

# Summary

## Introduction

Rapid environmental change, IPCC, estimated temperature rise.

Trend to precocity in plants, flowering time, etc. Advance in phenology.

**Problem:** Understanding (and predicting?) long-lived plant adaptation to climate change

Based on previously developed demographic and quantitative genetics model (see ), added fluctuating environments. Made theoretical predictions. Estimated fluctuations using data from phenological data (PHENOFIT).

## Materials and Methods

### Population model

We used a previously developed model with stage-structure (Cite XXXXX Sandell et al.). We have two classes in our simulated tree population: immatures (I) and matures (M). Explain the parameters. The corresponding Lefkovich matrix is:

$$A = \begin{pmatrix} a_{II} & a_{IM} \\ a_{MI} & a_{MM} \end{pmatrix} = \begin{pmatrix} s_0 m f_1 + s_I(1 - m) & s_0 f_2 \\ s_M m & s_M \end{pmatrix} \quad (1)$$

### Life-history traits

We considered certain life-history trait  $s_I, f_1, f_2$  as gaussian for each individual such as:

$$s_I(z) = s_I(\theta_s) \exp\left(-\frac{(z - \theta_s)^2}{2\omega_s}\right) \quad (2)$$

Averaging over the population it gives:

$$\overline{s_I}(\overline{z_I}) = s_I(\theta_s) \sqrt{\frac{\omega_s}{\omega_s + P_I}} \exp\left(-\frac{(\overline{z_I} - \theta_s)^2}{2(\omega_s + P_I)}\right) \quad (3)$$

Thus at the population level, the mean is: ...

**Density-dependence!**  $s_0$

### Iterations at each timestep

Using the given parameters, the mean phenotype in each class can be described as (Barfield et al., 2011) ...

When there is a reproduction event, the phenotype of the newborn is computed as such: ...

### Approximation under weak selection

From (Engen et al., 2011) and Sandell et al. we get the following approximation of the mean phenotype in the population:

$$z = \dots \quad (4)$$

Parameter	Notation	Value
<b>Life Cycle</b>		
Optimal phenotype for fecundity	$\theta_f$	100
Optimal phenotype for immature survival	$\theta_s$	130
Fecundity function width	$\omega_f$	400
Survival function width	$\omega_s$	400
Heritability	$h^2$	0.5
Phenotypic variance of immatures	$P_I$	40
Phenotypic variance of matures	$P_M$	40
Genotypic variance of immatures	$G_I = P_I \times h^2$	20
Genotypic variance of matures	$G_M$	20
Survival of immature at phenotypic optimum	$\overline{s_I}(\overline{z} = \theta_s)$	0.8
Fecundity of first time reproducers at optimum	$\overline{f_1}(\overline{z} = \theta_f)$	100
Fecundity of experienced reproducers at optimum	$\overline{f_2}(\overline{z} = \theta_f)$	200
Maturation rate of immature	$m$	0.02
Combined survival and germination rate of seed	$s_0$	0.03
Survival of mature stage	$s_M$	0.99
<b>Density-dependence</b>		
Maximum $s_0$ in density-dependence function	$s_{0,max}$	0.12
Decreasing factor due to immatures	$k_I$	0.0001
Decreasing factor due to matures	$k_M$	0.005
<b>Fluctuations</b>		
Sensitivity of optimum for fecundity to fluctuation	$\alpha_f$	5
Sensitivity of optimum for survival to fluctuation	$\alpha_s$	5
Noise variance for fecundity	$\sigma_{\xi_f}^2$	3.725
Noise variance for survival	$\sigma_{\xi_s}^2$	3.725
Correlation between noises	$\rho_N$	0.5

Table 1: Standard parameter set

## Fluctuating environment

To mimic a fluctuating environment, the optimums are fluctuating in various ways around a mean.

Under fluctuations we get another approximation supposing weak selection ([Engen et al., 2011](#)):

...

## Trend in change

...

## Phenofit data

PHENOFIT is phenology model...

On 6 localities (see map .) we had modelled budburst date and predicted fitnesses  $\pm 21$  days around this date, from these data we predicted the optimums fluctuations: ... All statistical analysis were made using R, for the plots we used the package ggplot2.

## Results

### Constant environment and density-dependence

From Sandell et al., we simulated populations. With the introduction of density-dependence, the blablabla...

**Figure1:** See Fig. 1

Introduction of DD should decrease mean phenotype (lower  $s_0$ ) and limit population size

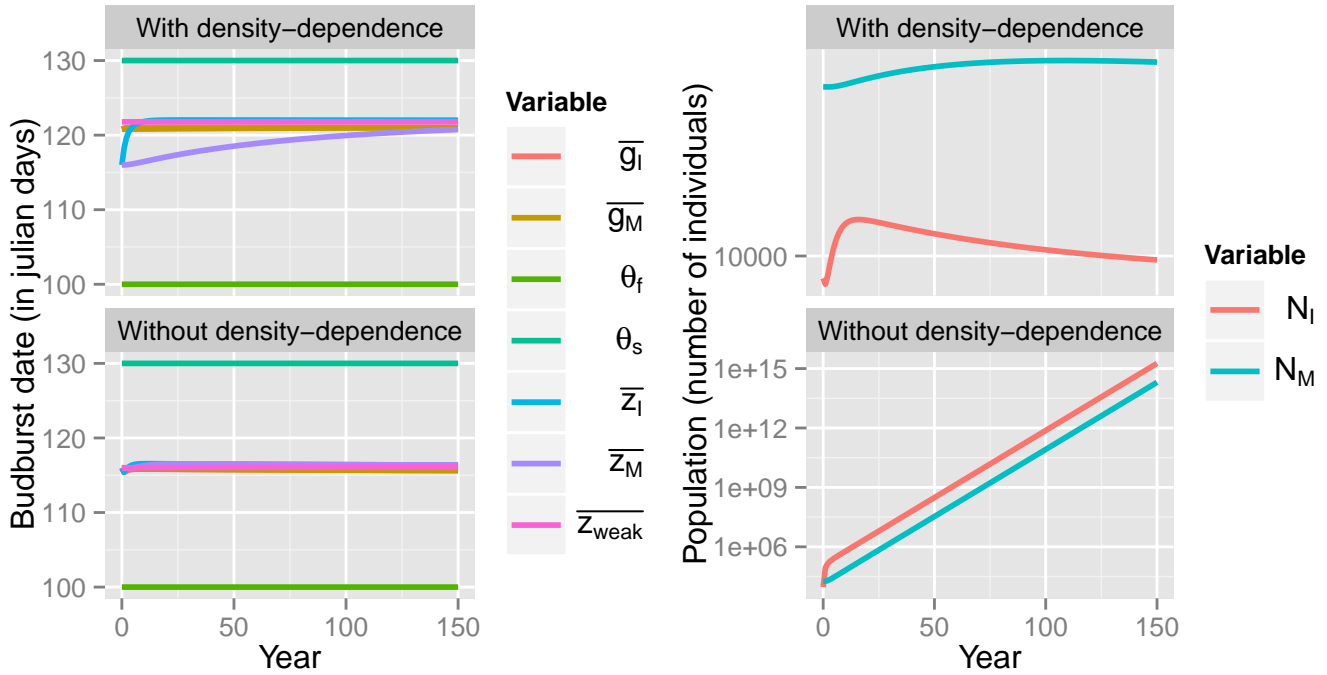


Figure 1: Effect of density-dependence on phenotypes and populations.

### Fluctuating optimums

The noises were drawn from a bivariate normal distribution to make the optimums fluctuate. We varied the correlation between them.

**Figure2:** See Fig. 2

Explain in the text correlation of  $z_I$  with  $\theta_s(t)$

### Trend in the environment

Decreasing optimums through time to mimic the advance in phenology with climate change.

**Figure:** Trend 2 panels with and without fluctuations, simulations results phenotype/time (with and without DD)

### Estimation of the fluctuations

From phenofit.

**Figure:** Fig. 3

**Table:** table with slope and noise variance estimates for all years, years before 2001 (simulated climate close to real one), after 2001 (projection in climate evolution)

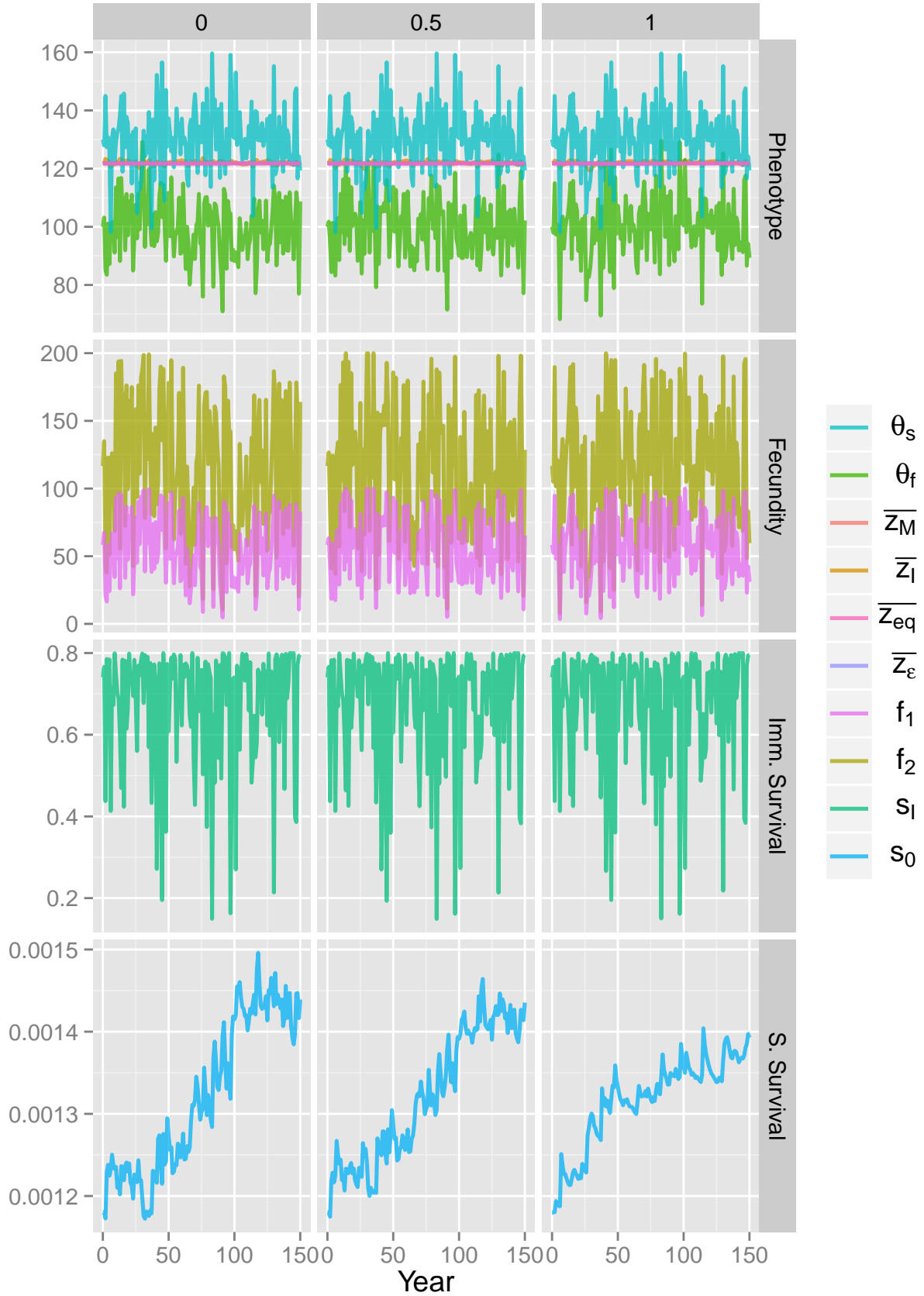


Figure 2: **Effect of the correlation of fluctuations on phenotypes and life-history traits.** Correlation coefficient  $\rho_N$  values of noises are indicated on the top.

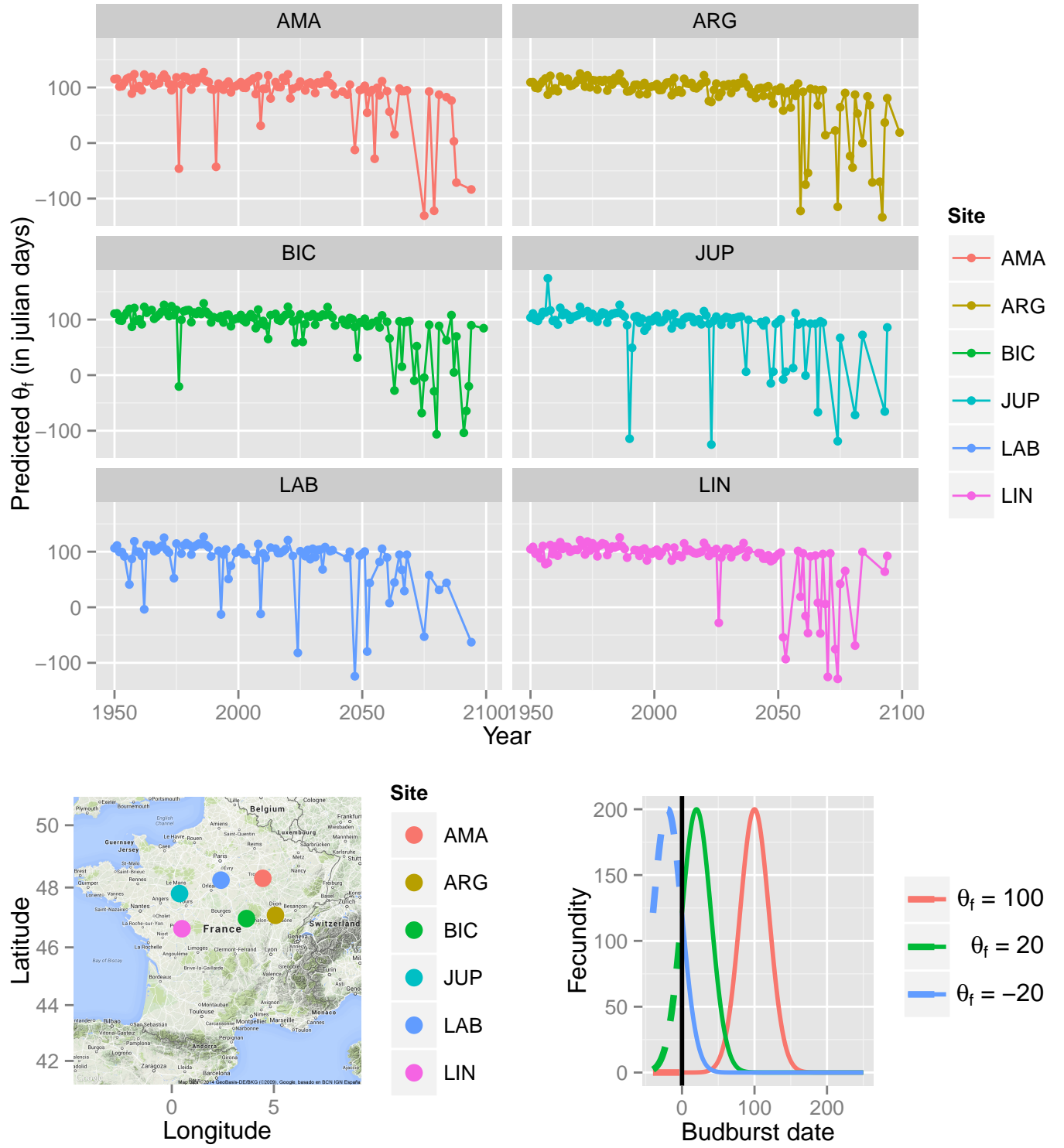


Figure 3:  $\theta_f$  estimations from PHENOFIT data.

## Discussion

Difference in  $\bar{z}$  and  $\bar{g}$  with fluctuations because of selection on viability.

Increasing number of extreme events from predictions.

## **Authors Contributions and Acknowledgments**

## **References**

- Barfield, M., Holt, R. D. and Gomulkiewicz, R. (2011). Evolution in Stage-Structured Populations (2 versions). *The American Naturalist* 177, 397--409.
- Engen, S., Lande, R. and Sæther, B.-E. (2011). Evolution of a Plastic Quantitative Trait in an Age-Structured Population in a Fluctuating Environment. *Evolution* 65, 2893--2906.