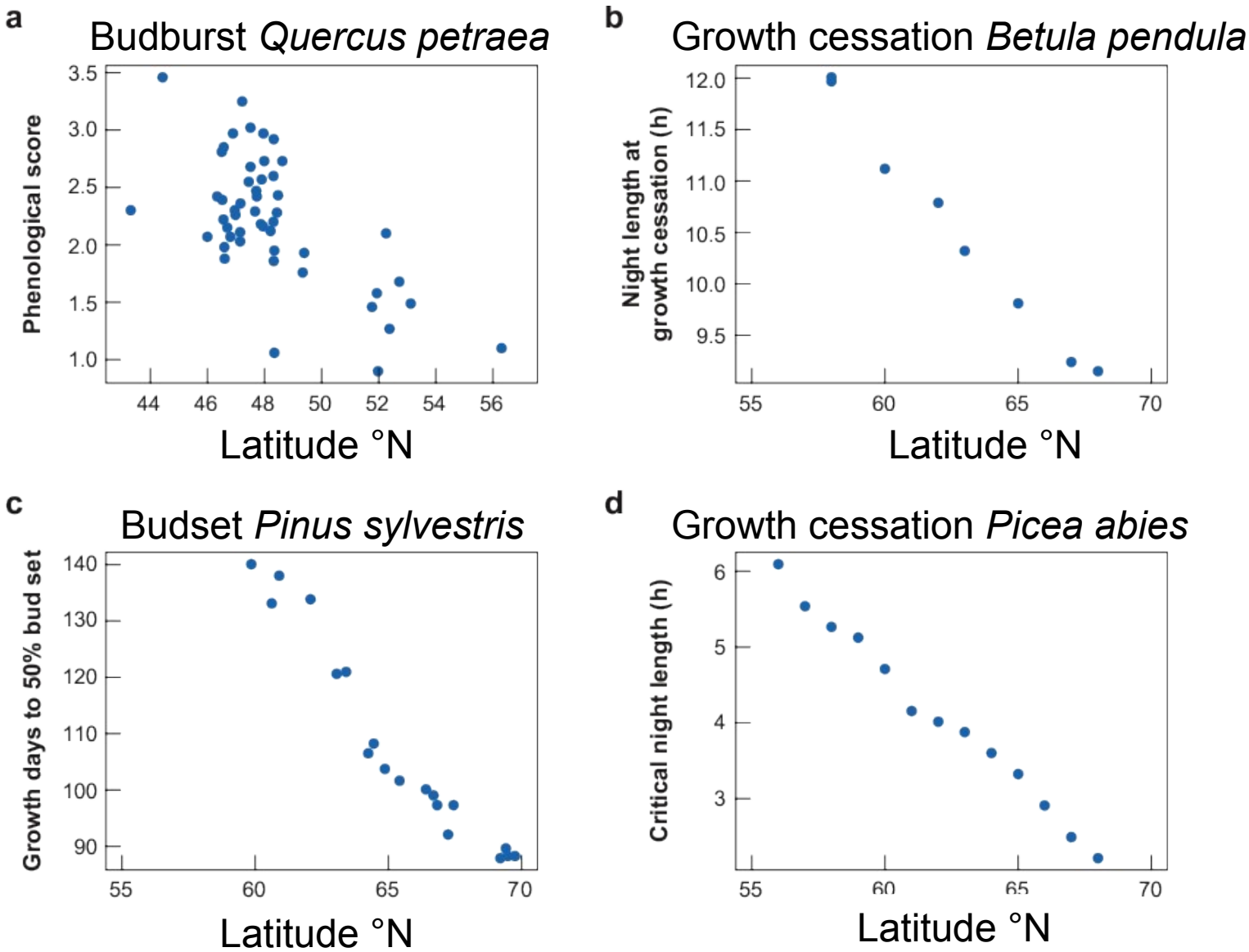
genetically oriented practices, why not ?

Thanks to plasticity and evolution, trees may perform well (survive, grow and reproduce) in new environments.

Pinus radiata : 4th version of its climatic enveloppe (*Yan et al, 2006*)

Region	**Annual rainfall (mm)**	**Tmean (°C) coldest month**	**Tmean (°C) warmest month**
California (5 pops)	420 – 700	10 – 11	16 – 18
N-Z (Southland)	***960 – 1000***	***3 – 5***	***13 – 15***
N-Z (Kaingaroa)	***1300 – 1500***	***7 – 9***	*11 – 19*
Chile (Valdivia)	***2350***	***7.7***	*17*
South Afr. (Cape)	***900 – 1100***	*10 – 13*	***20 – 24***
China (Sichuan)	*490 – 590*	***-3.4 – -0.7***	***25 - 28***
Aust. (Bathurst)	*650 – 950*	***0.4 – 0.6***	***24 – 28***
Aust. (Tumut)	*800 – 1300*	***0.5 – 0.8***	***25 – 30***

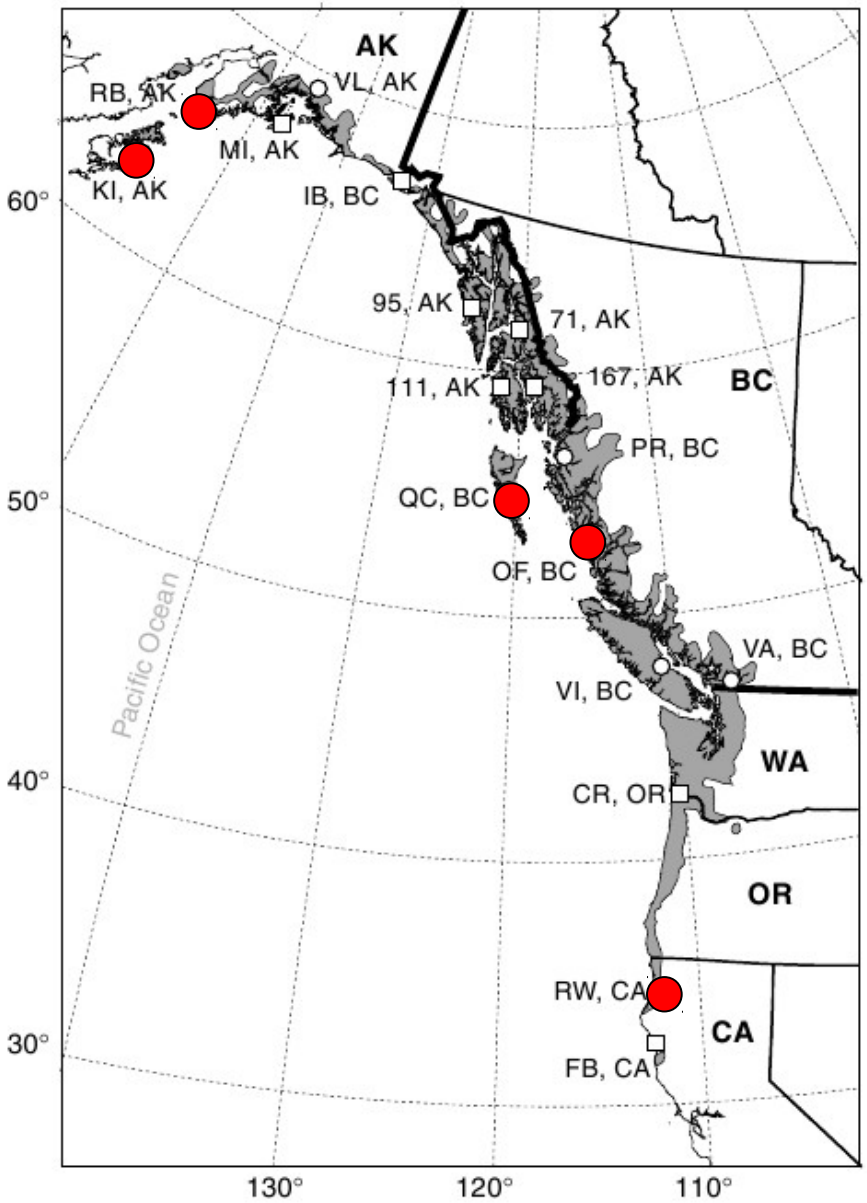
Local adaptation emerged after post-glacial recolonisation



Savolainen et al (2007)

Appetizer : high evolvability and limits to adaptation

Still important genetic variation within populations for adaptive traits



Qst estimates, the between-pop component of the genetic variation in *Picea sitchensis*

height age 3	0.79
bud break	0.29
bud set	0.89
growth period	0.87
daily growth rate	0.28
cold injury index	0.89

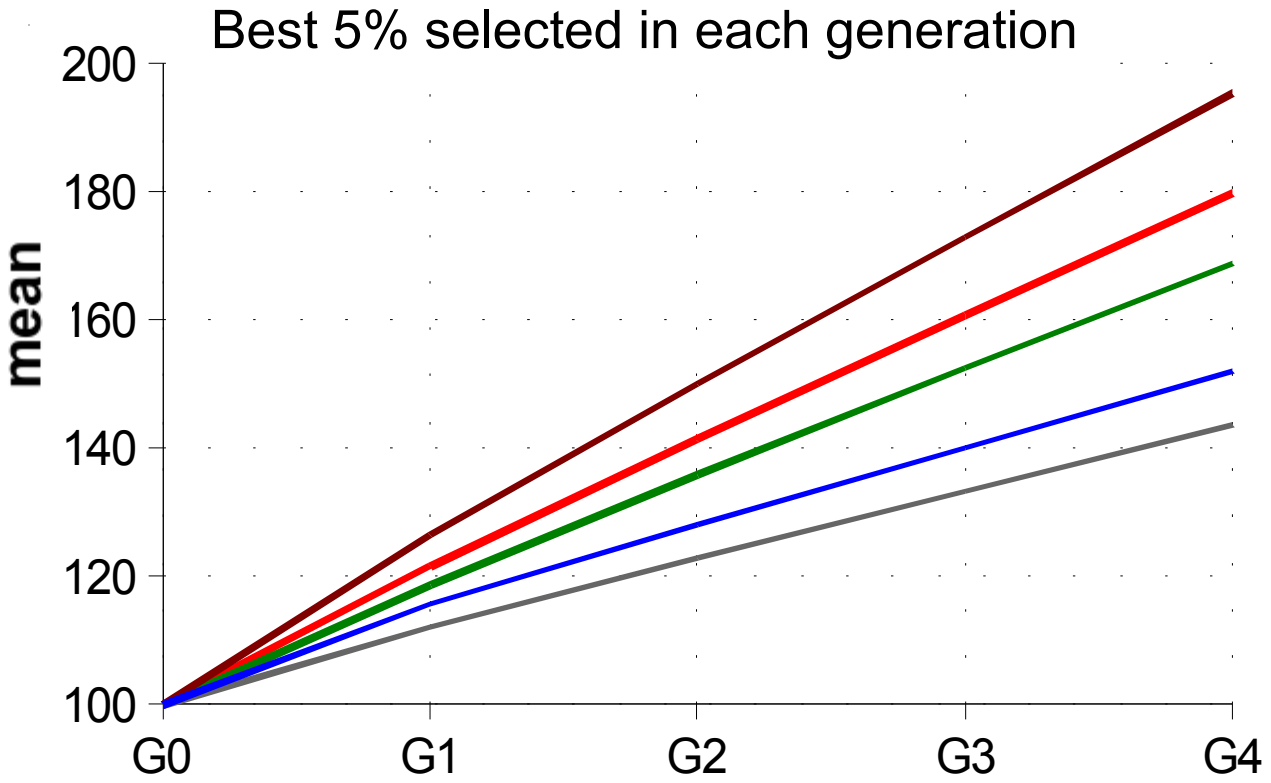
Mimura & Aitken (2007)

(between-pop component lower on shorter scale)

Theoretical (simplistic) short term response to selection

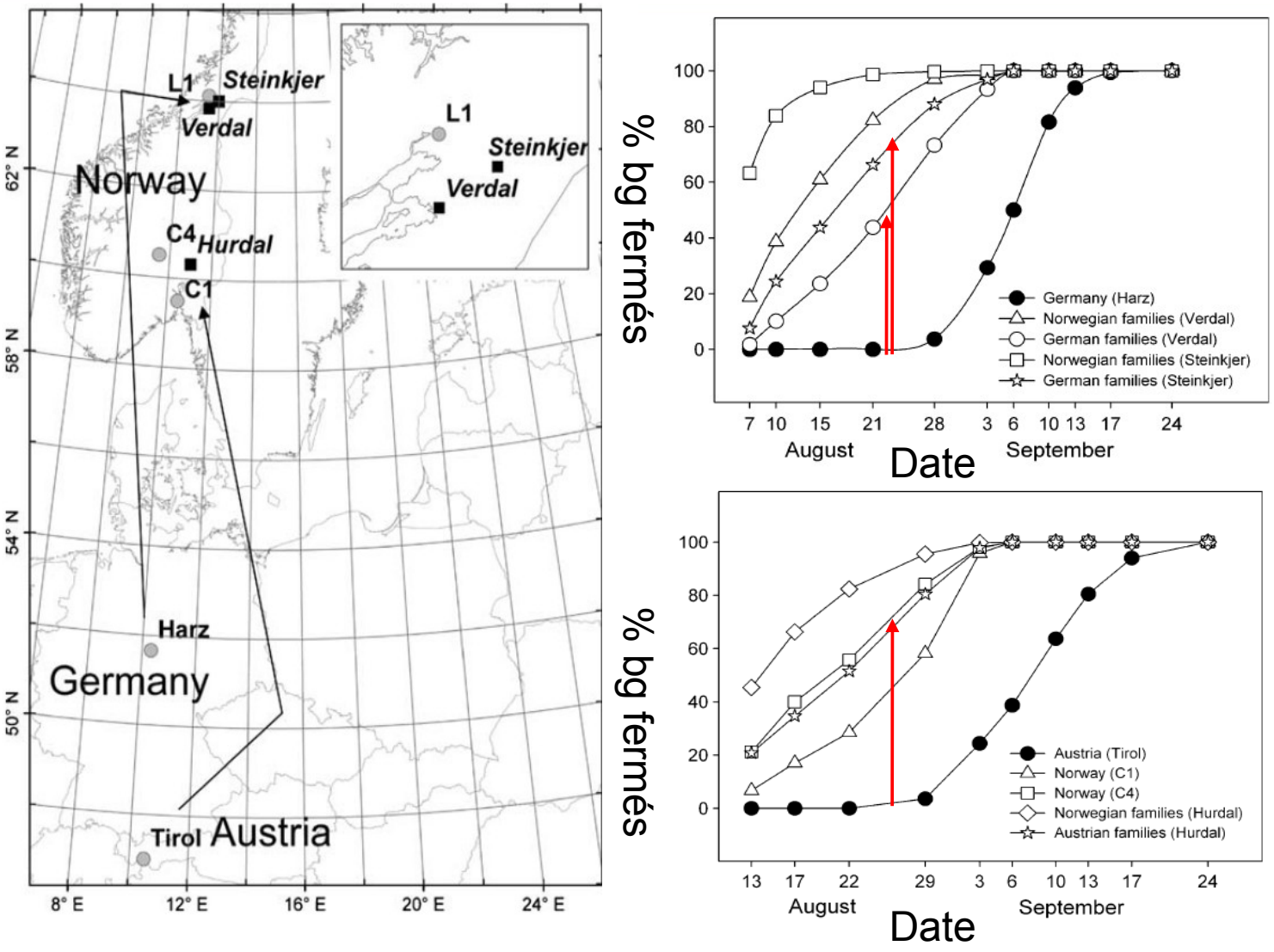
Traits / populations do not all have the same evolvability

evolvability can also change



	h^2	σ^2_P	σ_A/μ	
budburst	0.30	1850	**24**	(*Ducousso, unpub.*)
volume	0.21	2500	**23**	(*Cornelius, 1994*)
height	0.24	1450	**19**	(*Ducousso, unpub.*)
branch angle	0.73	111	**9**	(*Kremer, 1994*)
height	0.28	440	**11**	(*Cornelius, 1994*)

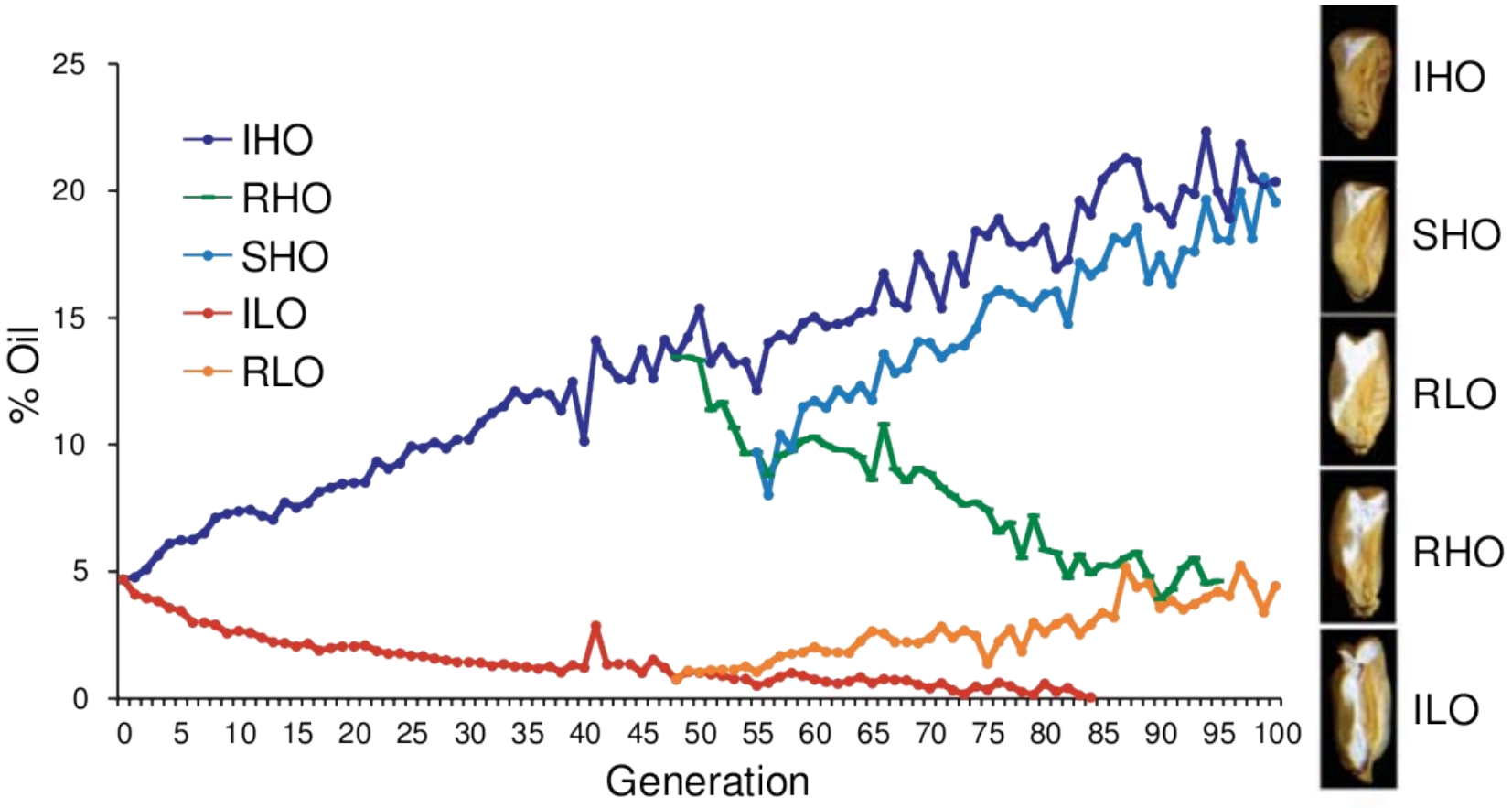
Observed rapid evolution after 1 generation in transplanted Norway spruce : role of epigenetic mechanisms



Skrøppa et al (2010)

Long-term persistence of the response in a stepwise selection process

The longest breeding experience : recurrent selection of maize (Illinois, USA)



(Moose et al, 2004)

Appetizer : high evolvability and limits to adaptation

… but **species' niches still have limits** and there are **empty niches**

=> genetic diversity and heritability are necessary but not sufficient to effectively achieve evolutionary adaptation

Limits to adaptation *(Fukuyma, 2010 ; Kuparinen et al, 2010)*

- genetic constraints
- developmental constraints

➔ *lack of genetic diversity*

➔ *demographic stochasticity*

➔ *random genetic drift*

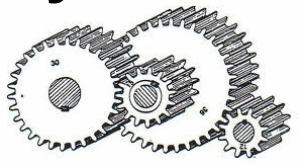
➔ *low mortality*

➔ *asymetric gene flow (e.g. niche limit)*

=> need to consider the complexity of evolutionary processes

Evolutionary adaptation : 3 hierarchical levels + environmental filter

Dynamics



Environment **Environment**

GENES' DIVERSITY → **TRAITS' VALUES** → **PERFORMANCE** **+** or **-**

1 environment = multiple factors + interactions + heterogeneity

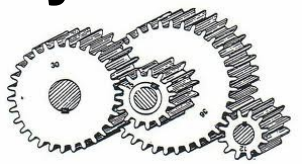
1 performance = multiple trait values + interactions
(syndrome => developmental constraint)

1 trait value = multiple gene alleles + interactions
(genetic architecture => genetic constraint)

Evolutionary adaptation : a stepwise dynamic process

Relatives are *alike* but not *identical* : sexual reproduction continuously generates new genetic combinations

Dynamics

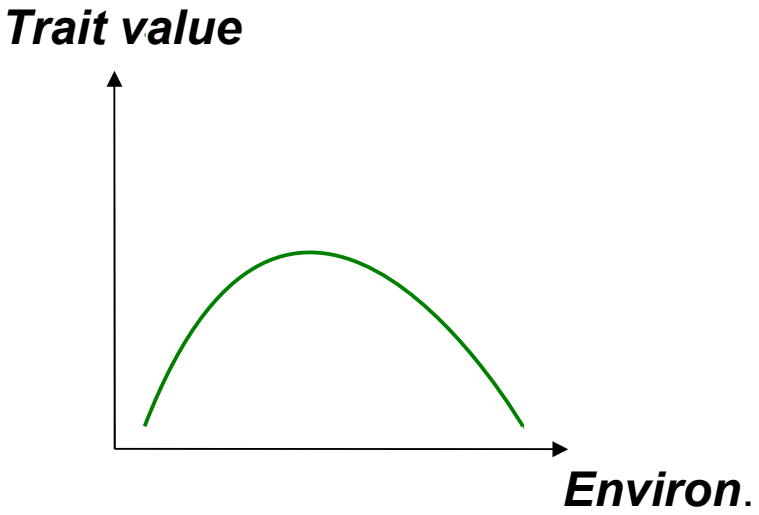


evolution is successful if :

(1) better performing genotypes emerge during reproduction

(2) the best performing genotypes spread in the population before it goes extinct

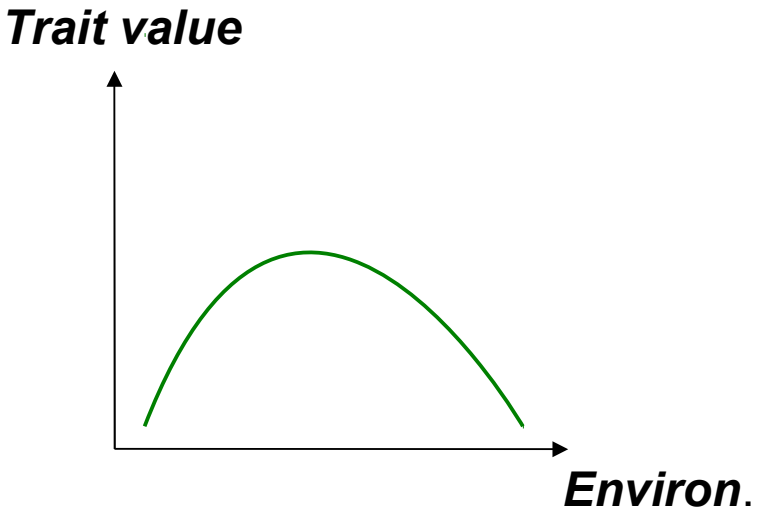
Evolutionary adaptation : integration of 3 basic functions

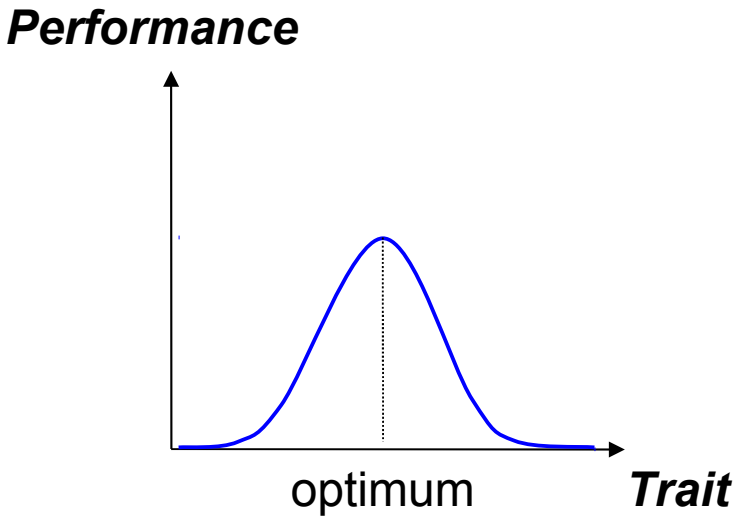


The reaction norm (plasticity)

it varies between individuals & traits

Response to selection : integration of 3 basic functions

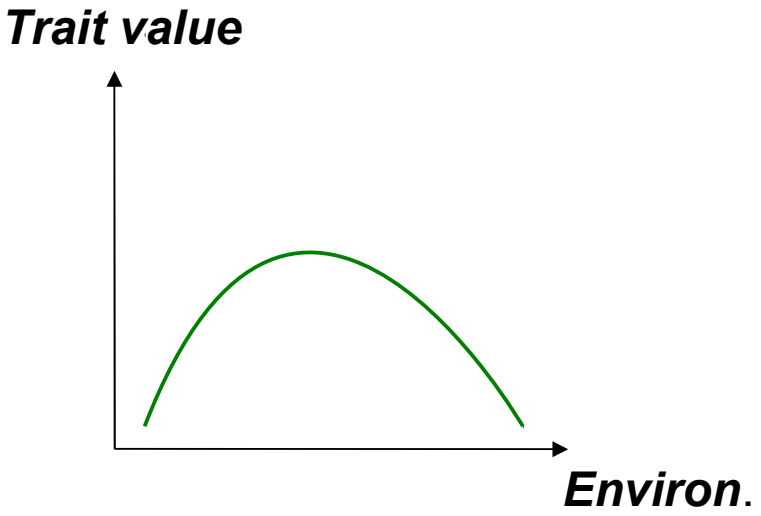


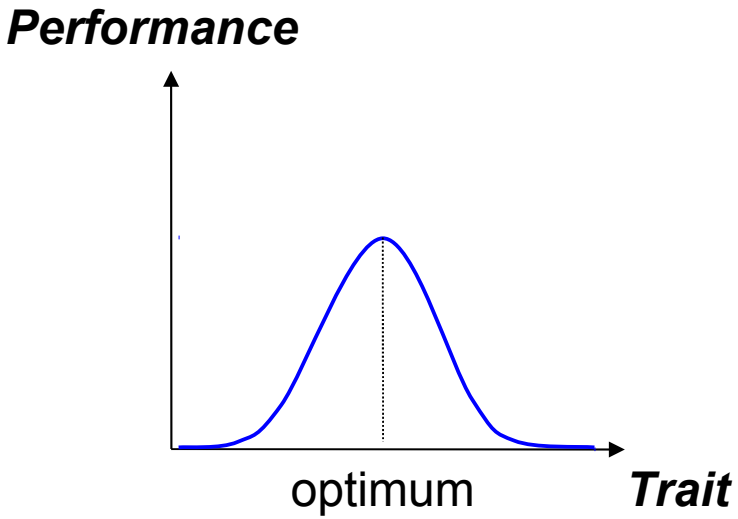


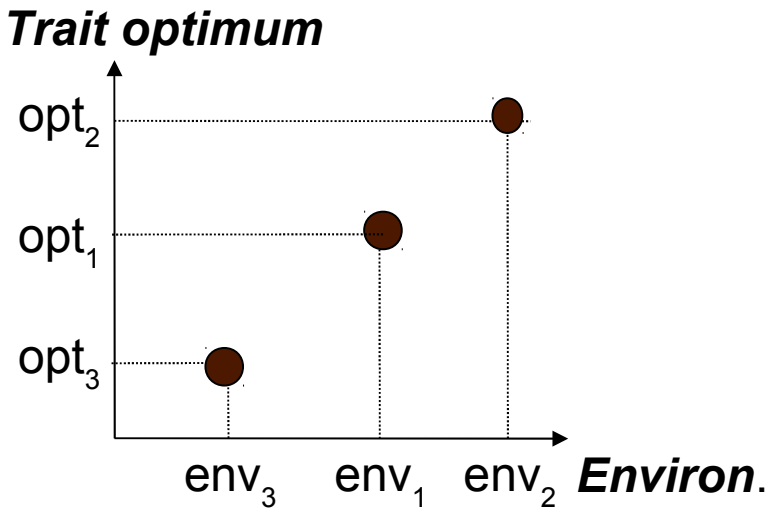
The selection gradient

it varies between environments
and depends on the other traits

Response to selection : integration of 3 basic functions







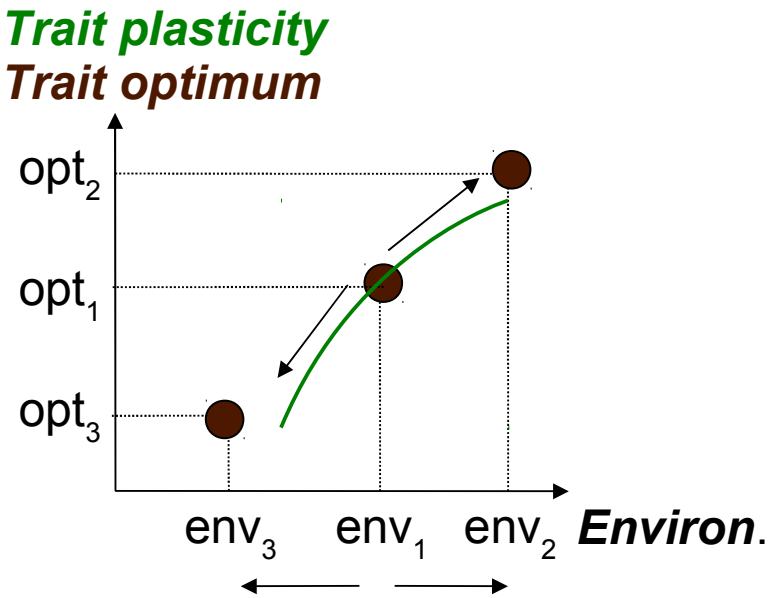
The environmental sensitivity of selection

how the optimal value varies with the environment

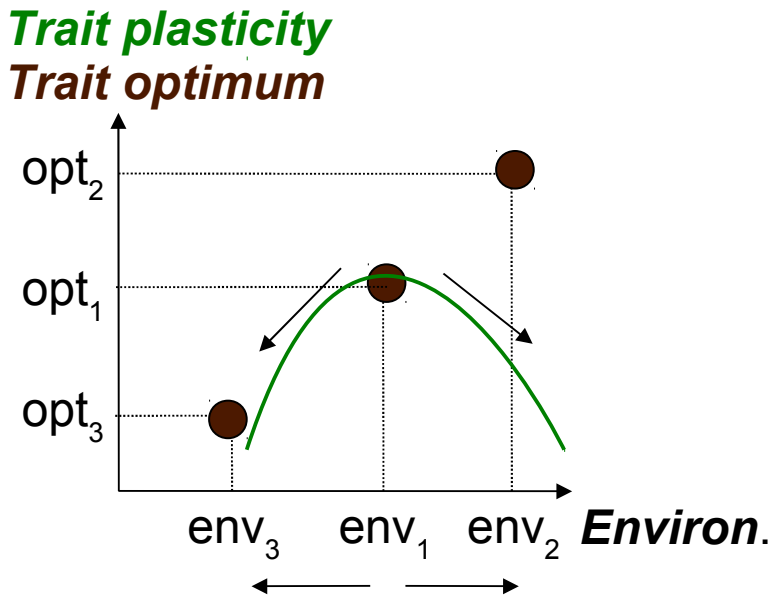
Response to selection : integration of 3 basic functions

The evolutionary response to environmental change
depends on te combination of these 3 functions

case of adaptive plasticity



case of maladaptive plasticity



=> resulting in different evolutionary responses

While facing global change and increased uncertainties, **forestry objectives** should be to accelerate adaptation and preserve the evolutionary potential by :

(1) increasing the chance of emergence of new genotypes

- *limit random drift*
- *increase the diversity of mating pairs*

(2) facilitating the spread of best adapted types

- *limit random drift*
- *limit consanguinity*
- *avoid counter-selection*
- *maintain selection pressure*

Use the global frame to anticipate multiple-level **forestry impacts** :

on the genetic diversity

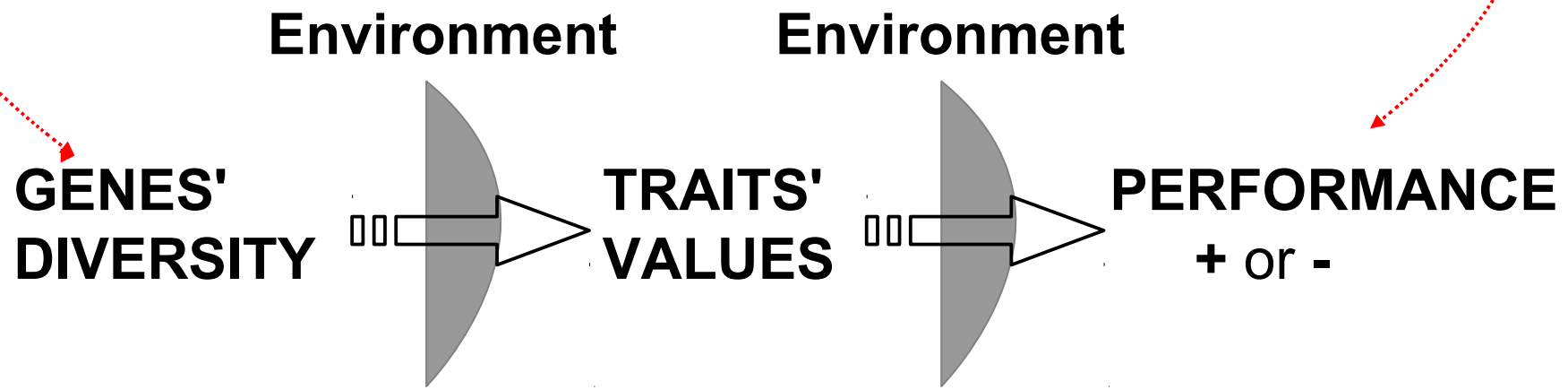
- *directly through plantation*
- *indirectly through the demography*

on the performance

- *through selective thinning*

on the environment

- *biotic and abiotic*
- *attenuation, adaptation & migration ?*



Dessert : genetically oriented practices, why not ?

- ✓ Genetic rescue of endangered populations
  - avoid over-elimination
  - large genetic base of introduced material
  - anticipate trade-off, e.g. drought vs frost resistance

- ✓ Enhance local gene flow
  - spatial distribution of seed trees
  - cumulate several seed years
  - homogenise fecundity

- ✓ Local (selective) seedling
  - reshuffling effect
  - possible selection
  - save the lone tree

- ✓ Future : genetic thinning ?

- ✓ … *(each point deserving detailed investigation)*