

Thesis Proposal

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1 Climate change impacts on tree phenology

Research from the past two decades have shown increasing evidence that human activity keeps affecting many worldwide environmental processes. This is shown by the increasing impact of invasive species, their corresponding loss of biodiversity which is furthermore affected by its main driver, habitat loss and fragmentation. That alone raises major concern and actions have been deployed to mitigate these impacts. Human activity, notably their greenhouse gas emissions may have long-lasting consequences, for which predictions by the IPCC have been overwhelmingly alarming since some of their reports have been shown to have been to pessimistic. Climate change currently holds the status of a scientific consensus i.e. scientific consensus around the world, experts in their domain all agree that climate change happens and the speed and the magnitude at which it happens is caused by human activity. However, how climate change impacts thousands of environmental and social processes worldwide is to be discussed with precaution as attribution of its impacts lacks evidence for the most part.

1.1 Trends of spring and autumn phenological events and their drivers

The most frequently observed biological impact of climate change over the past decades are major changes on spring and autumn phenology — the timing of recurring life history events. Understanding the consequences of these shifts on ecosystems requires understanding how much the growing season has changed. Spring phenological events (e.g. budburst and leafout) have been advancing from 0.5 to 4.2 days/decade and are mainly driven by temperature. In contrast, autumn phenology (e.g. budset and leaf colouring) is delayed, though to a much lesser extent than spring. The drivers regulating autumn phenology are far less understood than those of spring for many reasons. First, autumn phenology has attracted much less attention compared to spring. Second, the data is often much noisier, since meteorological conditions in the fall can drastically influence the phenology phenomena (e.g. trees going through leaf senescence are subjected to a gradual leaf abscission, and the leaves might be at different abscission stage, but a strong wind spell may trigger leaf drop for all leaves, thus affecting data quality. However, the belief is that autumn phenophases are driven by shortening photoperiod and colder temperatures and colder temperatures.

1.2 Evidence of declining sensitivity to warming

1.3 Mechanisms that could limit growth despite having a longer growing season

I hypothesize two possible drivers that could explain why a longer growing season might not lead to increased growth: external (environmental) or internal (via physiological constraints) limits to growth.

The complex nature of climate change makes predicting the external drivers to growth hard to quantify at the individual level, as these drivers affect communities as a whole. Drought, spring frost and heat waves are commonly mentioned as the main extreme events that could limit tree growth under climate change. (See tables).

As for the internal drivers, recent hypothesis propose that broadleaf deciduous tree species may be sink-saturated, such that longer growing season with more carbon fixation do not necessarily augment growth (Dow2022). To better understand these mechanisms, experiments are paramount to robustly tease apart

the external vs internal drivers (e.g. warmer springs from severe drought later in the season—a common co-occurring reality in natural environments)[?][?]. This is essential to refine forest carbon sequestration projections[?][?]. However, experiments are most often performed on juvenile trees, which are critical for their role in forest regeneration projections, but their responses can hardly be translated to mature trees, which hold the overwhelming carbon biomass proportion of forests[?][?][?][?][?][?].

1.4 How these shifts translate into effects on trees/forests are not clear

Shifts in spring and autumn phenology support a long-lasting and intuitive assumption that earlier spring and delayed autumn events lead to longer seasons—and thus increased growth[?]. However, research from the past three years has cast doubt on this hypothesis[?][?][?]. Recently, Dow *et al.* (2022) showed that despite an earlier growth onset, neither growth rate nor overall annual increment was increased by longer seasons. This could substantially affect carbon-cycle model projections and thus feedbacks to future climate[?][?]. Understanding these findings requires answering why trees do not grow more despite longer growing seasons. ** Carbon allocation in wood is poorly understood and the common linear relationship of wood growth as a function of C assimilation is an important limitation of vegetation models because of the poor understanding of empirical and mechanistic basis (Cabon2022). The debate revolving around whether wood growth is controlled via photosynthesis (source limitation) or environmental limitations to cambial cell development (sink limitation) seem to bend toward a sink limitation as a result of recent work. Cambial activity appears to be more sensitive than photosynthesis to a range of environmental conditions including water, temperature and nutrients (Cabon2022). The decoupling between these two processes suggest that internal constraints to growth might be more prevalent than originally thought/

1.5 Growing season shifts and consequences on forest ecosystems and services

Spring and fall phenological events are shifting with debatable consequences on tree growth. Since cambial activity is highly sensitive to water, temperature and nutrients suggesting a sink limitation to growth, this could have far-reaching consequences given the hard-to-predict future climate change where any of these variables have the potential to have huge amplitude changes. This expected asymmetry of environmental changes under climate change makes understanding the internal and external drivers to growth critical. Especially, the capacity to tease apart different biomes—as for example boreal vs tropical forests are expected to react differently—is critical and empirical data coming from experiments, but also from observations are paramount if we want to be able to predict the changes of forest carbon offset from human GHG emissions. Thus, I propose to use a combination of one experiment to test internal (Chapter 1) limits to growth along with two observational studies (Chapter 2). This will allow me to address the paradox of the absence of increased growth despite apparently improved growing season conditions.

1.6 Climate change impacts on tree phenology

Climate change impacts on biological systems and how phenological trends are already shifting with warming temperatures.

1.7 Wildchrokie

1. Common garden from 2015 to 2023
2. Four species within the Betulacea family (Table 2)
3. Data: phenology, height, tree rings
4. Analysis: Hierarchical model to understand how tree ring width relates to GDD

1.8 Treepotters

1. Citizen science project from 2015 to today (Table 3)

- 83 2. Tree coring
- 84 3. Data: phenology, tree rings
- 85 4. Analysis: Hierarchical model to understand how tree ring width relates to GDD

86 **2 References**

Table 1: Fuelinex species grouped by tree type, life history, and wood anatomy.

Deciduous Trees			
Common Name (Latin)	Life History Strategy	Wood Anatomy	n (approx)
Bur oak (<i>Quercus macrocarpa</i>)	Slow-growth, long life	Ring-porous	87
Bitter cherry (<i>Prunus virginiana</i>)	Fast-growth, short life	Diffuse-porous	78
Box elder (<i>Acer negundo</i>)	Fast-growth, short life	Diffuse-porous	90
Balsam poplar (<i>Populus balsamifera</i>)	Fast-growth, short life	Diffuse-porous	84
Paper birch (<i>Betula papyrifera</i>)	Fast-growth, short life	Diffuse-porous	90
Evergreen Trees			
White pine (<i>Pinus strobus</i>)	Slow-growth, long life		89
Giant Sequoia (<i>Sequoiadendron giganteum</i>)	Slow-growth, long life		54

Table 2: Wilchrokie species grouped by tree type, life history, and wood anatomy.

Deciduous Trees			
Common Name (Latin)	Life History Strategy	Wood Anatomy	n
Paper birch (<i>Betula papyrifera</i>)	Fast-growth, short life	Diffuse-porous	8
Yellow birch (<i>Betula alleghaniensis</i>)	Moderate-growth, moderate life	Diffuse-porous	21
Grey birch (<i>Betula populifolia</i>)	Fast-growth, short life	Diffuse-porous	29
Grey alder (<i>Alnus incana</i>)	Fast-growth, short life	Diffuse-porous	31

Table 3: Treepotters species grouped by tree type, life history, and wood anatomy.

Deciduous Trees			
Common Name (Latin)	Life History Strategy	Wood Anatomy	n
American basswood (<i>Tilia americana</i>)	Fast-growth, moderate life	Diffuse-porous	5
Eastern cottonwood (<i>Populus deltoides</i>)	Fast-growth, short life	Diffuse-porous	4
Northern red oak (<i>Quercus rubra</i>)	Moderate-growth, long life	Ring-porous	4
White oak (<i>Quercus alba</i>)	Slow-growth, long life	Ring-porous	5
Pignut hickory (<i>Carya glabra</i>)	Slow-growth, long life	Ring-porous	4
Shagbark hickory (<i>Carya ovata</i>)	Slow-growth, long life	Ring-porous	4
River birch (<i>Betula nigra</i>)	Fast-growth, short life	Diffuse-porous	5
Yellow birch (<i>Betula alleghaniensis</i>)	Moderate-growth, moderate life	Diffuse-porous	4
Sugar maple (<i>Acer saccharum</i>)	Slow-growth, long life	Diffuse-porous	5
Red maple (<i>Acer rubrum</i>)	Slow-growth, long life	Diffuse-porous	4
Yellow buckeye (<i>Aesculus flava</i>)	Moderate-growth, moderate life	Diffuse-porous	5