Assessing the effects of forecasted climate change on tree phenology of European temperate trees species along an altitudinal gradient

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Introduction

→ Good results on cross validation, RMSE < 5.1 days for all species
→ Similar accuracy of 1-phase model for Acer, Fraxinus and higher for Quercus
→ Higher accuracy of 2-phases models for Abies, Fagus and Ilex

Climate change

Flushing timing | Senescence timing

↓

Growing season length

↓

Carbon Uptake Period

↓

Competitive balance between species

→ Modelling **tree phenology** is crucial to assess the impact of **climate change** on tree growth and therefore on the **competitive balance** between species

Objectives

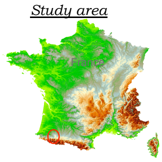
The first aim of this study was to assess through a comparison of **phenological models** for six dominant tree species in Europe
(i) the role of **chilling and forcing temperatures on leaf flushing**
(ii) the role of **autumn temperature and daylength on leaf senescence**

The second objective was **to predict phenological shifts over the 21st century** along the altitudinal gradient and to assess, under climate change, **variations in competitive balance** of co-existent species through their **growing season length**.

Material & Methods

1. Study area, studied species & phenological measurements

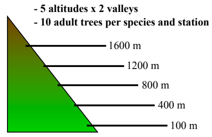
Study area



▲ Fig. 1: Map of the study area

Design

- 5 altitudes x 2 valleys
- 10 adult trees per species and station



▲ Fig. 2: Altitudinal level selected

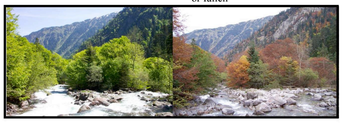
6 woody species

Microclimate

- Air temperature hourly recorded in each station
- Temperature range between low and high stations is about 7°C

Phenology monitoring (2005-2007)

- Leaf unfolding (LU), date of LU = 50% of tree leaves unfolded
- Leaf senescence (LS), date of LS = 50% of tree leaves either coloured or fallen



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2. Flushing and senescence models

Flushing models:
- 1-phase models (forcing temperature-based models): "SW"[1], "SW4" (SW variant), "Sigmoid"[2], "Unimodal"[3] and "Normal"[4]
- 2-phases models (chilling/forcing temperature-based models): "CS-SW"[1], "CS-SW4" ("CS-SW" variant), "Unichill"[4] and "Unified"[4]

Senescence models:
- 3 models of leaf senescence:
(i) photoperiod + low temperature thresholds, "White"[5]
(ii) interacting photoperiod and temperature functions, "Jolly"[6]
(iii) photoperiod trigger + photoperiod sensitive cold-degree sum, "Delpierre"[7]

3. Model fitting, validation, and performance comparison

- All the models were fitted on one altitudinal transect (fitting subset) and tested for external validation on the second valley (validation subset)
- Model performance was compared on the basis of their root mean square errors (RMSEs), model efficiency (ME) and Akaike information criterion corrected (AICc) and the best model was chosen per species for prospective analyses.

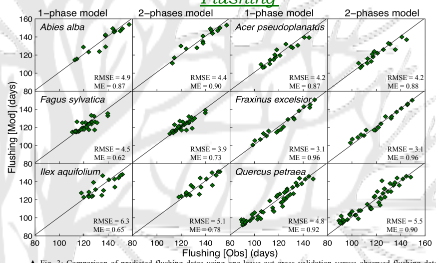
4. Simulations of LU, LS and GSL over the 21st century

- Phenological simulations over the 21st century were performed using the ARPEGE climatic model under the A1b IPCC-defined scenario.
- Simulations were applied at five elevations corresponding to the beech stands sampled

Results

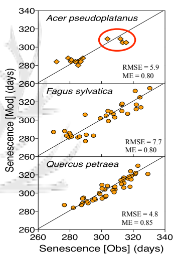
1. Model fitting & validation

Flushing



▲ Fig. 3: Comparison of predicted flushing dates using one-leave-out cross validation versus observed flushing dates with the best of 1 and 2-phases models.
The best models were used for each species; 1-phase models: "sigmoid" for Fagus, Ilex, Quercus and "SW" for Abies, Acer and Fraxinus; 2-phases models: "CS-SW4" for all species. The identity line is reported.

Senescence



▲ Fig. 4: Comparison of predicted senescence dates using one-leave-out cross validation versus observed senescence dates for Fagus, Quercus and Acer.
The "Delpierre" model was used for the three species; the graph of Fraxinus is not plotted here because we found no senescence models better than the null model. The identity line is reported

Flushing

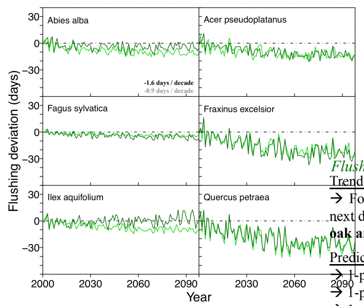
→ Models predicted accurately the timing of LU **for all species** (ME > 0.65 and RMSE < 6.3)
→ Higher accuracy of 2-phases models for Abies, Fagus and Ilex

Senescence

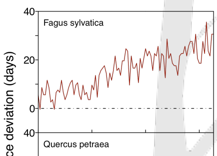
→ The cold-degree day sum model ("Delpierre") was the best model for beech and oak (with higher ME for oak)
▪→ All tested senescence models **failed to explain LS timing for ash and the model is not enough robust for sycamore** as it is constrained by only two populations from 400 m of elevation, see red circle)

2. Simulations

Flushing



Senescence



▲ Fig. 5: Interannual variations of predicted LU timing by the best 1 and 2-phases models over the 2000-2099 period in three altitudes (100, 400 and 800 m ASL).
▲▶ Fig. 6: Interannual variations of predicted LS timing by the DM model over the 2000-2099 period in three altitudes (100, 400 and 800 m ASL) for beech and oak

Flushing

Trends:
→ For all species LU is expected to **advance** in the next decades: predictions showed the **highest shift for oak and ash** and the **lowest ones for beech and holly**

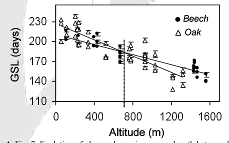
Predicted advance between 1-phase / 2-phases models
→ 1-phase ≈ 2-phases models for beech, ash and oak
→ 1-phase < 2-phases models for sycamore
→ 1-phase > 2-phases models for fir and holly

Senescence

→ LS timing of beech and oak is predicted to be **delayed** over the next decades with a **stronger delay for beech**

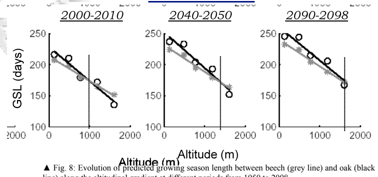
3. Evolution of the competitive balance along the altitudinal gradient between oak and beech

Observations (2005-2007)



▲ Fig. 7: Evolution of observed growing season length between beech and oak along the altitudinal gradient for the 2005-2007 period

Simulations



▲ Fig. 8: Evolution of predicted growing season length between beech (grey line) and oak (black line) along the altitudinal gradient at different periods from 1950 to 2098

Observations

→ At present, GSL of beech and oak are **similar** at approximately **700 m** of elevation: above **this elevation threshold**, the GSL of beech is longer, whereas under this elevation the opposite pattern occurs

Simulations

→ A **lengthening** of GSL is expected under climate change with higher rate for oak than beech
→ The elevation where GSL is similar between both species **dramatically increased** over the 21st century

Conclusion / Discussion

1. Factors involved in phenology

Flushing

Forcing Temperatures
→ 6 species
Chilling Temperatures
→ Predictions of models taking into account chilling temperatures were different from 1-phase models for holly, sycamore and fir

Senescence

Beech / Oak — **Warm Temperature → senescence delayed**
Ash / Sycamore — **Photoperiod + other factors (??)**

2. Expected phenological shifts

▪ **LU:** expected to **advance** for all species **from 0.5 to 2.5 days / decade**
→ However, global warming could lead to **insufficient chilling** and predictions should be considered with caution especially using 1-phase models.

▪ **LS**: expected to **delay** for beech and oak **from 1.4 to 2.3 days / decade**
→ More data are needed to accurately predict LS timing of ash and sycamore

▪ **GSL**: expected to **lengthen** for beech and oak **from 2.8 to 3.8 days / decade**

3. Expected evolution of competitive balance

Under moderate warming for the 21st century, our models predicted a **stronger extension of the GSL for oak than for beech**.

We suggest that the **competitive balance** between these two species could be **strongly modified** under climate warming, and shifts in their **distribution area** might occur.

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