

Changes and trends in budburst and leaf flush  
across Europe and North America  
A meta-analysis of local adaptation in spring phenology  
studies

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# Abstract

## 1 Introduction

- Define spring event, fall event
- Research question (links to results)

## 2 Methods

Our methods are divided into four main steps.

### 2.1 Literature Search

We searched Web of Science, Google Scholar, and Connected Papers for common garden experiments that documented the timing of spring events of woody plant species. To be included, studies needed to (a) focus on woody plants originating from either Europe or North America, (b) report spring event in units of calendar days instead of a quantitative scale on a particular day, (c) report locations of provenances and gardens.

will reword things later

- Read AB 2015 and A 2013, took paper with spring doy and provenance coordinates from them
- Searched online for more papers (explain criteria here)
- Out of 59 papers related to common garden/spring phenology that I read, only 22 can supply data that we need; Out of the 22, 4 studies have provenance and gardens on different continents, which were subsequently archived (can document in supplements)).

### 2.2 Dataset Assembly

We reviewed all returned results and assembled a dataset of spring event dates, during which we used ImageJ to scrape data from figures whenever possible and necessary. We primarily focused on papers with spring data.

will elaborate later

### 2.3 Climate Data Gathering & Analyses

- Simple climate matrix (MAT & MSP/MAP) gathering
  - ClimateNA by Dr. Tongli Wang
  - Climate Information Tool by FAO
- Daily climate data gathering: Gridded daily climate data downloaded for all provenances and gardens: We hope that coarse metrics such as latitude and MAT ultimately represent how similar the climates are between the provenances and gardens in times that matter for the events. If climates are very similar, then we would expect similar timings [add more here]. To this end, we estimated climate overlap in relevant months: For spring events, we considered overlap across March to May.
  - North American daily climate data from Daymet R package
  - Europe daily climate data (gridded: NetCDF-4) retrieved from E-OBS

- 2.3.1 Estimate climate overlap using daily climate data using Overlap R package
- 2.3.2 Calculated GDDs, spherical distances
- 2.3.3 Corrected for DOY (taking the difference)

will put results in supplement

## 2.4 Mixed effects modelling

We used hierarchical Bayesian models where we partially pooled by species. We estimated effects of continent and species type (angiosperm VS gymnosperm) from posterior estimates, in relation to single predictors (including provenance latitude, MAT) and two predictors (climate overlap percentage and standard deviation).

will elaborate later

## 3 Results

all subsection titles are placeholders

Out of the 59 papers on common garden experiments and spring phenology that we reviewed, only 22 supplied data met our criteria to be included: (a) focus on woody plants originating from either Europe or North America, (b) report spring event in units of calendar days instead of a quantitative scale on a particular day, (c) report locations of provenances and gardens. Out of the 22, four studies had provenances and common gardens on different continents. These studies were excluded from our main analysis, but we document them in our supplements. Our final dataset captures seven angiosperm and eight gymnosperm species from 19 common gardens, encompassing data from 384 North American provenances and 101 European provenances with observations from 1962 to 2019. Seven species had fall event information available. It is worth noting that most common gardens included in this study only had observations of one species. Therefore, it is difficult for a model to interpret if variations across gardens are due to the species or the garden's location and climate. We thus focused on estimating species effects because we expect a larger effect from species.

need to reword

can refer to the fit we did where we fitted each species & common garden instead of just species

add map here

add a table documenting studies attributes

### 3.1 Provenance latitude and MAT do not affect spring event timing

Overall, our models show that spring events are not related to provenance latitude or mean annual temperature in North America, and only weakly related in Europe (Fig. 1) & Table.1).

Should I add climate overlap plots here too?

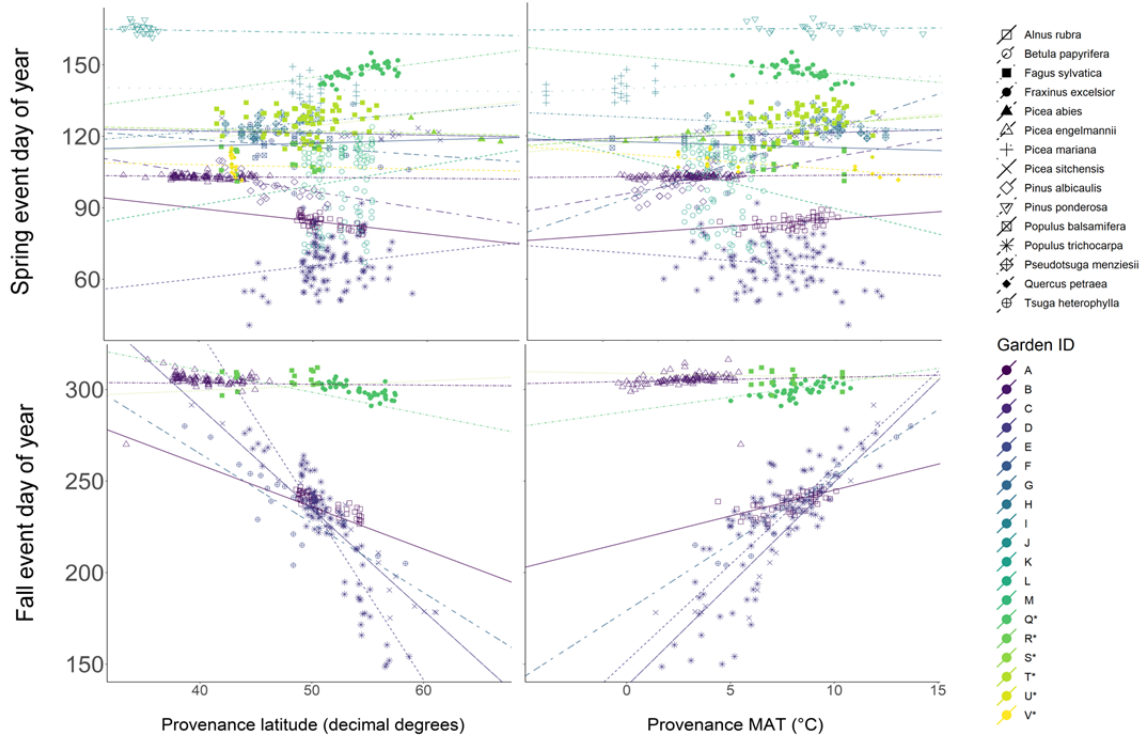


Figure 1: Spring event Day of Year (DOY) in relation to provenance latitude and MAT, coded by symbol for species and color for garden with linear fits from hierarchical Bayesian models. Spring events shown on top and fall event at the bottom.

### 3.1.1 Similar results across provenance latitude, latitude difference, and distance

need to find a name for each metric and stick to it.

Along with (a) provenance latitude, we also looked at how spring event timing is related to (b) the absolute difference between provenance latitude and garden latitude, as well as (c) the spherical distance between the garden and each provenance. All three metrics depict little to no relationship between spring event timing and the geographical location of the provenance (Supplement Figure #).

### 3.1.2 Climate overlap does not predict event dates much better than provenance latitude or MAT

While comparing how similarity in climate relates to event dates, we observed very weak effects of climate overlap on spring events, nearly identical across angiosperms and gymnosperms. Fall events diverge as climate overlap declines for both angiosperms and gymnosperms, but slightly more strongly for gymnosperms.

### 3.1.3 Strong relationship between provenance latitude, MAT, and GDDs

Flagged for Lizzie: I am unsure about how to comment on what we are seeing in this plot. There is a strong relationship between GDDs of each event day recorded and the latitude and MAT, but isn't that self-apparent?

Placeholder text (Fig. 2).

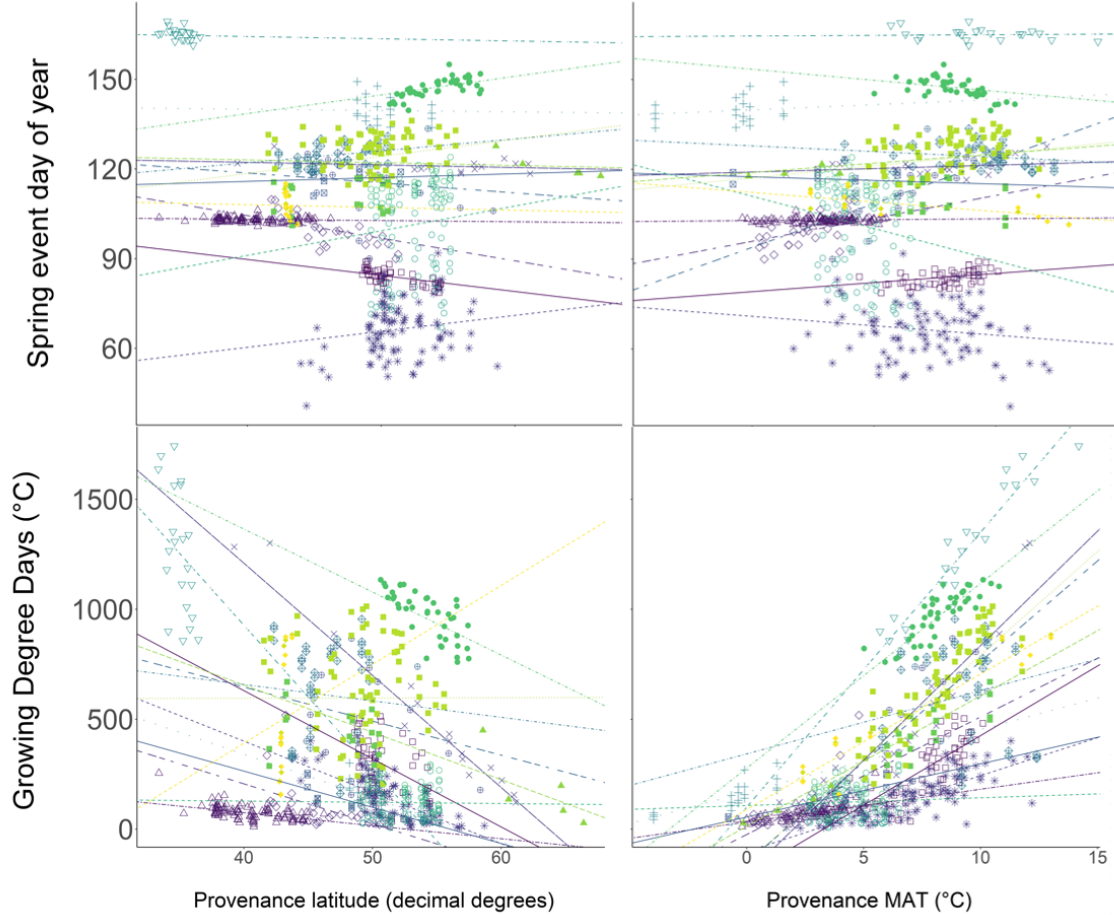


Figure 2: Growing Degree Days (GDD) on each day of spring event in relation to provenance latitude and MAT, coded by symbol for species and color for garden with linear fits from hierarchical Bayesian models.

### 3.2 Stronger clines in fall events observed in North America than Europe

We find that fall events (budset, leaf senescence, leaf abscission) advance strongly with provenance latitude and mean annual temperature, meaning fall events are earlier where provenance mean annual temperature is lower (higher, more northern latitudes). This relationship, however, is observed mostly in North America where fall events advance 4.2 days per degree we move north, or 6.4 days when the MAT decreases by one °C. In Europe, such relationship is weak: advance 0.5 days per degree we move north, or 0.6 days when the MAT decreases by one °C.

### 3.3 Effects of MAT on spring events diverge across angiosperms and gymnosperms

Effects of provenance latitude on both spring and fall events are similar across angiosperms and gymnosperms. However, effects of MAT on spring events weakly diverge: spring events get earlier as MAT increases in angiosperms and delay as MAT increases in gymnosperms, except for *Pseudotsuga menziesii*. Fall events delay in warmer locations for both species types, but slightly more so for gymnosperms (3.7 days VS. 6.2 days).

## 4 Discussion

The weak relationship between spring event dates and provenance latitude and MAT that we find in European studies might be explained by the higher extent of climate overlap in those studies. The more similar the climate is between provenances and gardens, the less difference between spring event dates.

The inconsistent and weak clines in spring events that we found suggest high plasticity in spring phenology across continents and species. Fall events, on the other hand, exhibit stronger clines which suggest more local adaptation, especially in North America. Overall, our results predict that warming springs will continue to be tracked more closely phenologically by trees than warming fall temperatures.

In contrast to spring events, we found strong latitudinal clines in fall events across both continents, with local adaptation appearing much stronger in North America than in Europe. Our results show that spring events are highly plastic, and thus may shift with warming, but data on more species and greater information on important factors, such as their geographic location in relation to their origins and elevation, are needed for forecasting.

## 5 Figures