Thesis Proposal

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1 Introduction

1.1 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 framentation. 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 pesimistic. Climate change currently holds the status of a scientific consensus i.e. scientifics arounds 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.

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[?][?]. Different hypothesis are proposed to explain delayed autumn phenophases. First, warmer autumn temperature may extend the activity of photosynthetic enzymes which could be maintained at a a higher level. Thus, the degradation rate of chlorophyll would decrease and timing of senescence would be delayed (Tao2021Divergent). Another mechanism would be through summer conditions... However, a counterinteractive hypothesis suggests an antagonistic effect of warming and brightening—caused by reductions in atmospheric pollution and cloud cover (Sanchez2015Reassessment)— on leaf senescence (Wu2021Atmospheric). Brightening accelerates the leaf senescence process and reduces the temperature sensitivity of leaf senescence, counteracting the expected warming-induced delays in leaf senescence. The photo-protection and sink limitation hypothesis provide plausible explanations for the negative effect of radiation on leaf senescence and the declining effect of temperature sensitivity of leaf senescence in response to brightening **Evidence of declining sensitivity to warming** Bud dormancy needs to be broken by exposure to cold temperatures during the dormancy period (chilling).

The advancement of spring phenology that has been observed over the past decades might decelerate and this relates to winter dormancy. In the fall, trees in boreal and temperate forests slowly enter dormancy which is initiated with budset. During this phases, cold hardiness increases which prepares the trees for

the upcoming cold temperatures and prevents tissue damage. Then, the trees go through dormancy in the winter, during which a certain duration of chilling temperatures between 0 and 5 °C —with some interaction with photoperiod for some species—- is necessary for the trees to be ready to accumulate forcing (Vitasse2014TheInteraction). In the late winter and early spring, they go through two forms of deacclimation before the buds are ready to burst (Vitasse2014TheInteraction). Trees require a certain amount of heat (forcing) after they come out of the dormancy period to initiate leaf unfolding in spring. Heat requirement is met sooner in warm springs. However, heat requirement is negatively correlated with chilling (Yongshuo2015Declining), but it is this interaction between chilling and forcing requirements that determines the timing of leaf unfolding. Consequently, a decrease in chilling accumulation could explain the observed weaker spring temperature sensitivities as a decline in the relative importance of warm spring temperatures for spring phenological events in the temperate zone, as other environmental triggers (e.g. winter temperatures that determine "chilling") play a larger role (Wolkovich2021ASimple).

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[?][?][?].[?][?][?].

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 pooly 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 controled 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 enviromental 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.

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 assymetry of environmental changes under climate change makes understanding the internal and external drivers to growth critical. Especially, the capacity to tease appart 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.

1.2 Nature of the problem, and how to address it

1.2.1. Past phenological trends don't predict future phenological changes "The past is not necessarily a guide to the future, but it does partly help explain the present." Observed phenological trends in the last decades cannot be used directly to extrapolate future phenological changes because: (1) the mechanisms guiding them aren't clear and (2) phenological responses of trees to warming are very likely to not be linear (Fu2013Sensitivity). Indeed, accurate predictions require an in-depth accurate mechanistic understanding of leaf unfolding process and its sensitivity to environmental drivers, especially to temperature and photoperiod (Fu2013Sensitivity). Therefore, the very foundation of the assumption that longer seasons increase growth may change under future climate change. The well observed and understood advance in spring phenology may be offset by warmer winters and delayed autumns may stop being delayed and instead advance in results to earlier growth cessation of increase summer stress.

1.2.2. The assumption that longer seasons lead to increased growth is called into question

1.2.3. Impacts on carbon source-sink projections

1.2.4. Goals of my thesis

1.3 Complexity of measuring growth

1.3.1. Traditional diameter measurements miss the resolution of annual growth increment Foresters have measured tree diameter and height for decades to infer allometries that could give them a good estimate of how much wood they could collect in a forest. This growth data provides unsufficient resolution to infer a relationship between growth environmental conditions. Well-known dendrochronology methods have been used for decades and served many purposes such as calibrating radio carbon scales and understanding earth's past climate.

1.3.2. Growth increment needs to incorporate wood density in order to evaluate how much structural carbo58 hydrates were stored within a single year.

1.3.3. Primary and secondary growth do not start and end at the same time

1.3.4. Getting growth temporal resolution is labor-intensive and expensive (e.g. dendrometer costs)

1.4 Objectives

1.5 Research questions

1.4.1. Fuelinex

1.4.2. CookieSpotters

2 Methods

2.1 Climate change impacts on tree phenology

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

2.2 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

2.3   Treespotters

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

2. Tree coring

3. Data: phenology, tree rings

4. Analysis: Hierarchical model to understand how tree ring width relates to GDD

3   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 (ap-prox)**
Bur oak (*Quercus macrocarpa*)	Slow-growth, long life	Ring-porous	87
Bitter cherry (*Prunus virginiana*)	Fast-growth, short life	Diffuse-porous	78
Box elder (*Acer negundo*)	Fast-growth, short life	Diffuse-porous	90
Balsam poplar (*Populus balsamifera*)	Fast-growth, short life	Diffuse-porous	84
Paper birch (*Betula papyrifera*)	Fast-growth, short life	Diffuse-porous	90
Evergreen Trees			
White pine (*Pinus strobus*)	Slow-growth, long life		89
Giant Sequoia (*Sequoiadendron giganteum*)	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 (*Betula papyrifera*)	Fast-growth, short life	Diffuse-porous	8
Yellow birch (*Betula alleghaniensis*)	Moderate-growth, moderate life	Diffuse-porous	21
Grey birch (*Betula populifolia*)	Fast-growth, short life	Diffuse-porous	29
Grey alder (*Alnus incana*)	Fast-growth, short life	Diffuse-porous	31

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

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