**Title:** Effect of spring temperatures on tree growth phenology in a temperate deciduous forest

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### Abstract

**Keywords**:

### Introduction

As global atmospheric greenhouse gas levels are rising, and little meaningful policy is being implemented to combat this, the planet is expected to surpass the 2.5 degree C warming mark that the Paris accord pledged to avoid. This will have potentially negative implications for nearly every ecosystem on Earth, including forests. -importantce of forests Deciduous forests in the Northern Hemisphere have the potential to remove up to ## tons of carbon in the next ## years, and currently represent %% of the worlds carbon reserves. Trees remove CO2 from the atmosphere, and fix it into structural components like wood, roots, or leaves, through the process of photosynthesis. Current theory suggests that tree growth could benefit from global warming, as warmer early Spring time allows leaves to emerge earlier and increased CO2 concentrations increase plant water use efficiency. This increase in growth can slow the rate of global warming as CO2 sequestration is sped up, making forests key natural combatants in the fight against greenhouse gasses.

In recent decades, Spring has been arriving earlier as Spring temperatures are increasing. This leads to earlier leaf out in deciduous trees, meaning a potentially longer growing season (). Earlier Spring emergence has been shown to cause both positive and negative lagged effects on subsequent Autumn or Spring growth in European broad leaf deciduous and mixed forests, respectively (Crabbe et al, 2016). Even more, the timing of Spring warming seems to have a significant effect on leaf-out response, where warming events later in Spring were shown to impact leaf emergence timing more than earlier Spring warming (Freidl et al, 2014). These shifts in phenological timing are likely to affect woody productivity, carbon and nutrient cycling, and water use patterns in temperate forests. However, the fine-scale responses of temperate deciduous species to a warming Spring are not fully understood. Many predictions of phenological shifts like these are based on GIS, eddy-covarience measurements, or other broad scale observations of phenological timing, and do little to discern differences between individual species. In reality, we know little about the growth phenology of temperate deciduous species (see D’Orangeville et al., in revision for more info/ citations)—let alone how these are affected by an early spring.

To date, very little research has been done on the phenology of tree growth. While observations of leaf phenology have shown a decent relationship with NPP, understanding intraannual wood-growth phenology allows a finer-scale look at differences in climate sensitivity and growth responses between individual species. Recent results from D’Orangeville et al. (in prep) have shown that wood-type plays a significant role in the timing of leaf and wood phnology, as ring-porous begin growth earlier in the season compared to diffuse-porous, but both reached 75% total annual growth around the same time. This implies evolutionary differences in the mechanisms controlling growth of these species, which have the potential to expose each group to different climate stressors.

Temperate trees are projected to increase NPP and sequester greater amounts of CO2 as climate warms, to a point, but the contribution of individual species, and the implications of potentially chanign species compositions is less well known. This simplification is necessary at larger scales, as generalizations are needed to ensure models are not overly complex. However, the results here indicate that all tree species may not be responding equally to an earlier Spring. We suggest that efforts be made to examine regions on a smaller scale, investigating indiviudual species or wood-types’ reaction to historic warming to forecast future NPP. For example, at SCBI, the loss of ring-porous Fraxinus spp., the high prolification of the diffuse-porous Lirodendron Tulipera, and Decline of mature individuals along with browsing pressure on Quercus saplings could lead to a population boom of diffuse-porous species, making our forest less likely to increase growth in response to a warming early-Spring and thus, lessening the impact our forest has on the global carbon balance.

Dendrometer bands allow a look at indivudal trees’ intraannual growth. Using many measurements taken within a year allows the creation of an idealized growth curve using a 5 paramter logistic model (Sean’s model). From this, growth milestones and variables can be extracted from each year and compared to other years, effectivley simulating a controlled experiment where climate variables were manipulated.

To our knowledge, no research has been done exploring the relationship between intraannual growth patterns and early Spring temperatures. Here, we use 9 years of biweekly dendrometer band measurements for 4 species to characterize intraannual growth phenology within the FOrestGEO plot at SCBI, calculating for each tree in each year where data was available: the day of year (DOY) where 25, 50, and 75% annual growth was achieved; the maximum growth rate; the DOY where maximum growth rate was achieved; and the total growth. These variables were then compared to pre-season temperatures over the 9 year period of 2011-2019 to search for correlation between early-spring temps and growth phenology.

We hypothesized that (1) ring-porous and diffuse-porous trees would both reach 25, and 50% total annual growth earlier and (2) both wood types would increase total growth in response to warmer early-Spring temperatures.

Here, we … - use 10 years of biweekly dendro band measurements for # species to characterize seasonal growth phenology • combine these records with 110 years of tree-ring data for 12 species to examine how spring temperatures impact annual tree growth • examine the effects of an extremely early spring (2020) seasonal growth phenology and annual growth

### Materials and Methods

Study site and data SCBI ForestGEO plot -SCBI met-tower Climate data was obtained from a meteorological tower in a clearing adjacent to, and within elevation range of the SCBI ForestGEO plot. This tower is part of the ForestGEO meteorological monitoring program. Temperature readings are taken every 5 minutes using a CR1000 datalogger. 9 years biweekly dendrometer measurements Dendrometer band measurements were taken every two weeks for 9 years (After cleaning: 2011- 105 trees; 2012 - 102 trees; 2013 - 102 trees; 2014 - 149 trees; 2015 - 149 trees; 2016 - 149 trees; 2017 - 148 trees; 2018 - 146 trees; 2019 - 145 trees ). Data manually cleaned by visual inspection. Three classes of mistakes: 1. Error in measurement - weekly measurement was drastically different from previous week and following week. Mistakes were removed from the raw data before modeling. (## cases) 2. Band slip or stuck - measurements freeze and remain unchanged until sudden jump followed by normal growth pattern. Band slips were sometimes followed by measurements indicating the band became stuck; in these cases, the tree was thrown out for the corresponding year. In cases where the slip was followed by normal growth, the initial slip-point was removed, and the following points were shifted down to the pre-slip level. (## cases) 3. Other - cases where data was clearly wrong but with unknown causes. This seemed to happen mostly in 2011, when the program was just beginning. In cases where several measurements were an issue, they were simply removed. If there were no clear solutions to ‘fix’ the data, the entire year was removed from the analysis.

leaf phenology data?

• leaf phenology data from NEON and/or satellite-based (leaf phenology network: <https://www.usanpn.org/news/spring>) ?

• NDVI or PRI? <https://onlinelibrary.wiley.com/doi/10.1111/gcb.15112> (from Ian)

• From Ian: I noticed how the growth patterns observed by remote sensing pretty much mirror what Sean was finding with his dendro R package (btw is that functional on CRAN yet?) for both SERC and SCBI dendroband data.

perhaps bring in cores?

• Sean’s model

• Climwin

The period where the phenology milestone(s) were most affected by Spring time temperature was determined using the R package Climwin. This package tests the correlation between climate variables (daily averaged temperature) and biological variables (DOY) within a specified time-frame, reporting the window with the highest correlation as the ‘best-model’. We instructed Climwin to search for the best window within ### to 0 days before the phenology milestone. This was done to find corresponding best-windows for both of our wood-types; ring-porous and diffuse-porous.

### Analysis

Here, I’ll insert a reference to Sean’s paper (McMahon & Parker, 2015). This is pulled from references.bib.

-Mixed effect model

A mixed effect model was used to test the response of wood phenology variables (25% DOY, max-rate, max-rate DOY, total growth) to fixed effects of wood-type and Spring temperature, and random effects of species and tag. We ran two separate models for each of our major wood-types and one combined model to use for comparison during the bayesian analysis. (talking to Albert about possibly doing this)

• Bayesian heirarchal model

### Results

• variable averages

Pooled across all species and all years the average DOY where max growth rate was achieved is DOY: 158, the DOY where 25% was achieved is DOY: 129, 50% - DOY: 157, 75% - DOY:184.

Ring-porous (1395 obs) max growth rate – DOY: 147, max growth rate = .048 (find units in Sean’s function), 25% - DOY: 113, 50% DOY: 147, 75% - DOY: 181…68 days

Diffuse-porous (993 obs) max growth rate – DOY: 172, max growth rate = .068 (find units in Sean’s function), 25% - DOY: 153, 50% - DOY: 171, 75% - DOY: 190… 37 days

• Climwin results

• Accounting for random effects of species and tag, pre-season temperatures had a greater effect on ring-porous species than diffuse-porous.

• Bayesian variable results (PRE-JOINT MODEL, updating ASAP)

Ring-porous 25% DOY estimate: -2.23 (credible interval: -2.94 - -1.55)

Ring-porous 50% DOY estimate: - 2.10 (credible interval: -2.71 - -1.42)

Ring-porous 75% DOY estimate: -1.89 (credible interval: -2.53 - -1.28)

Ring-porous total growth estimate: 0.0552 (credible interval: 0.00346 - 0.108)

Ring-porous max-rate DOY estimate: -2.20 (credible interval: -2.77 - -1.62)

Ring-porous max-rate estimate: 0.00113 (credible interval: 0.000151 – 0.00208)

Diffuse-porous 25% DOY estimate: -1.83 (credible interval: -2.86 - -0.822)

Diffuse-porous 50% DOY estimate: -2.39 (credible interval: -3.35 - -1.43)

Diffuse-porous 75% DOY estimate: -2.96 (credible interval: -4.03 - -1.92)

Diffuse-porous total growth estimate: -0.0642 (credible interval: -0.172 – 0.0460)

Diffuse-porous max-rate DOY estimate: -2.54 (credible interval: -3.41 - -1.69)

Diffuse-porous max-rate estimate: 0.00209 (credible interval: 0.000118 – 0.00413)

### Discussion

Diffuse-porous 25-75% growth period shrinking leaving trees more vulnerable to drought while ring-porous 25-75% growing, potentially making effect of drought less damaging? But RP still prone to cavitation + longer growth period could mean exposure to higher number of droughts resulting in serious damage to water transport system?

DIfferences in total relationship could be because of response difference in wood types OR could be because the diffuse-porous’ growth occuring during the later summer means it is exposed to drought/heat and on average, not feeling the effects of the earlier spring. differences in wood porosity growth timing means exposure to different periods of climate stress ring porous adaptable to spring temps, diffuse not so much leads to higher growth in ring however, diffuse still more resistant to cavitation potential for more frequent late frost events having large impacts as spring warms? offset of chilling requirements and spring leaf out requirements

much assumed about future forest productivity based on gis different wood types/species may respond differently need to understand at a finer scale what is happening

Content to incorporate: N. American strategies have conservative strategies when it comes to phenology, as historically they’ve been subject to more spring frosts. Thus, climate change is having less impact (Zohner et al., 2020)

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ForestGEO

### Authors’ contributions

### References