Adaptive silviculture regarding climate change: the geneticist's view

or

Facing the complexity of evolutionary processes to design adaptive forestry practices

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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

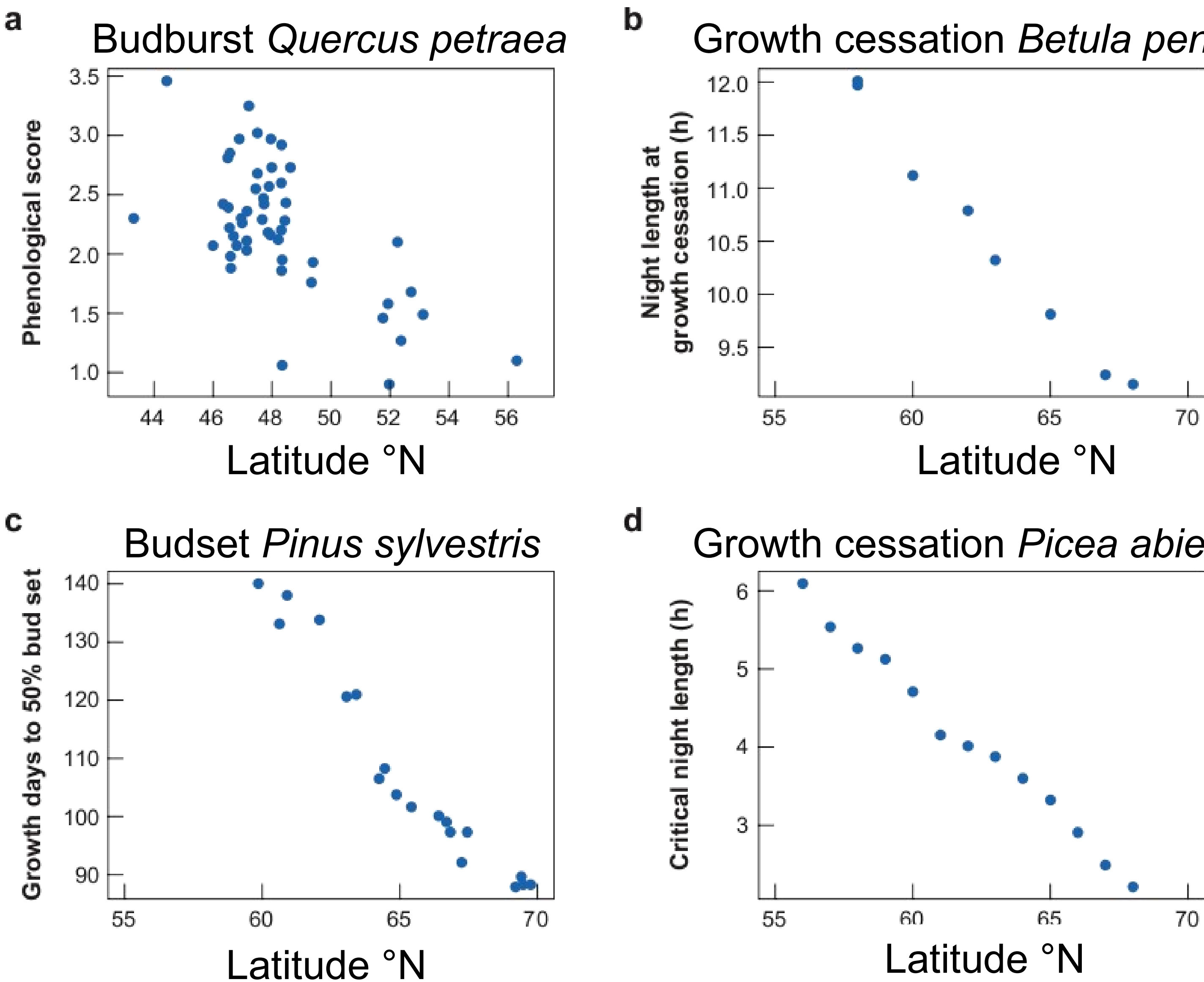
genetically oriented practices, why not ?

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*)

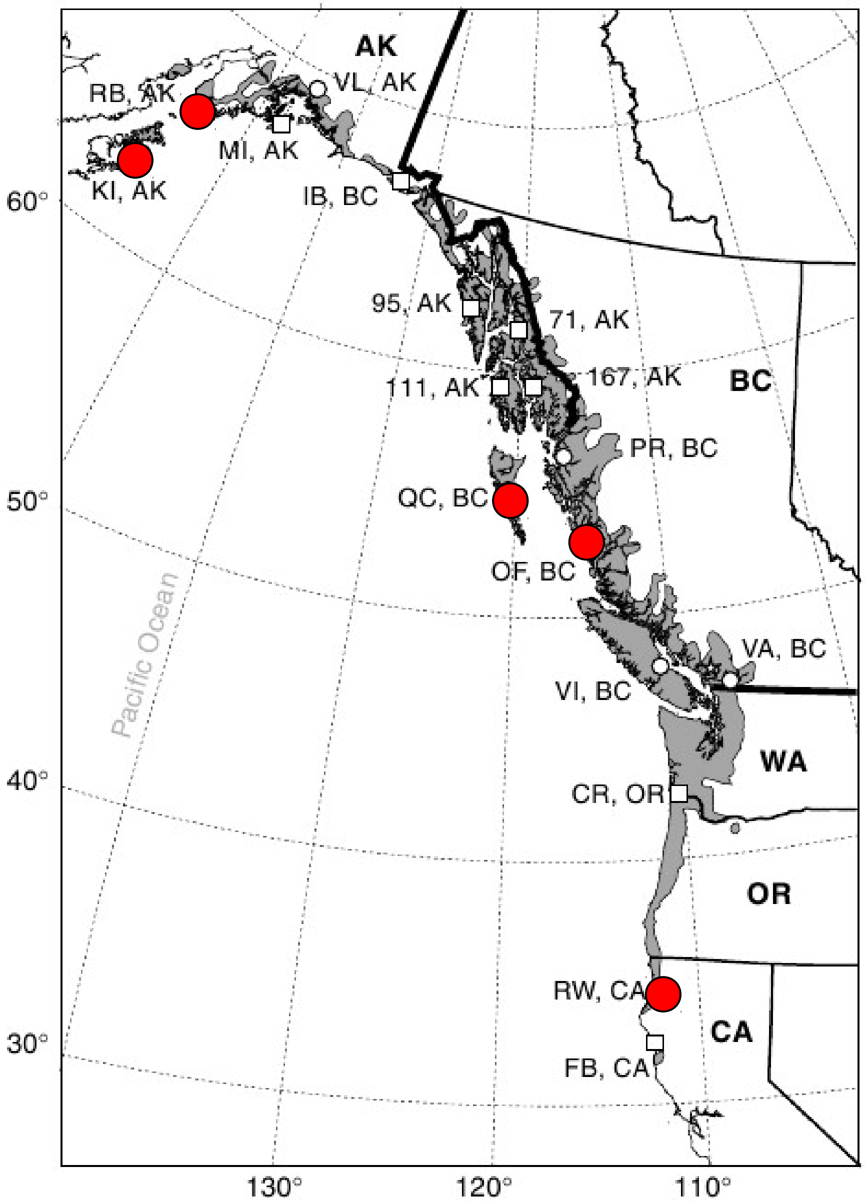
Region	**Annual rainfall (mm)**	**Tmean (°C) coldest month**	**Tmean (°C) warmest month**
California (5 pops)	420 – 700	10 – 11	16 – 18
N-Z (Southland)	***960 – 1000***	***3 – 5***	***13 – 15***
N-Z (Kaingaroa)	***1300 – 1500***	***7 – 9***	*11 – 19*
Chile (Valdivia)	***2350***	***7.7***	*17*
South Afr. (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)

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

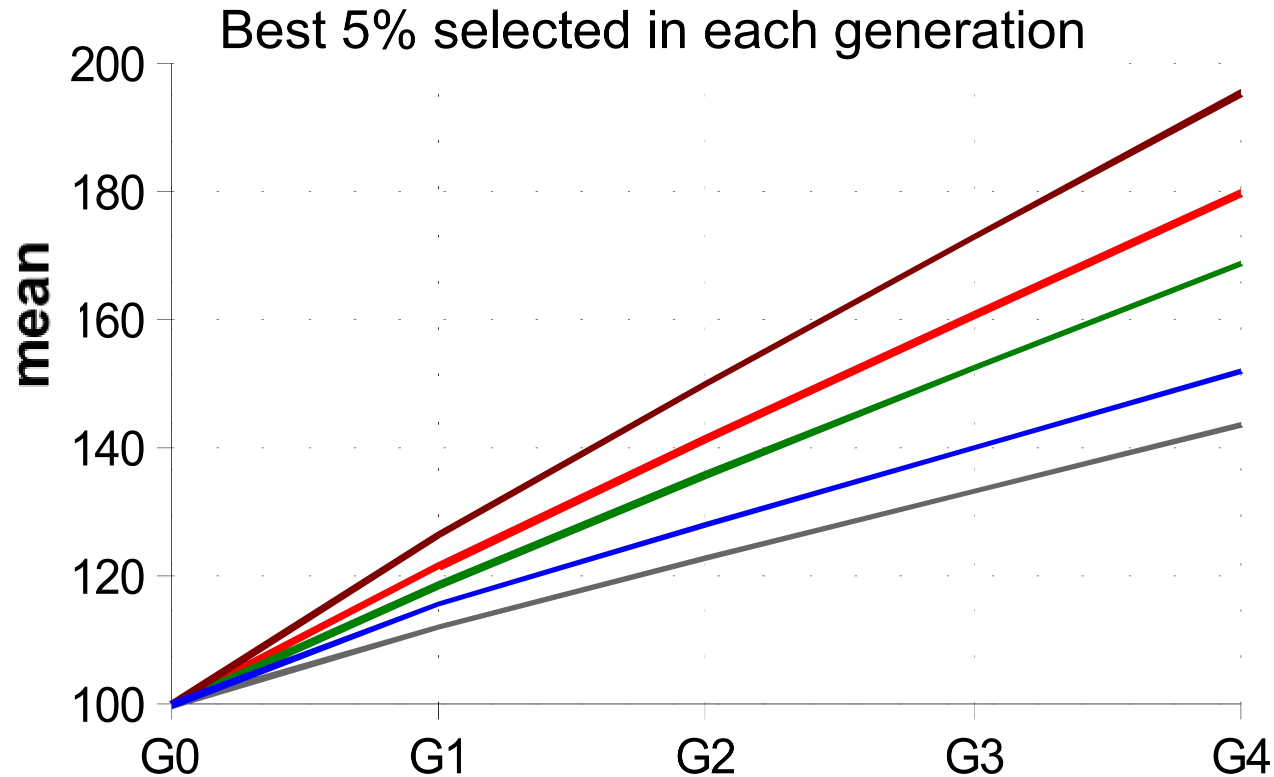
Mimura & Aitken (2007)

(between-pop component lower on shorter scale)

Theoretical (simplistic) short term response to selection

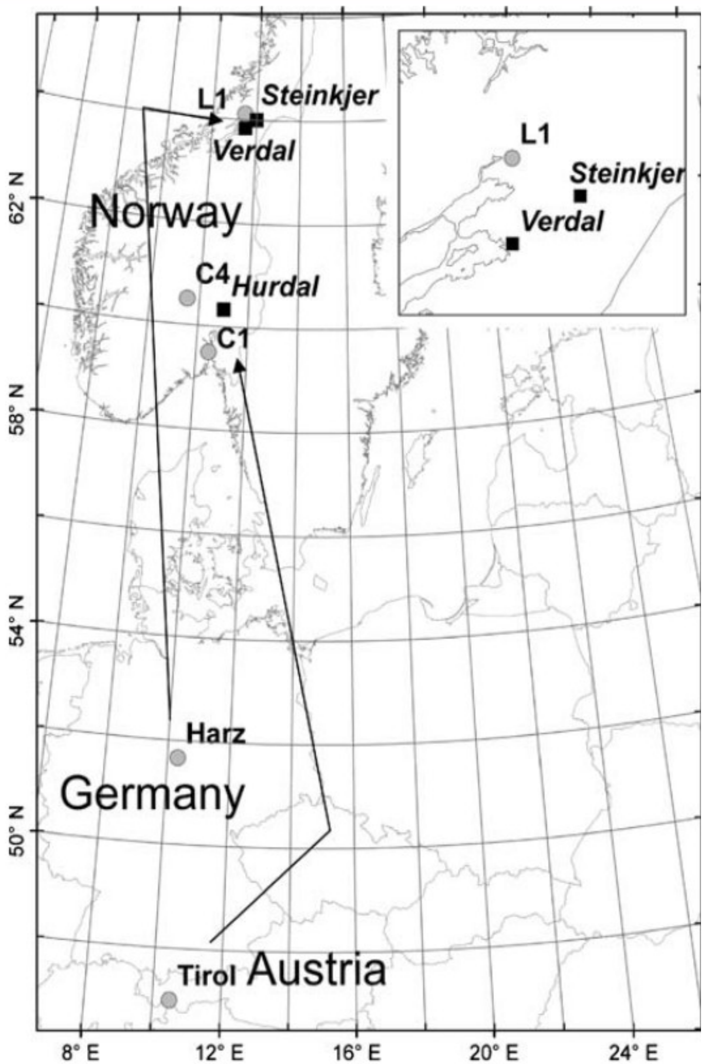
Traits / populations do not all have the same evolvability

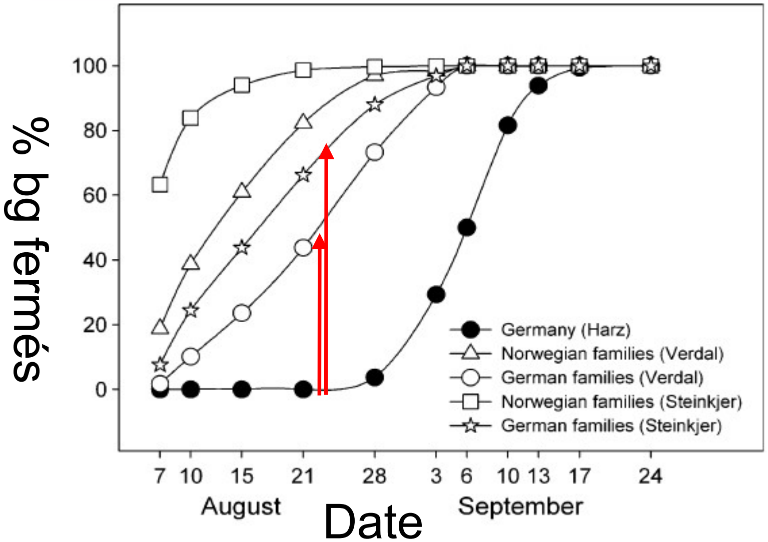
evolvability can also change

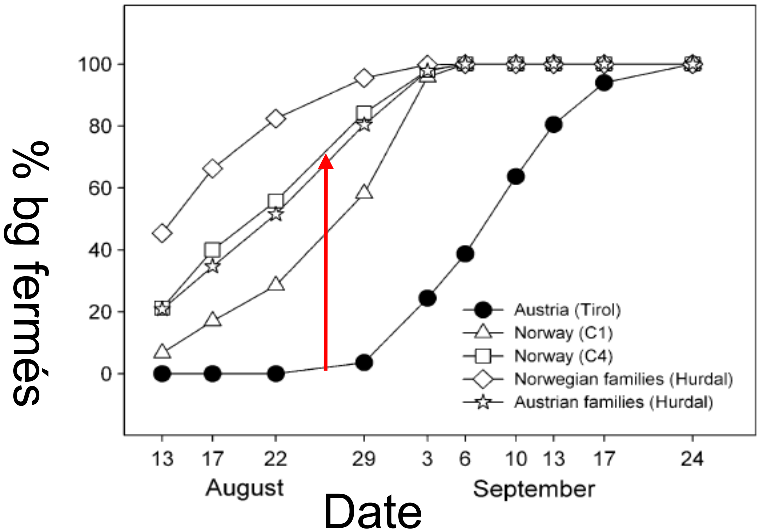


	h^2	σ^2_P	σ_A/μ	
budburst	0.30	1850	**24**	(*Ducousso, unpub.*)
volume	0.21	2500	**23**	(*Cornelius, 1994*)
height	0.24	1450	**19**	(*Ducousso, unpub.*)
branch angle	0.73	111	**9**	(*Kremer, 1994*)
height	0.28	440	**11**	(*Cornelius, 1994*)

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



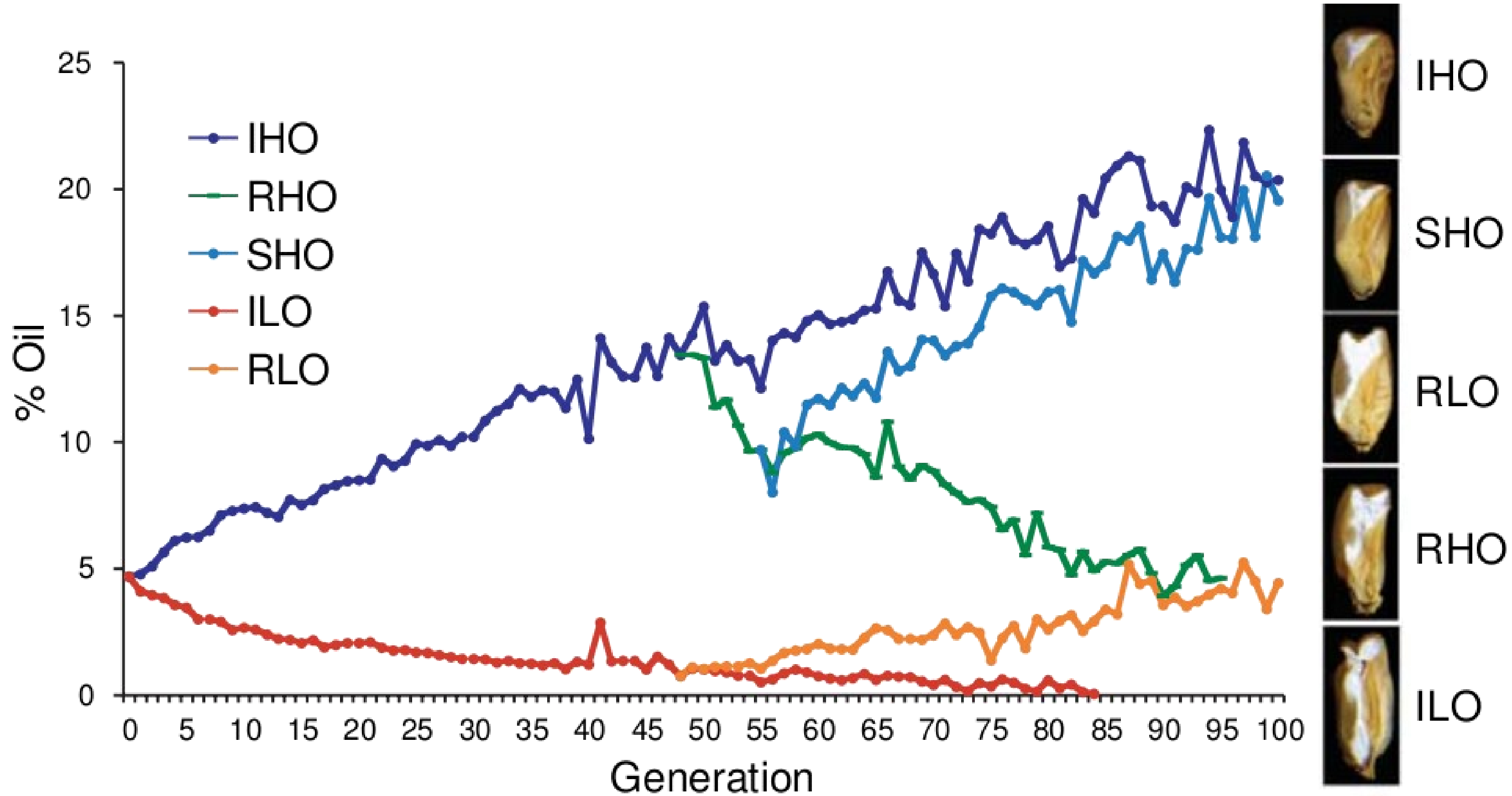




Skrøppa et al (2010)

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)

… 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)*

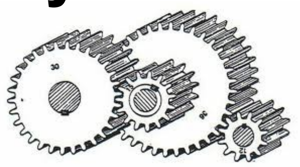
- genetic constraints
- developmental constraints
- → *lack of genetic diversity*
- → *demographic stochasticity*
- → *random genetic drift*
- → *low mortality*
- → *asymetric gene flow (e.g. niche limit)*

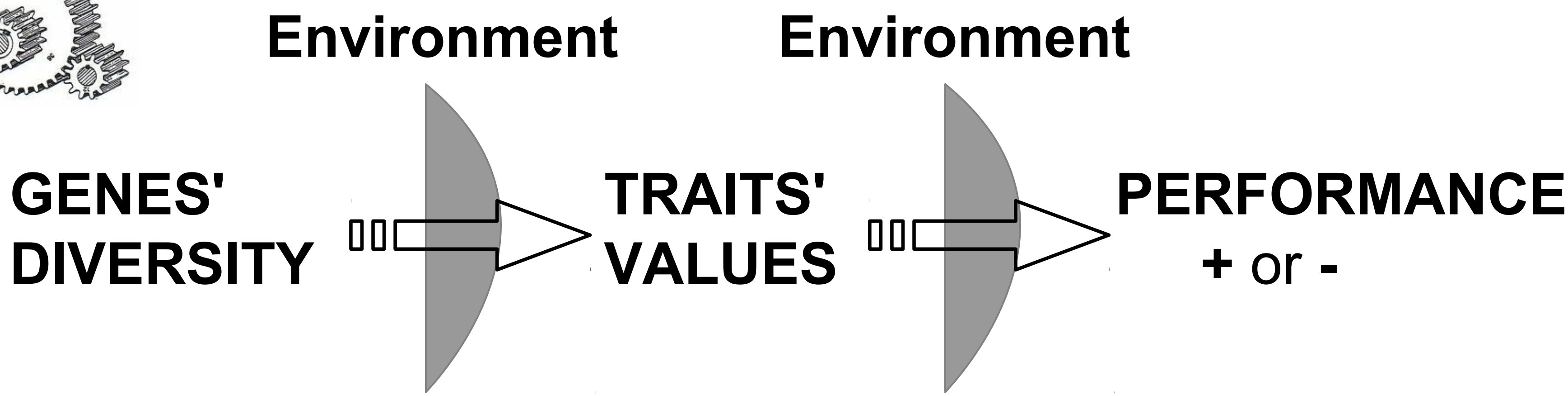
=> need to consider the complexity of evolutionary processes

Main course : global frame & complexity of evolutionary processes

Evolutionary adaptation : 3 hierarchical levels + environmental filter

Dynamics





1 environment = multiple factors + interactions + heterogeneity

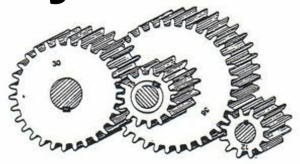
1 performance = multiple trait values + interactions
(syndrome => developmental constraint)

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

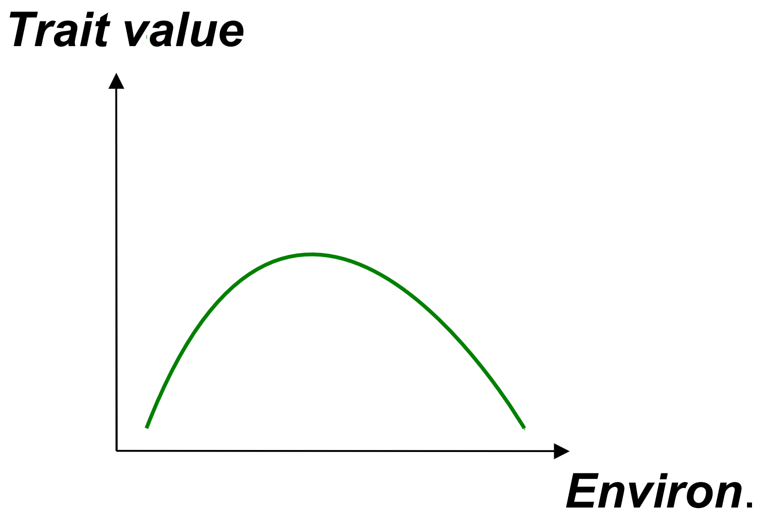


evolution is successful if :

(1) better performing genotypes emerge during reproduction

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

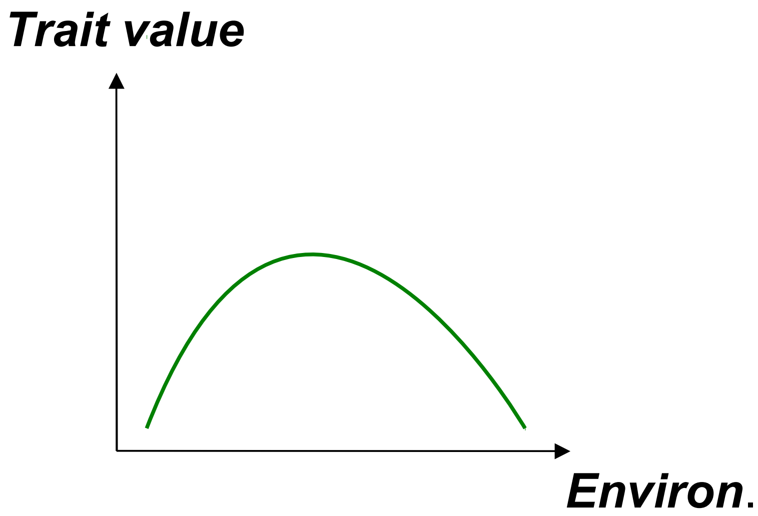
Evolutionary adaptation : integration of 3 basic functions

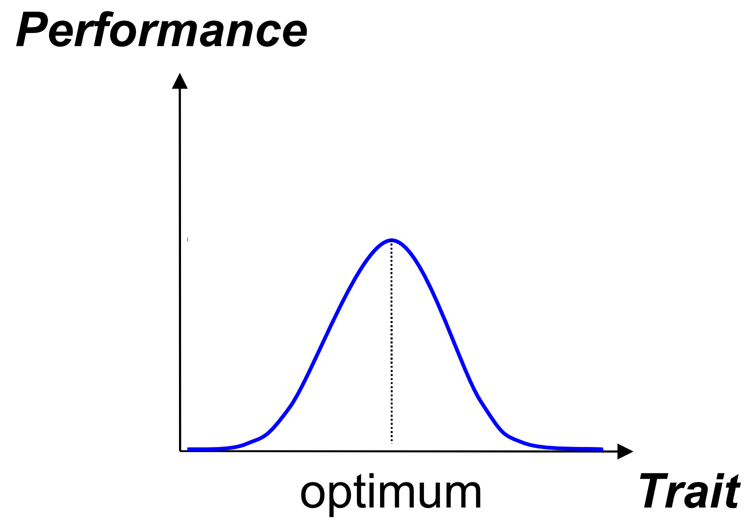


The reaction norm (plasticity)

it varies between individuals & traits

Response to selection : integration of 3 basic functions

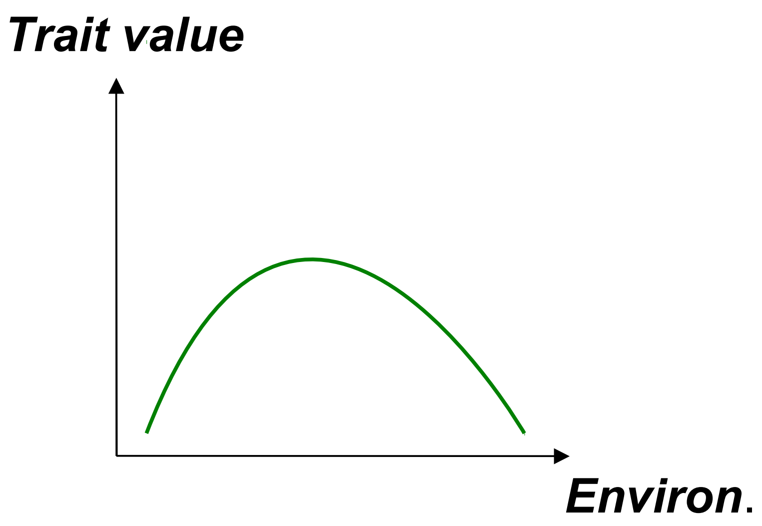


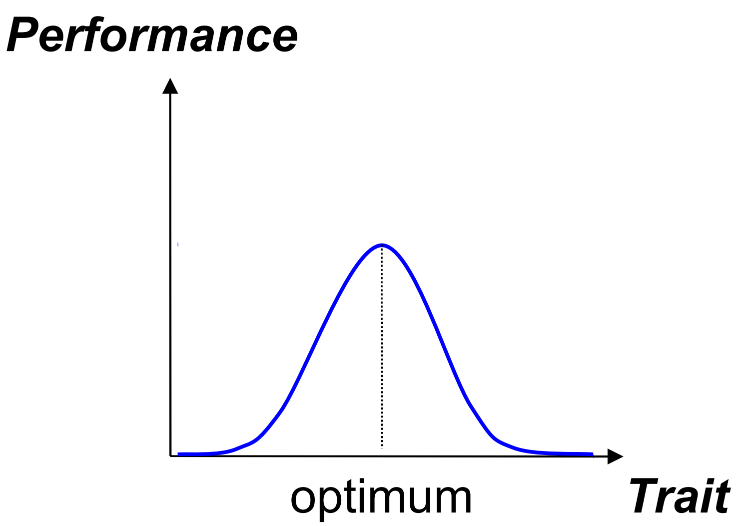


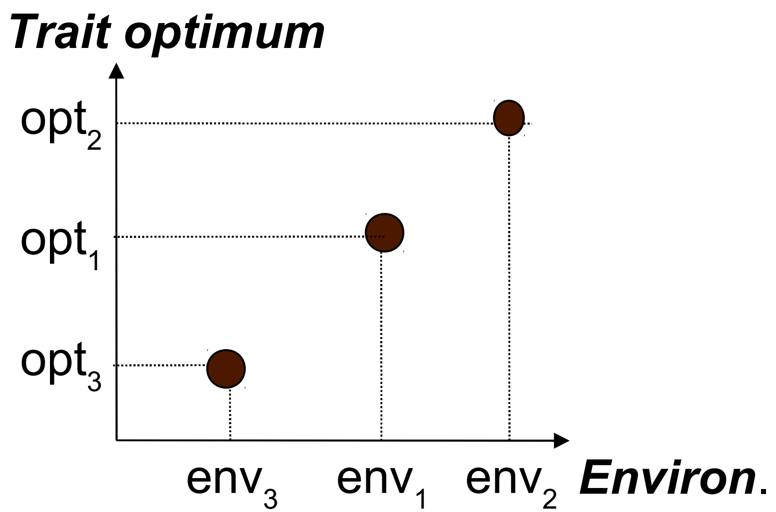
The selection gradient

it varies between environments
and depends on the other traits

Response to selection : integration of 3 basic functions







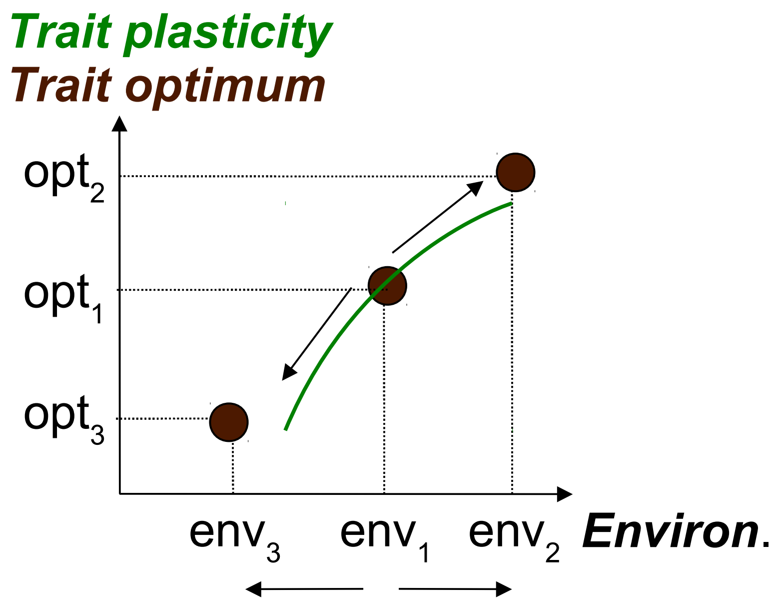
The environmental sensitivity of selection

how the optimal value varies with the environment

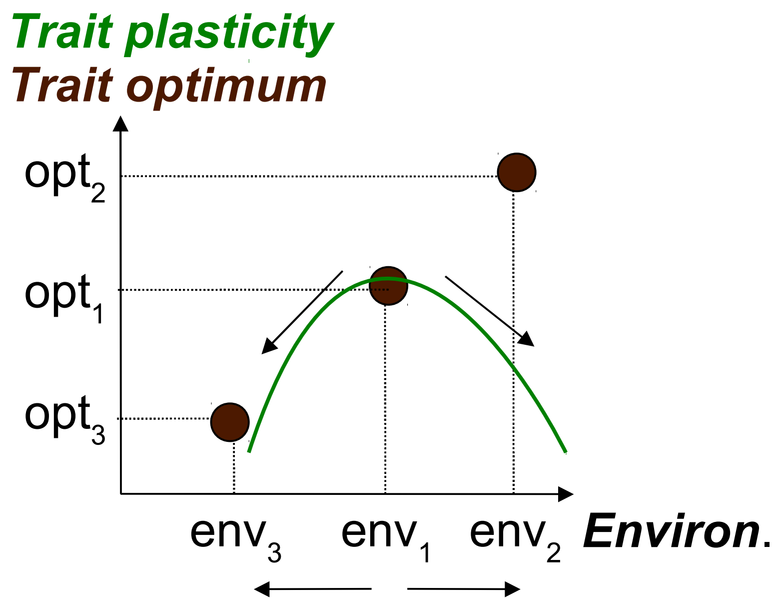
Response to selection : integration of 3 basic functions

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*

Main course : potential impacts of forestry practices

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

on the genetic diversity

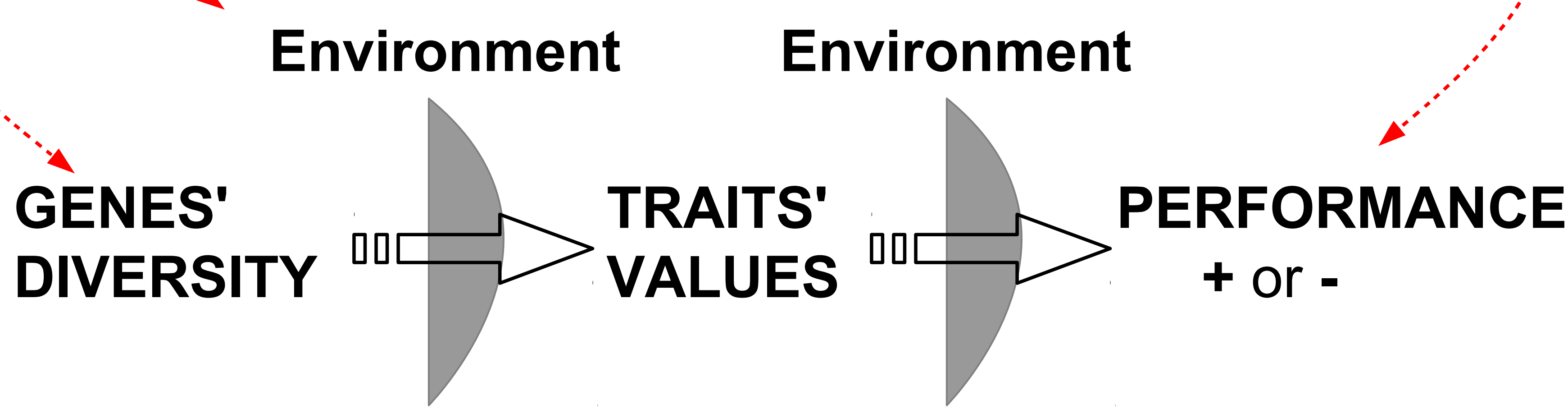
- *directly through plantation*
- *indirectly through the demography*

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)*