Mechanisms of local adaptation to climatic gradients: lessons from a physio-demo-genetics model

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Mechanisms of local adaptation to climatic gradients: lessons from a Physio-Demo-Genetics Model

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Accounting for evolutionary adaptation when predicting the response of tree populations to Climate Change (CC)

+ High levels of genetic diversity
+ High levels of gene flow

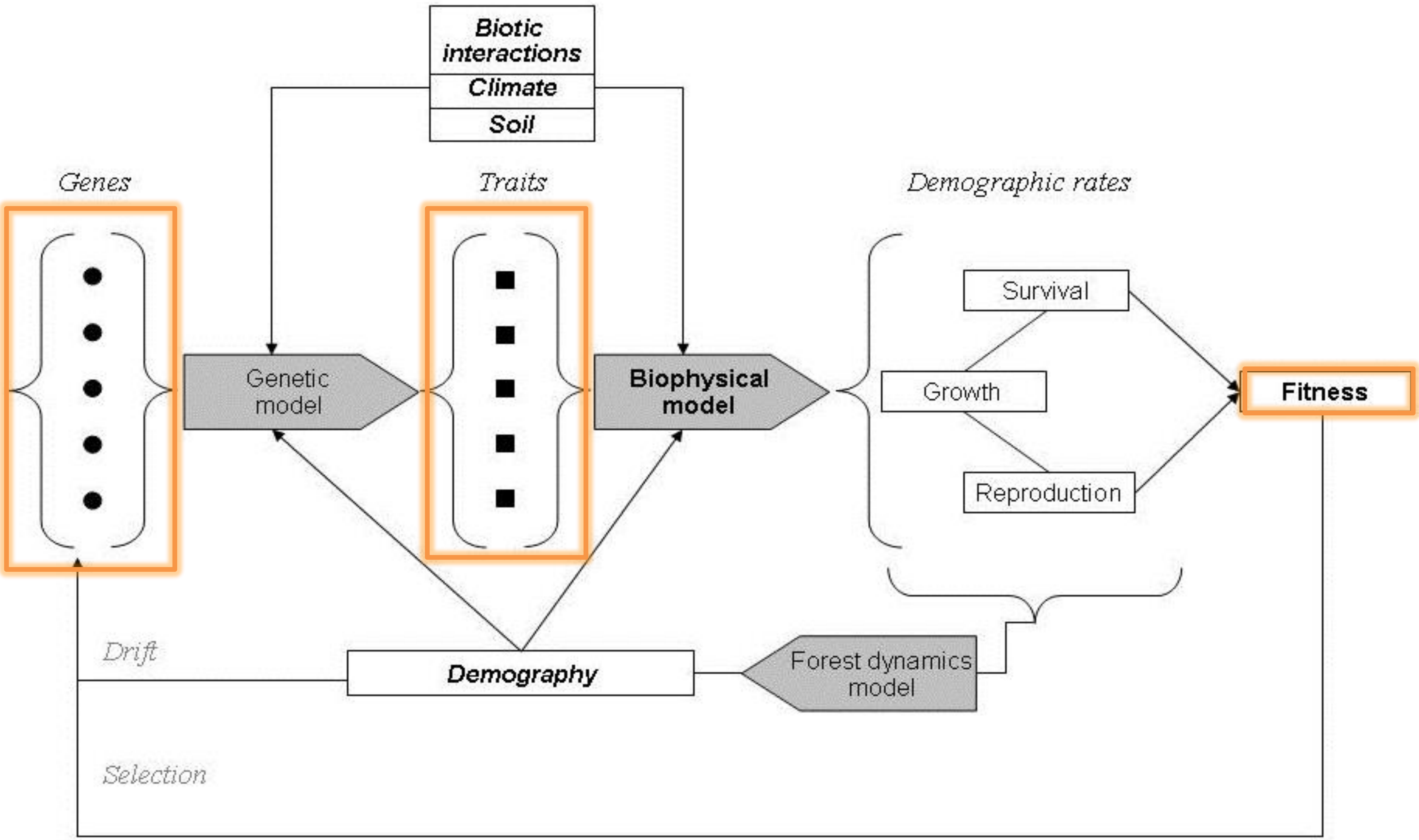
— Long generation time
— Low mortality of established trees
— Genetic and environmental constraints on traits involved in adaptation

1) Accounting for intra-specific genetic variability and phenotypic plasticity in Species Distribution Model (Benito-Garzon et al. 2011)
2) Accounting for adaptive processes in forest dynamic model : High mortality (Kuparinen et al 2010) or dynamic silviculture (Kramer et al. 2008) can favor rapid adaptation to a warming climate

- *Need to account simultaneously for plasticity, adaptation and gene flow/migration*
- *Need of short-time scale predictions (few generations), out of equilibrium and at local spatial scale*
- *CC effect is non linear and complex; the role of climate is difficult to predict without biophysical models*

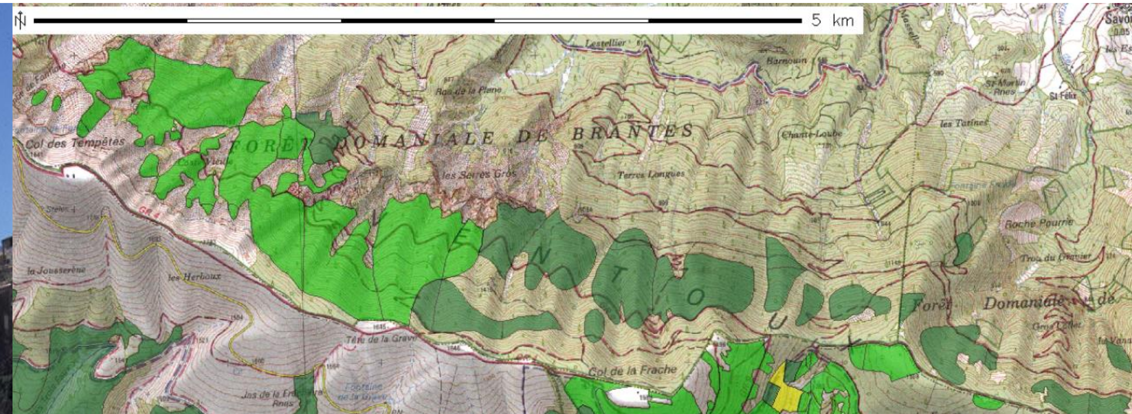
Objective

1. ***A new Physio-Demo-Genetics Model accounting for complex interactions among genes, functional traits and climate when environment or demography are unstable***



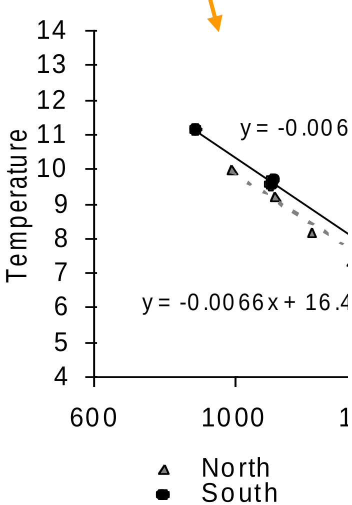
Objective

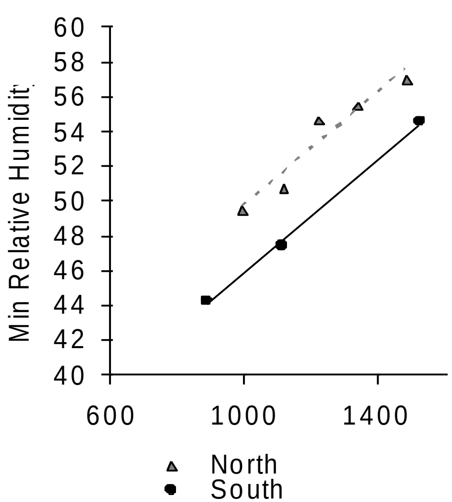
2. Application to the study case of Fagus sylvatica (European Beech) on Mont Ventoux



Beech populations occur between :
- 750 and 1700 m on North face
- 840 and 1615 m on the South face

Ecological data (growth, fructification, dispersal, phenotypic and genetic diversity)

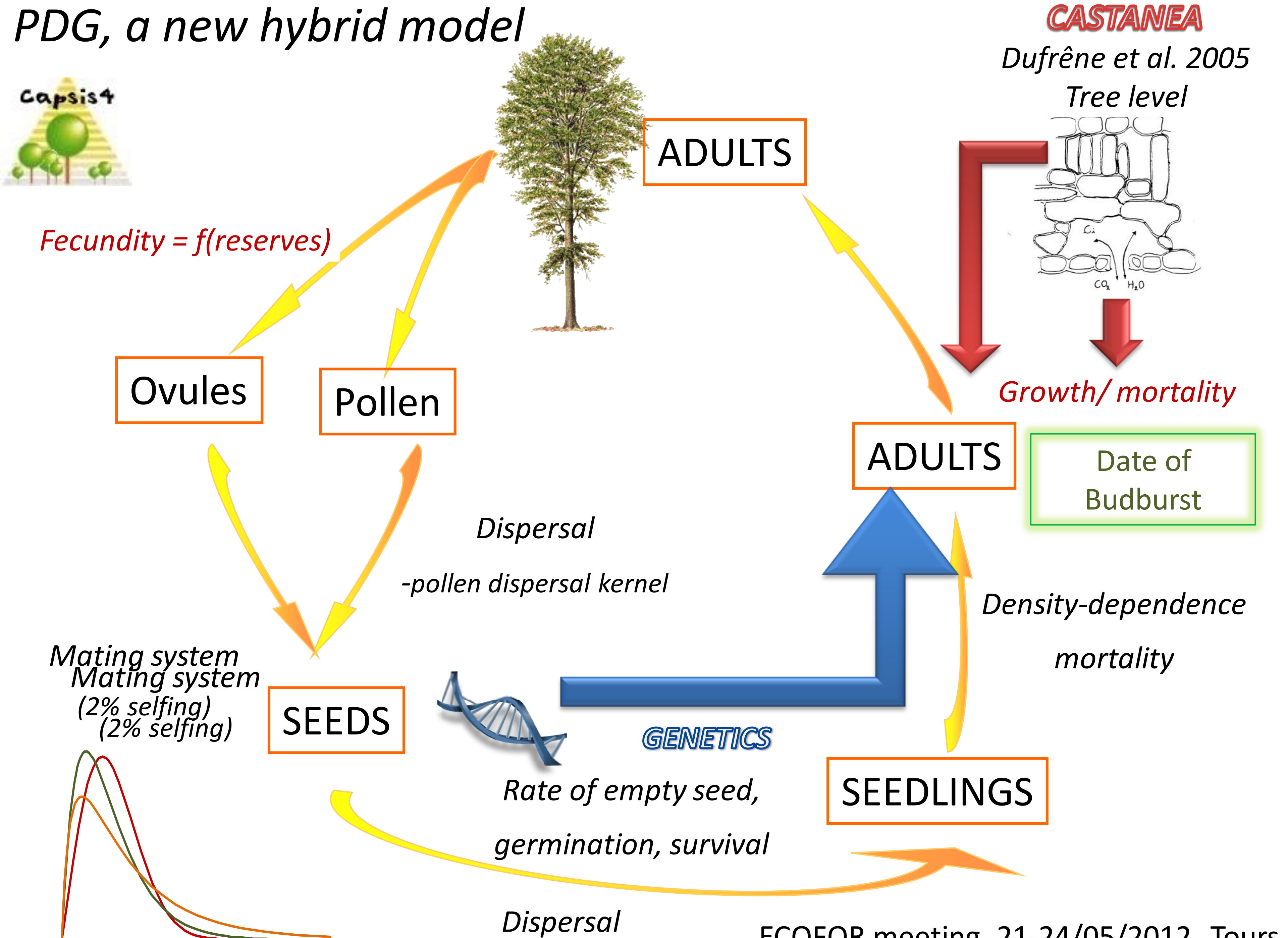




How adaptive genetic variation and phenotypic plasticity respectively contribute to the variation of functional traits along environmental gradient?

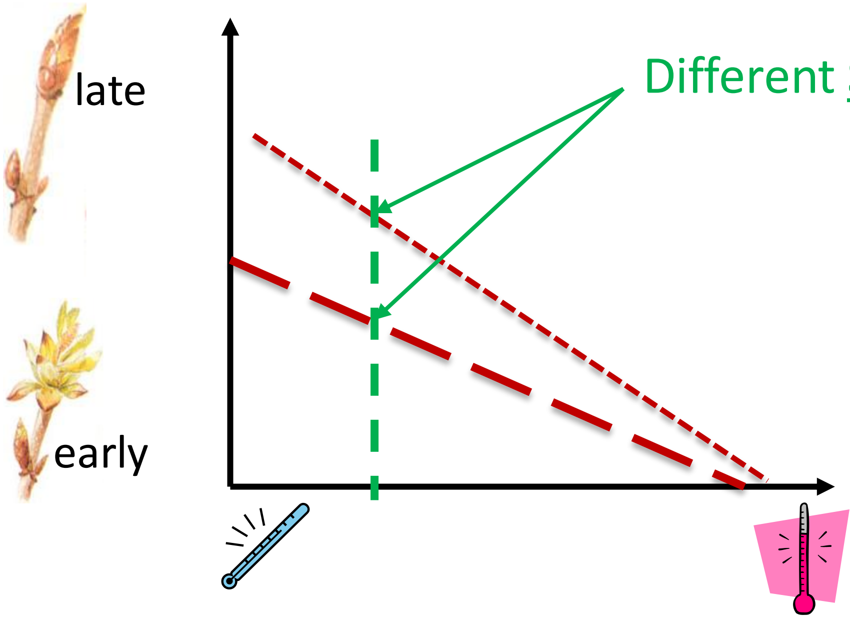
How fast can genetic adaptation develop ?

PDG, a new hybrid model



Genetic basis of date of budburst

***Trait* = date of budburst**



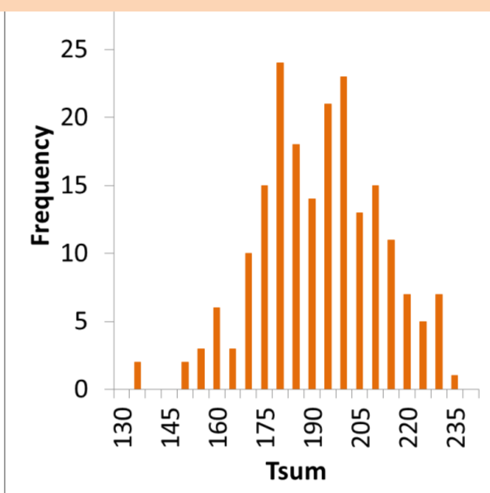
Different **Sum of temperatures required for budburst**, Tsum(late)>Tsum(early)

Trait: P= f(Env + Gen + Gen x Env)

P= f(T° + Tsum + Tsum x T°)

Environment = Temperature

The parameter Tsum of the biophysical model is genetically based and variable :



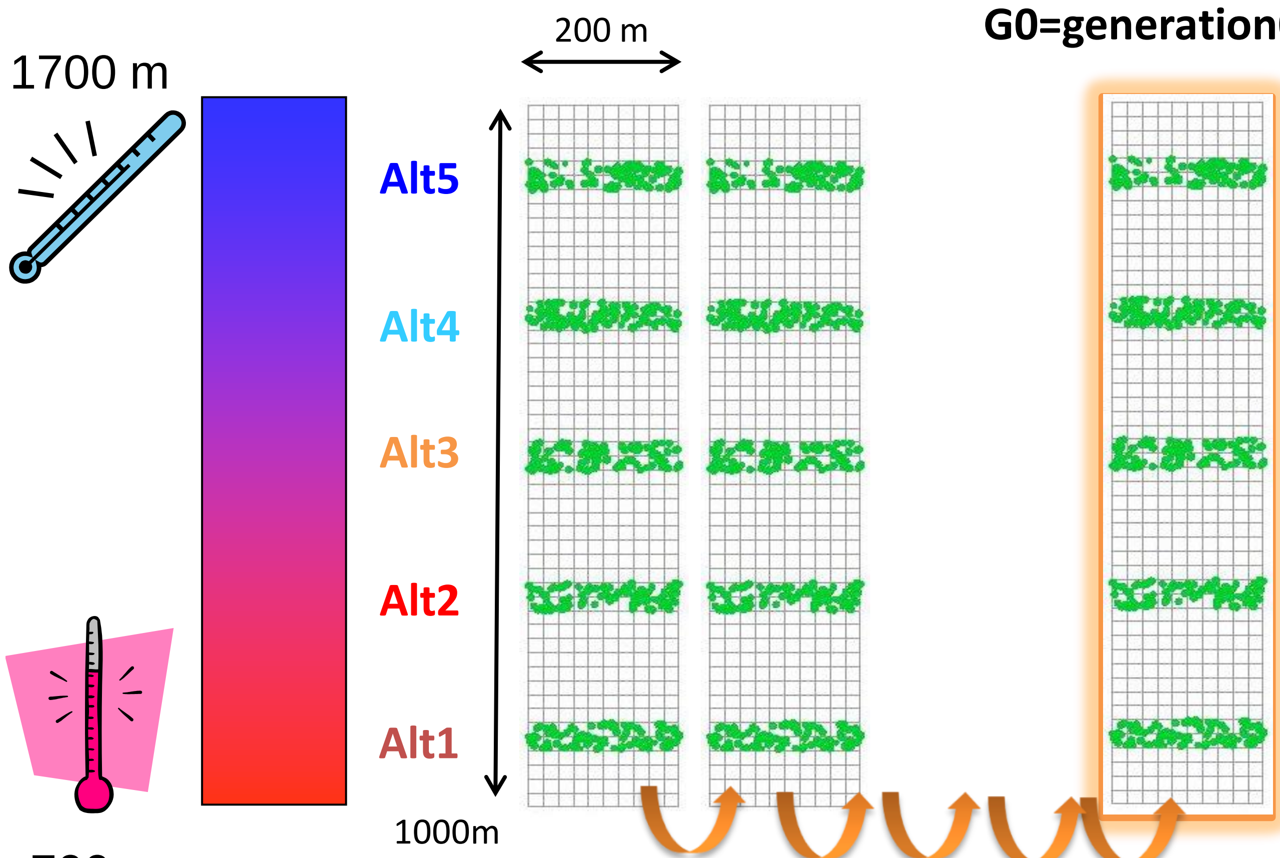
- 10 unlinked genes, 2 alleles /gene (=10 SNPs)
- Effect of each gene <- Gaussian distribution at initiation

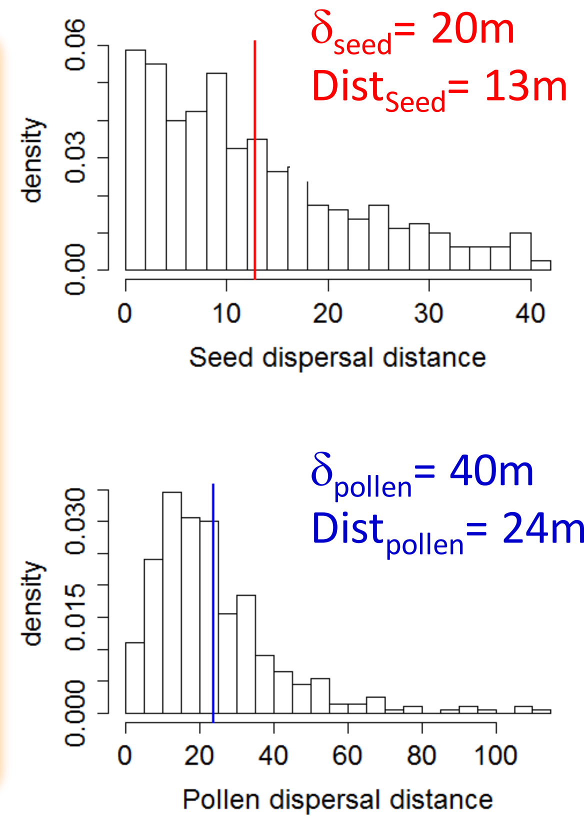
Mean Tsum = 190

Simulation design : Initial state

- N=500 adult trees, age 40
- 100 trees at each elevation
- Plot size = 200m×1000m

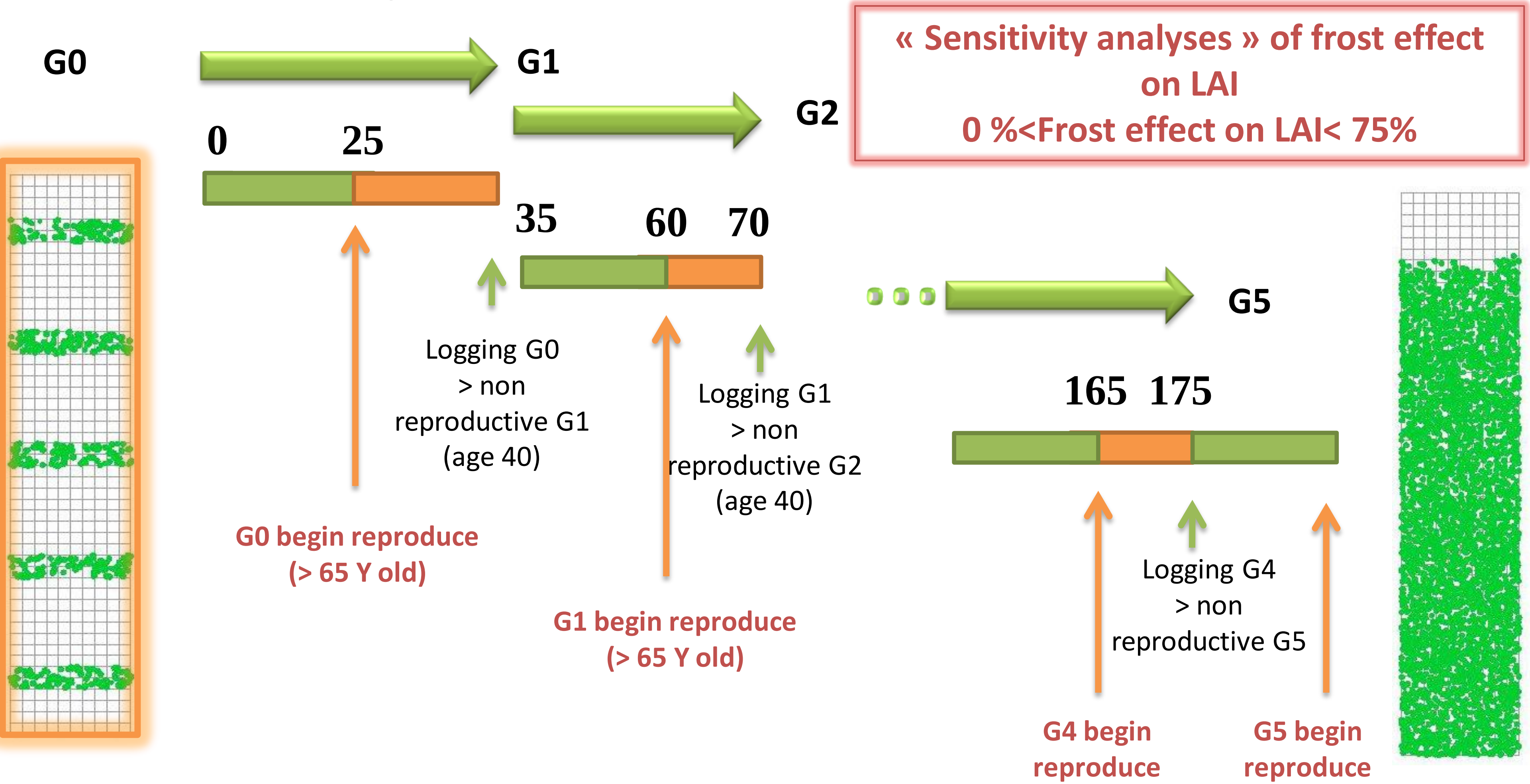
- Genetic equilibrium
- No adaptive differentiation for Tsum and for the underlying genes





Neutral pre-evolution = genetic drift + dispersal at constant population size

Simulation design : Evolution with selection

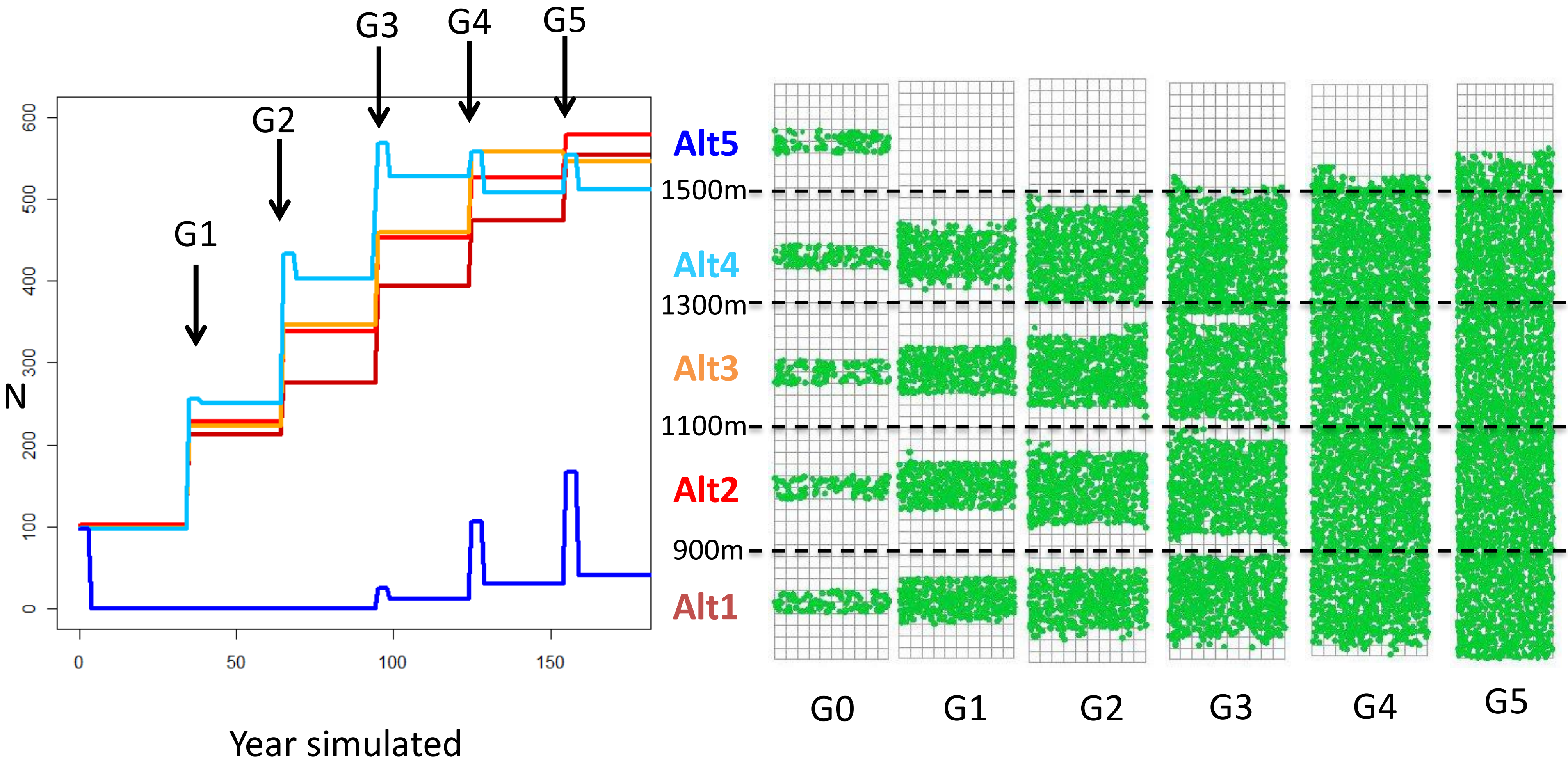


Working hypothesis for the studied case

- No overlapping generations (sequential logging of reproductive trees)
- No selection on date of budburst during the regeneration step
- No mutation (only standing genetic variation + recombination)
- No competition for light among adults
- Climate (2002-2006 repeated) with elevation effect on T, Rainfall, and relative humidity

Results: population dynamics

Frost effect on LAI = 0

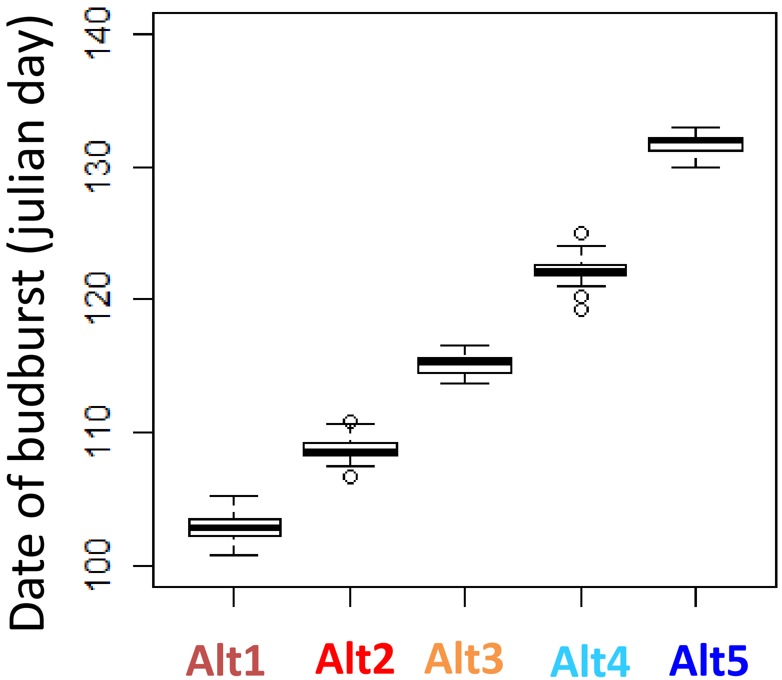


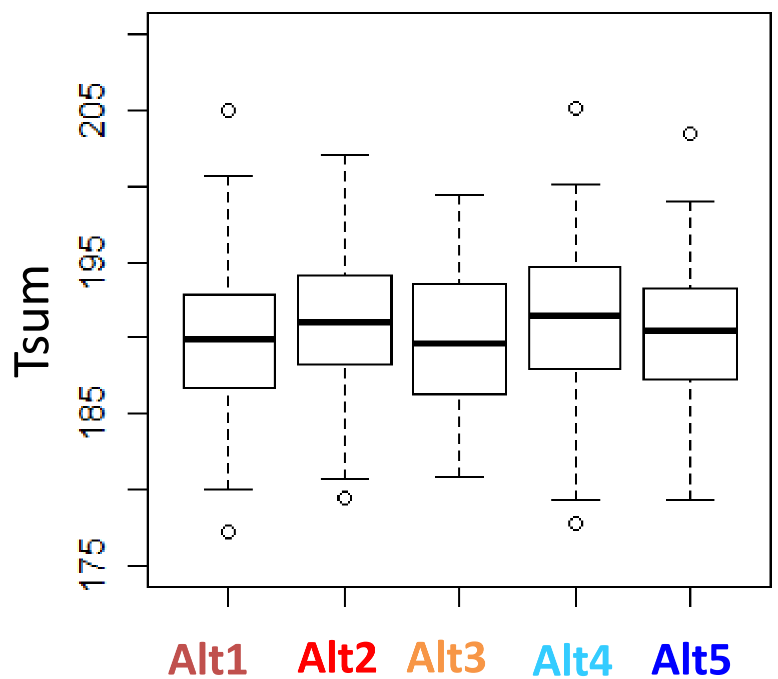
- Extinction of Alt5 at G0 and recolonisation at G3
- Treeline at 1620 m (versus observed =1700 m)

Results : spatial patterns of budburst

Frost effect on LAI = 0

At generation G0





— Temperature decreases with elevation → later budburst

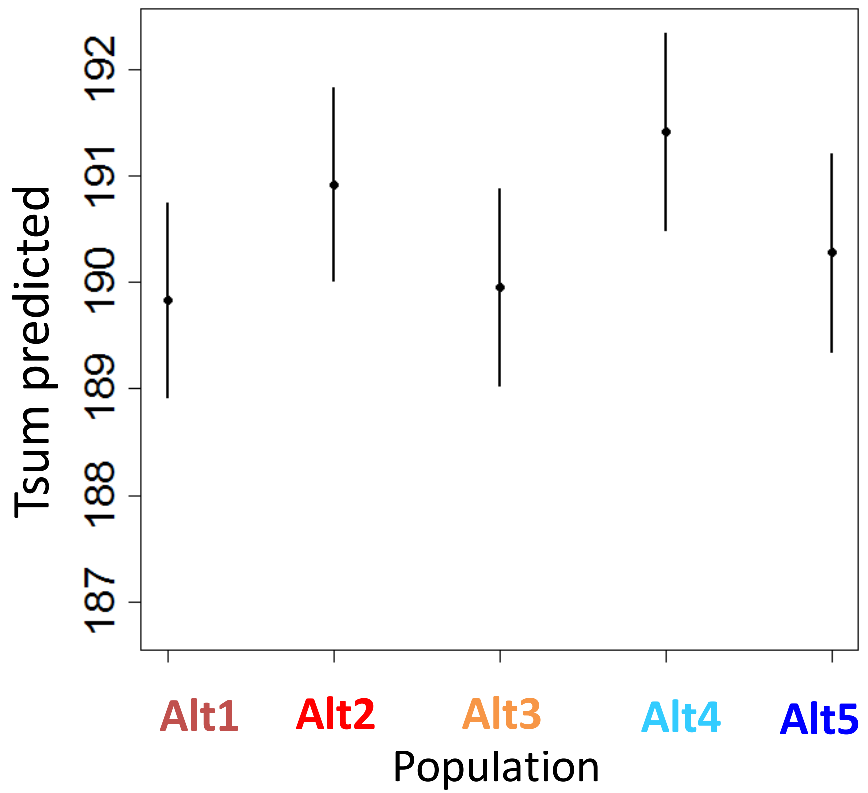
Results : spatial patterns of budburst

Frost effect on LAI = 0

At generation G0

Linear model: $Tsum_i = Population_i + \varepsilon_i$

Parameter	Estimate	P-value
Intercept	189.9	<0.001
Alt1	0	
Alt2	1.08	<0.01
Alt3	0.11	
Alt4	1.58	<0.05
Alt5	0.44	



— Marginal differentiation for Tsum due to genetic drift during pre-evolution

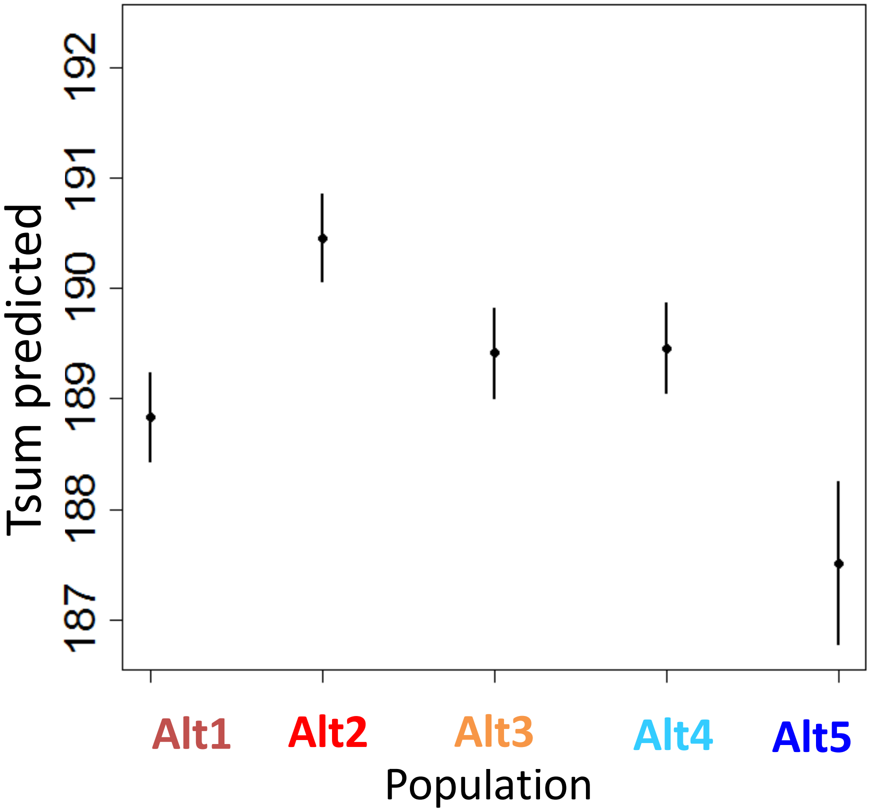
Results : spatial patterns of budburst

Frost effect on LAI = 0

At generation G5

Linear model: $Tsum_i = Population_i + \varepsilon_i$

Parameter	**Estimate**	**P-value**
Intercept	189.9	<0.001
Alt1	0	-
Alt2	1.62	<0.001
Alt3	0.57	<0.05
Alt4	0.62	<0.05
Alt5	-1.32	<0.01

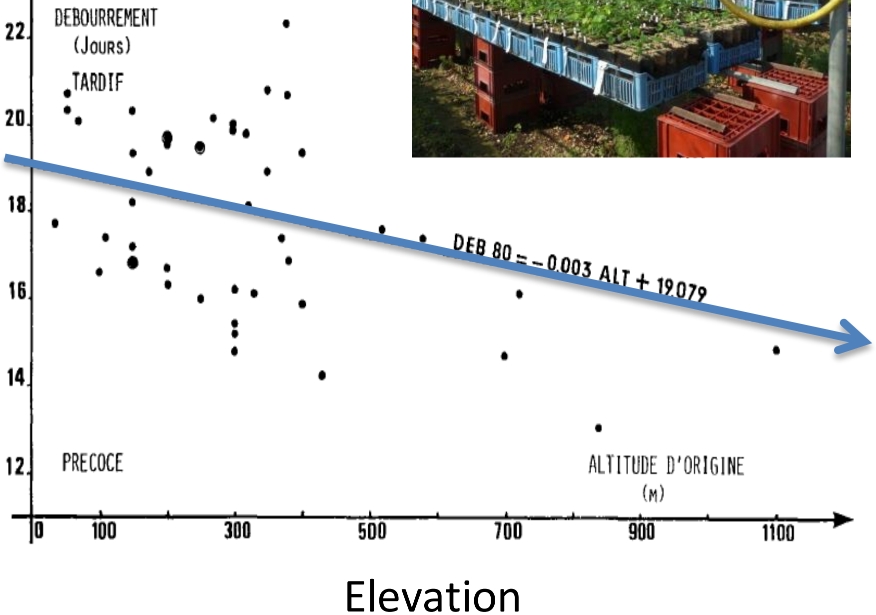


— Significant differentiation for Tsum due to selection :

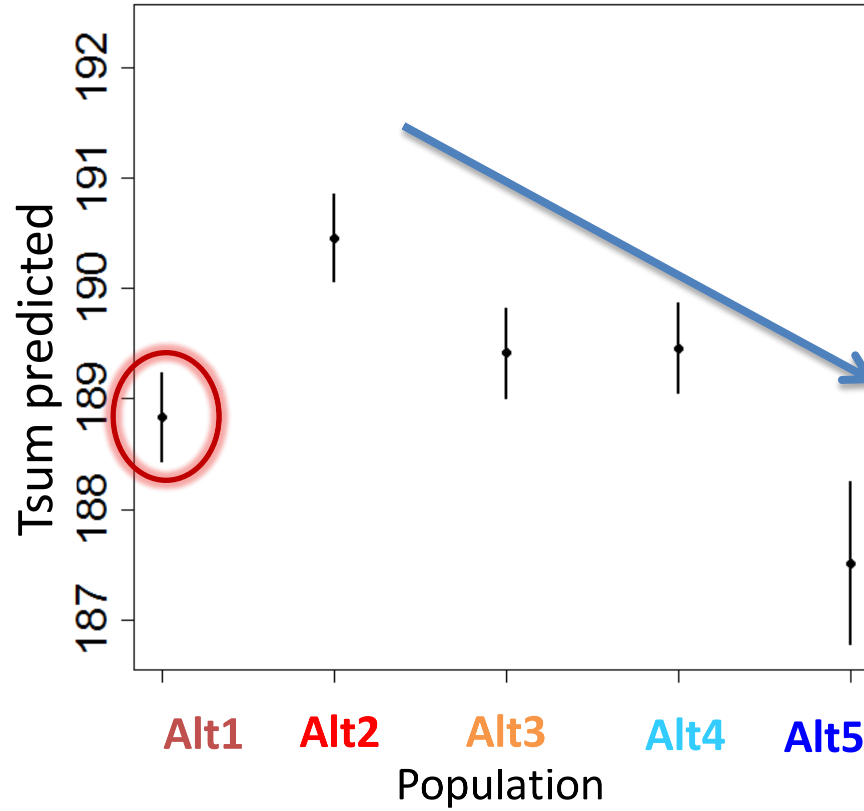
Results : spatial patterns of budburst

Frost effect on LAI = 0

At generation G5



E. TEISSIER DU CROS & B. THIEBAUT 1988

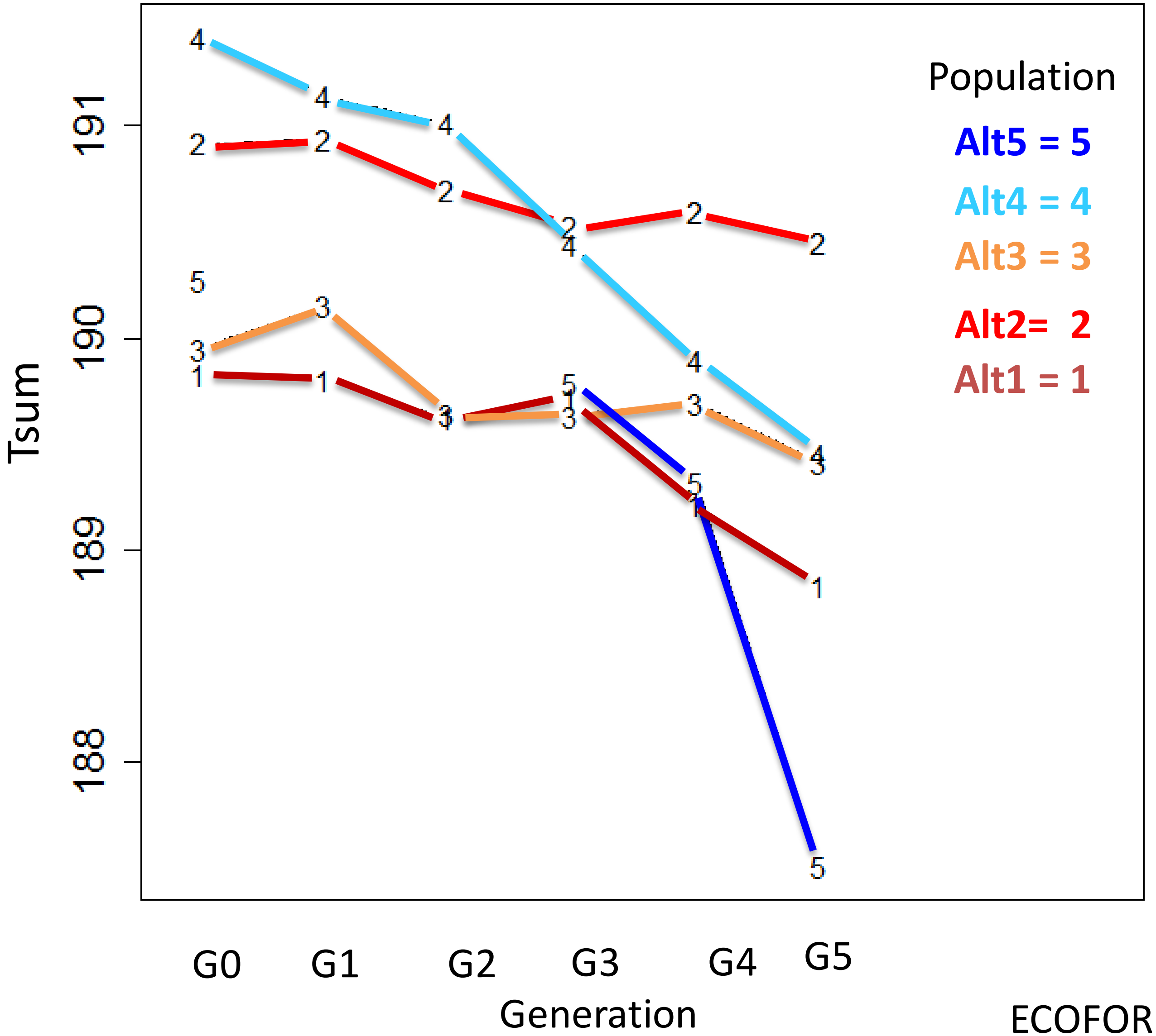


- Significant differentiation for Tsum due to selection :
  - Tsum decreases when elevation increases
  - Population Alt1 evolved significantly lower Tsum than Alt 2 (interaction with drought stress)

Results : temporal evolution for Tsum

Frost effect on LAI = 0

Linear model: $Tsum_i = Population_i + Generation_i + interaction(Population_i\ , Generation_i\ ) + \varepsilon_i$

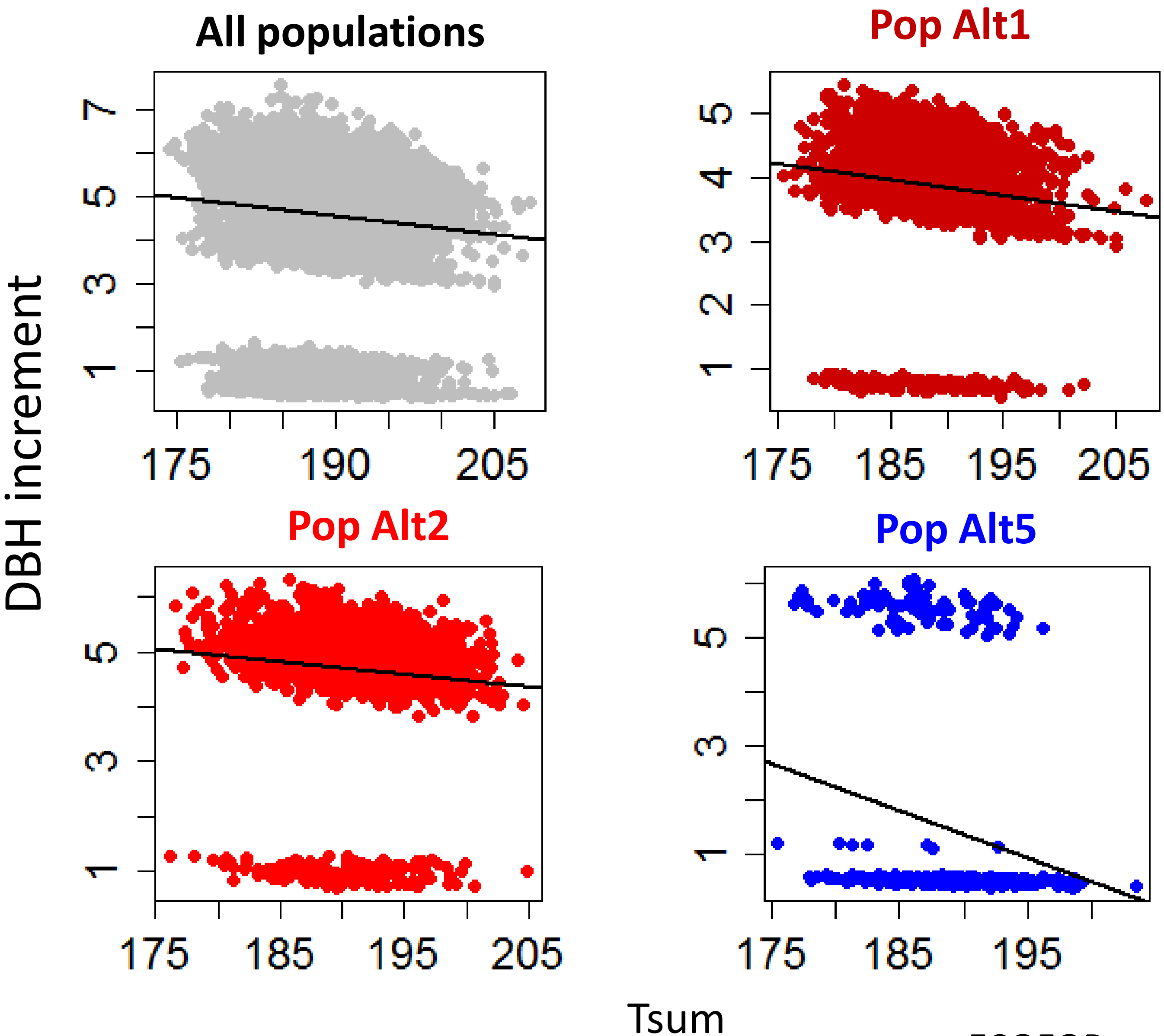


- Whatever the elevation, selection for lower Tsum
- Strength of selection varies with elevation
- In popAlt5, date of budburst advanced from 132 to 128 in 5 generations

Results : strength of selection on tsum

Frost effect on LAI = 0

Linear model: $DBHincrement_i = tsum_i + \varepsilon_i$



- In all populations, significant negative effect of Tsum of DBHincrement

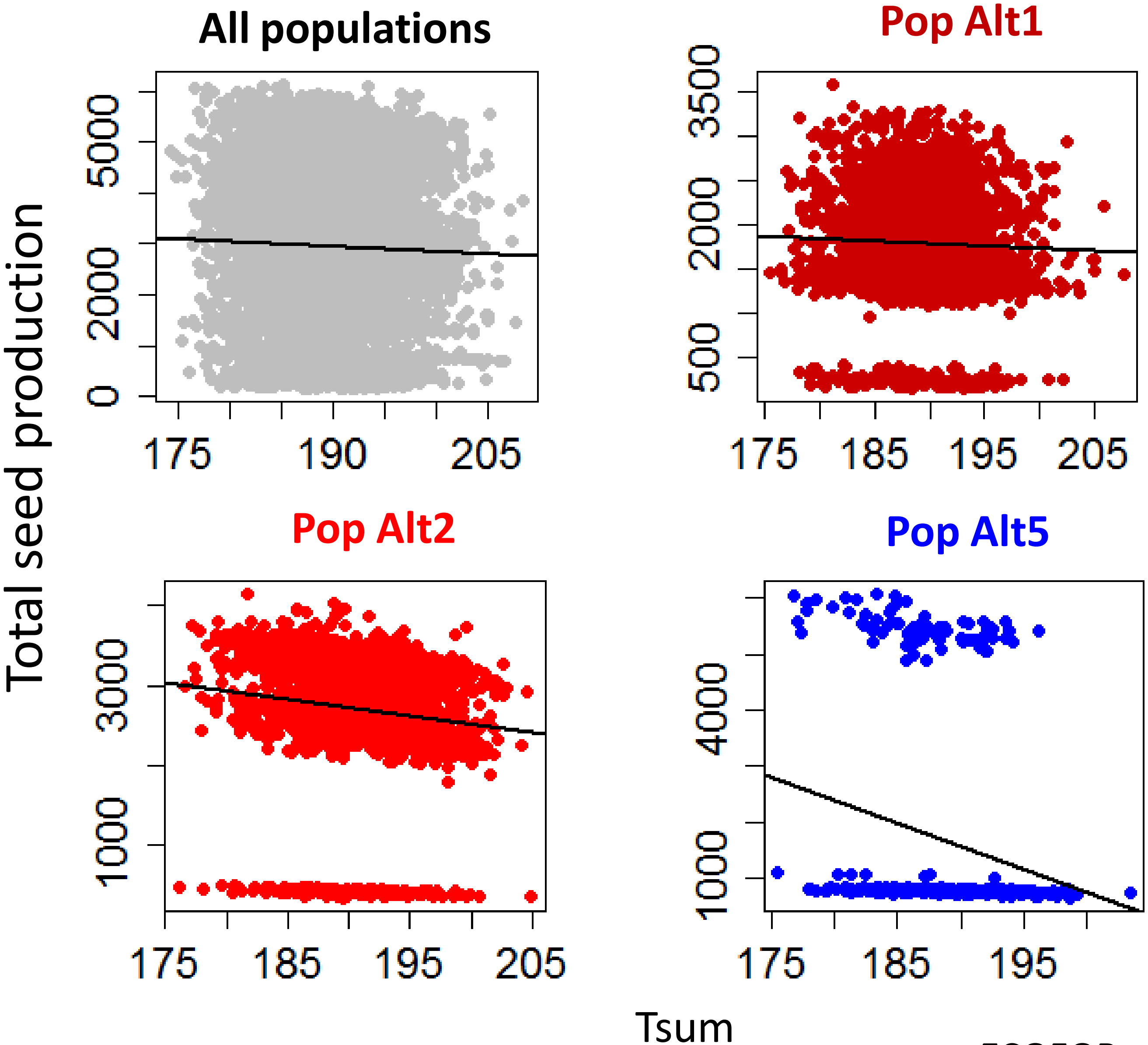
Pop	Estimate
Alt1	-0.02 ***
Alt2	-0.02 ***
Alt3	-0.04***
Alt4	-0.06***
Alt5	-0.09***

***p<0.001 *p<0.1

Results : strength of selection on tsum

Frost effect on LAI = 0

Linear model: $TotalSeedProduction_i = tsum_i + \varepsilon_i$



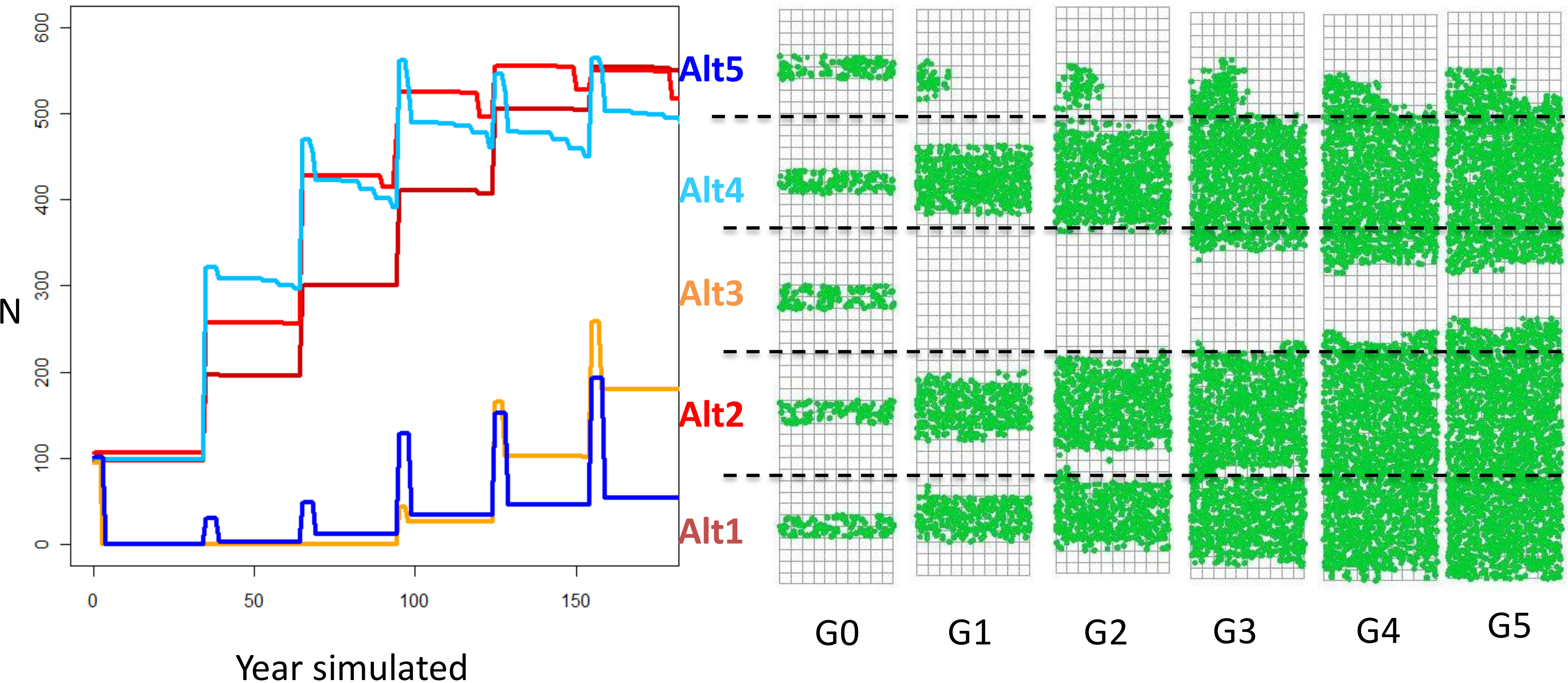
— Whatever the elevation, significant negative effect of Tsum of total seed production

Pop	Estimate
Alt1	-5.43 *
Alt2	-21.0***
Alt3	-19.6***
Alt4	-28.5***
Alt5	-81.8***

***p<0.001 *p<0.1

Results: population dynamics

Frost effect on LAI = 50%

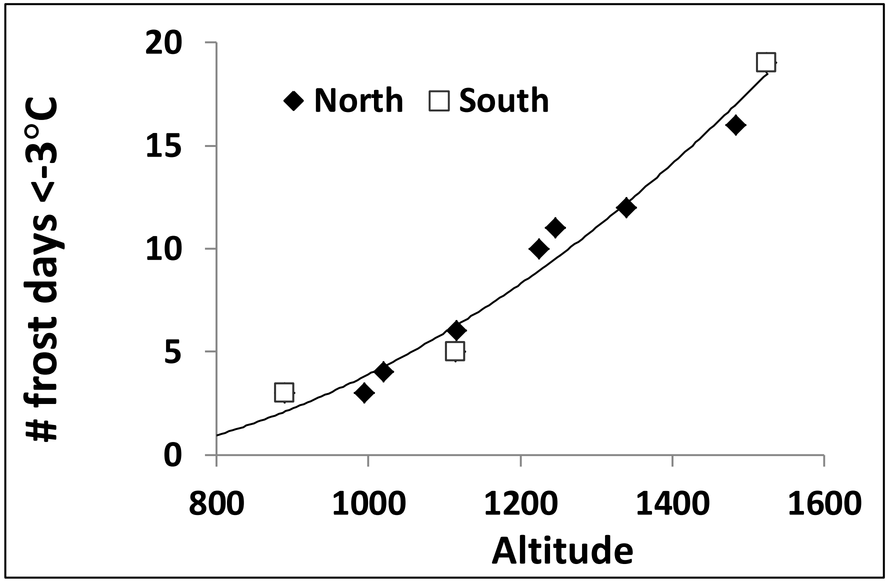


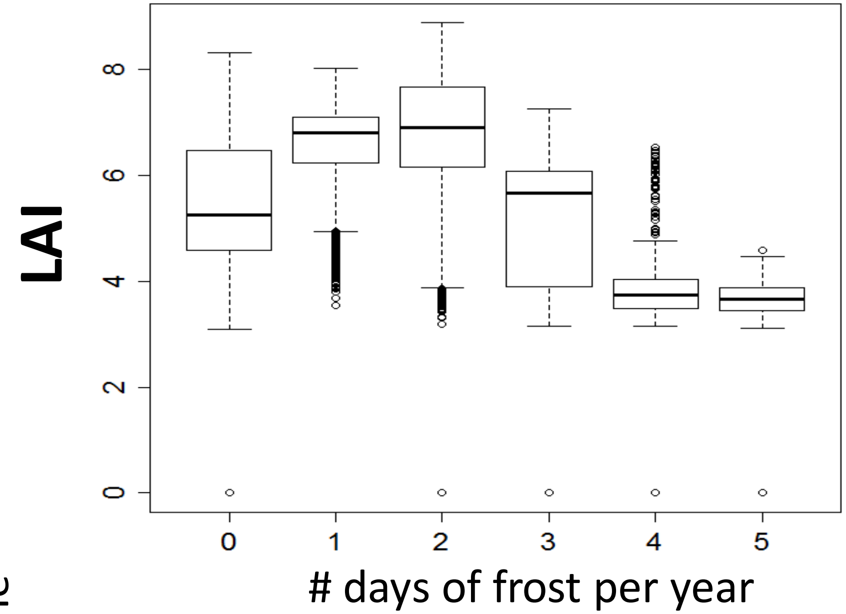
- Extinction of Alt3 at G0 and recolonisation at G3
- Quasi-extinction of Alt5
- Treeline at 1620 m (versus observed =1700 m)

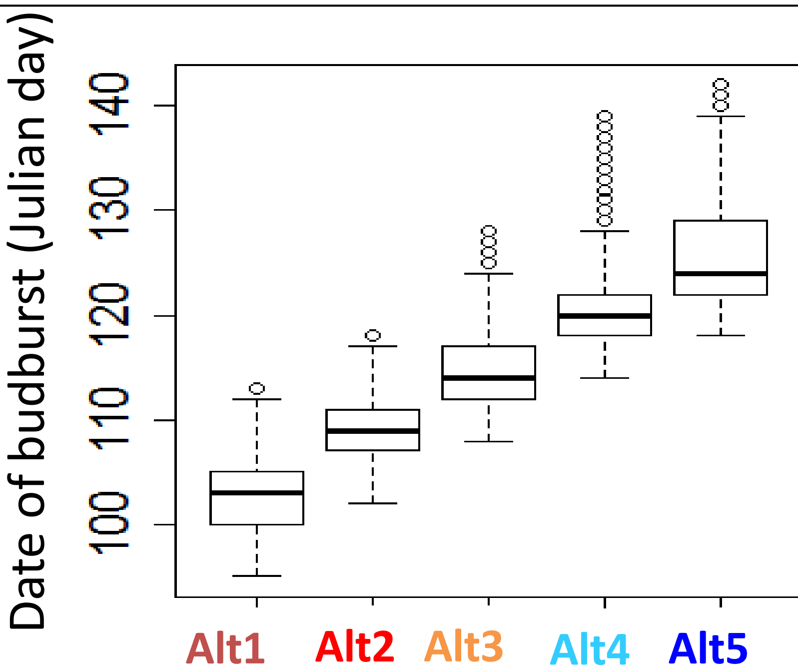
Results: budburst and frost days

(All generations)

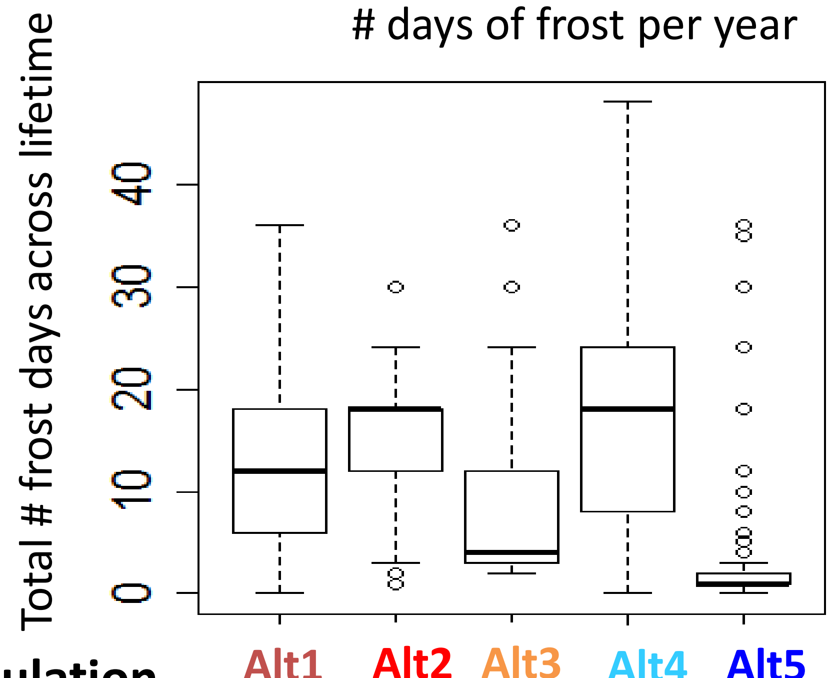
Frost effect on LAI = 50%







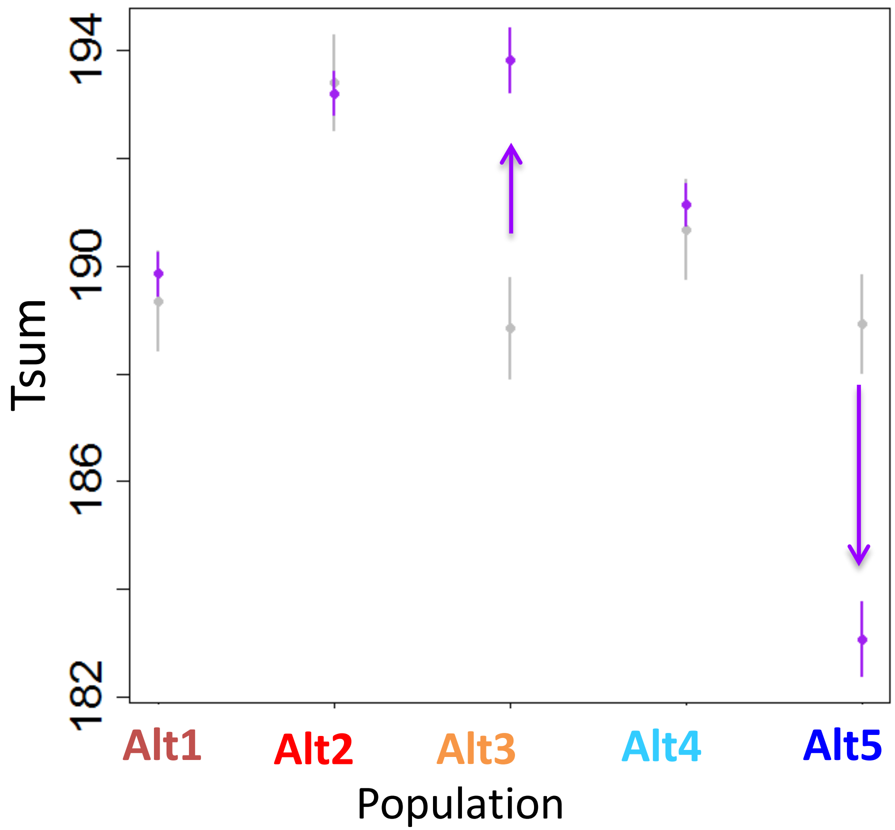
Population



Results: budburst and frost days

Frost effect on LAI = 50%

From G0 to G5



Linear model: $Tsum_i = Population_i + \varepsilon_i$

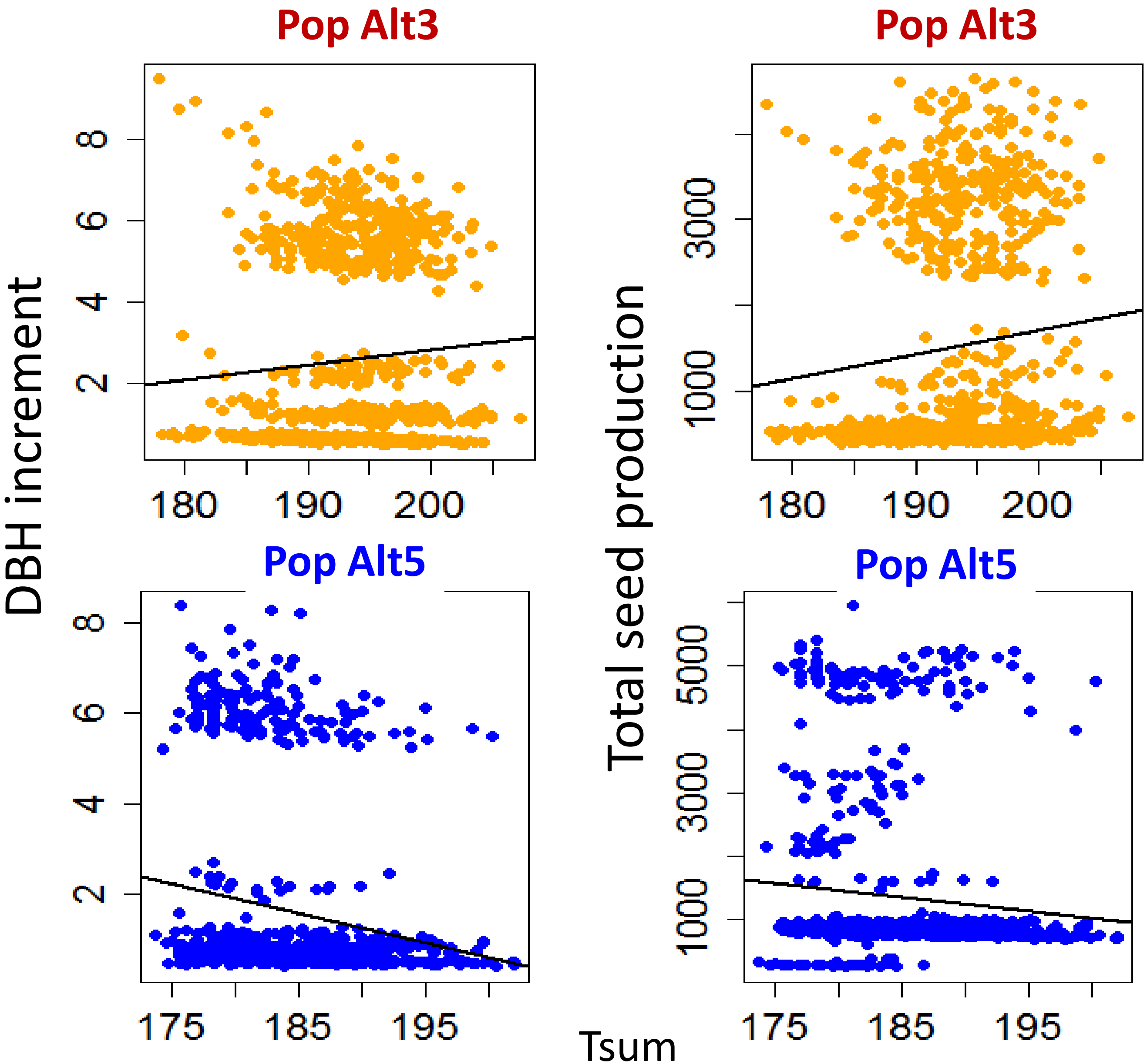
Parameter	Estimate	*p*-value
Intercept	189.9	<0.001
Alt1	0	-
Alt2	3.35	<0.001
Alt3	3.97	<0.001
Alt4	1.28	<0.001
Alt5	-6.78	<0.001

- At high elevation (Alt5) both late and early genotypes avoid late frost (low temperature) → early genotypes are selected
- At middle elevation (Alt 2- Alt 3) the effects of late frost are maximum → early genotypes are counter-selected
- At low elevation the risk of late frost is less important → early genotypes are selected (interaction with drought)

Results : strength of selection on tsum

Frost effect on LAI = 50%

Linear model: $FitnessComponent_i = tsum_i + \varepsilon_i$



DBH increment

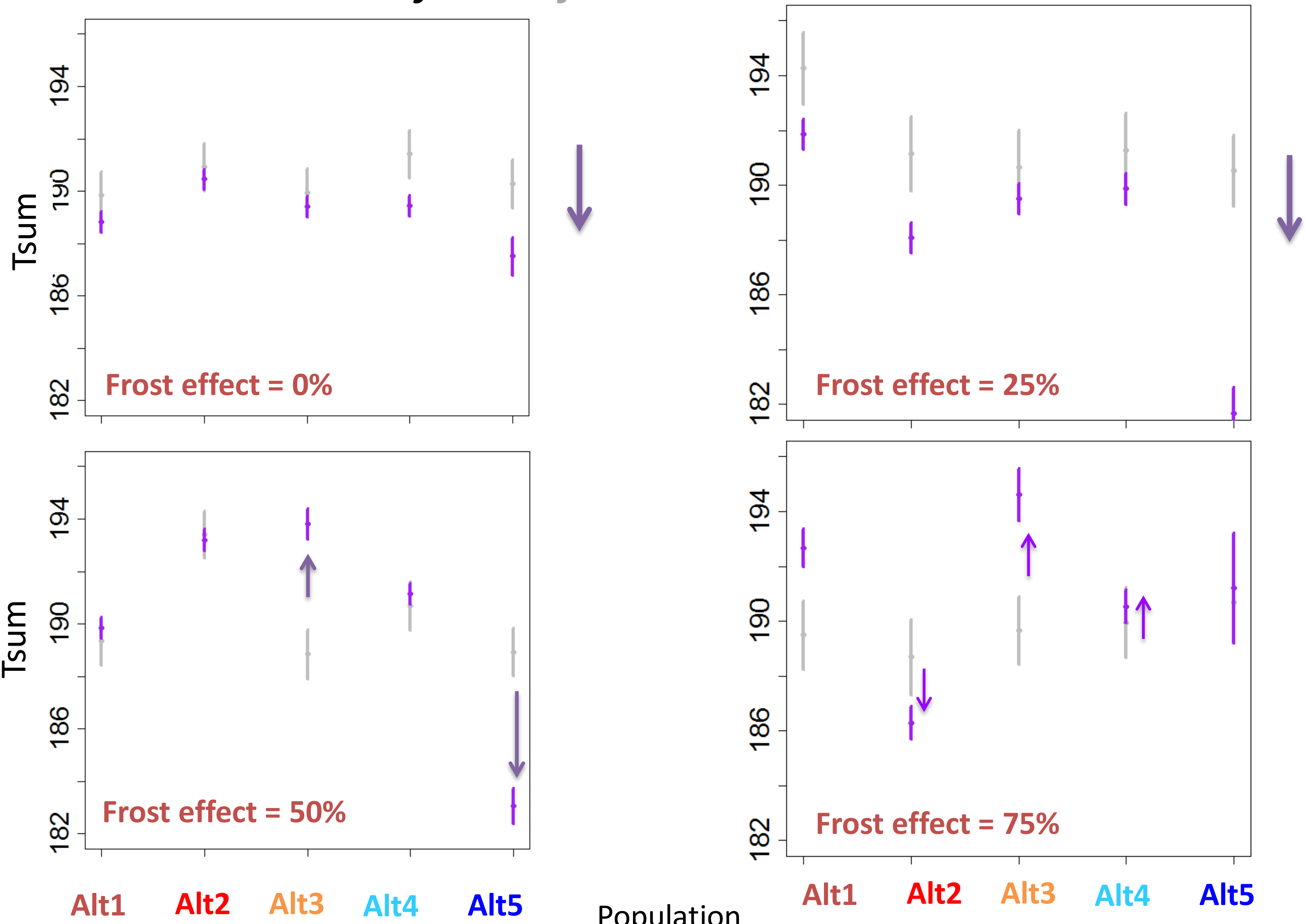
Pop	Estimate
Alt1	-0.10 ***
Alt2	-0.17 ***
Alt3	+0.04**
Alt4	-0.02*
Alt5	-0.07***

Total seed production

Pop	Estimate
Alt1	-33.54 ***
Alt2	-29.92 ***
Alt3	+28.0 **
Alt4	+14.8 NS
Alt5	-22.3 ***

***p<0.001 **p<0.05 **p<0.1

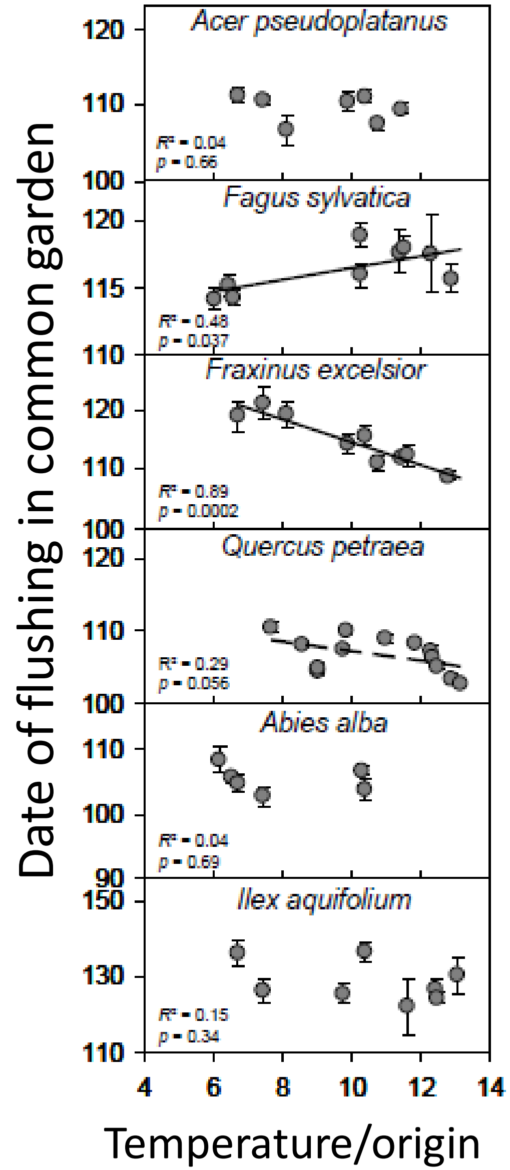
Results: evolution of tsum from G0 to G5



Conclusions

1. Evolution can be quick and strong

- ✓ At high elevation date of budburst advanced from 132 [min=130, max=133] to 128 [min=124, max=131] in 5 generations
- ✓ BUT — Role of the initial genetic variance
  - —Role of the climate series
  - —Non-overlapping generations → increased the speed of adaptation
  - —Multi-trait constraints on adaptation



Vitasse et al. 2009

2. Environmental effects are non linear

- ✓ Increasing effect of frost on LAI → either early or late genotypes are selected for depending on elevation
- ✓ Highlights patterns in common garden→

3. Mechanistic process-based models

- ✓ Mechanistic biophysical models → valid for other environment conditions
- ✓ Modularity → adapted to other species
- ✓ BUT need to validate output with experimental data (3 ongoing PhD)

Special Thanks :

- *François de Coligny*
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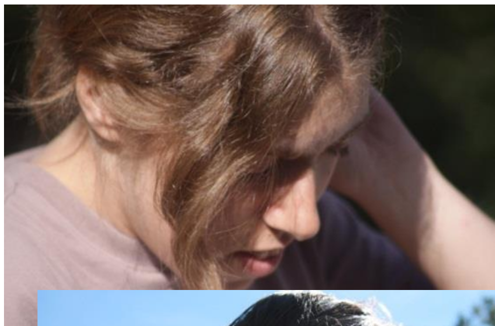



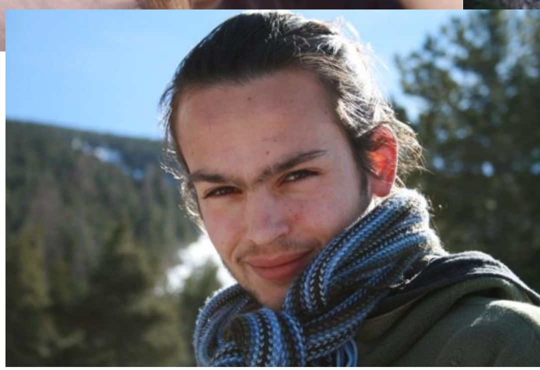
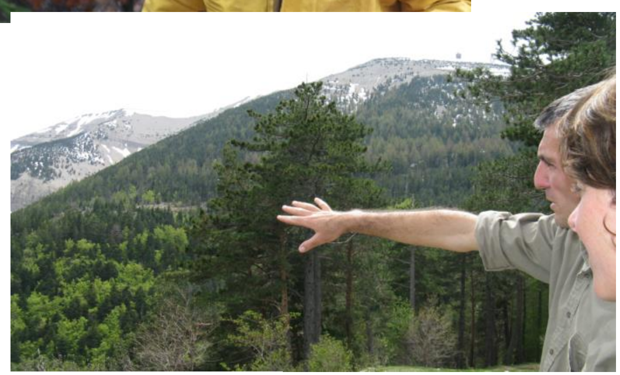
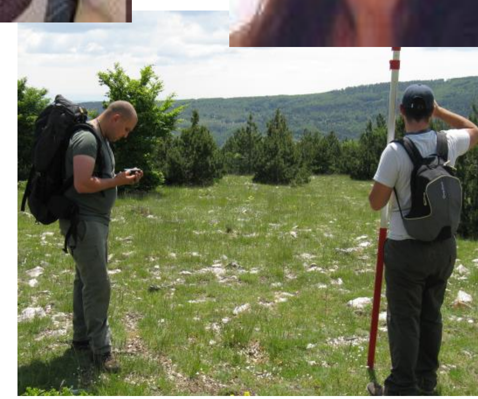


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