Thesis outline

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1 Introduction

1.1 Climate change impacts on tree phenology

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

1. Warmer temperature led to earlier spring events for amphibians, birds, butterflies and wild plants (Walther, 2002)

2. Autumn phenological events are delayed, but the trend is not as clear as spring's. Description of mechanistic drivers of autumn phenology vs spring

3. Long-term trends suggest that the pace of spring events advancement is slowing down. Counterinteraction of warmer winters that delays spring phenology because of non-met chilling requirements, which increase forcing requirements –¿ later budburst

4. Photoperiod perception interaction with warming requirements (Zohner 2016)

5. Potential impacts of spring frost on growth. *Explain how the strategy to rely on photoperiodic cues can decrease spring frost risks*

6. Overall, earlier spring and delayed autumn lead to a longer phenological growing season (Korner, 2023 for pheno GS definition)

7. Drought events are increasing in frequency and severity, which influences tree growth

8. Pros and cons of early Start of Season:
   Pros:

   - Potential competitive ability of carbon uptake at the individual and stand level (increased productivity) (Estiarte, 2015);
   - More days to reach fruit maturity.

   Cons:

   - Trophic mismatch (though limited support) (Loughnan 2024)
   - Incre ased summer drought-induced stress
   - Increased pest and disease pressure
   - Soil nutrient depletion (e.g. Reich 2006)

9. Pros and cons of delayed End of Season:
   Pros:

- Photosynthesis can occur for longer, increasing carbon sequestration (Keenan, 2014)
- May increase nutrient resorption efficiency (Richardson 2010)
- May delay frost exposure (Gunderson, 2012)

Cons:

- Delayed leaf senescence could kill leaves (cold spell) before nutrient resorption (Estiarte, 2015 ; Augspurger, 2013)
- Phenological mismatches
- Disruption of dormancy cycles –chilling requirements not met(Korner, 2010)
- Extension of pest life cycles (Ayres, 2000)

1.2 Tree rings measurements as a proxy for growth

Analyze tree rings to investigate the relationship between phenology and growth

1. Tree ring images allow for a more detailed assessment of the climate influence on tree growth than diameter and height measurements
2. Cambial phenology. Growth onset and duration vary because of inter-annual differences in weather, with cambium reactivation in spring being highly dependent on temperature.
3. Radial growth increased by temperature, depends on **when** it is warmer.
4. Growth rate has a more direct influence on tree growth than the growing season length.

1.3 Nature of the problem

1. Past phenological trends don't predict future phenological changes. Highlights the importance of understanding the drivers that control phenology and growth,
2. The assumption that longer seasons lead to increased growth is called into question
3. Impacts on carbon source-sink projections

1.4 Research questions

1. **Fuelinex**: How do extended growing seasons affect tree growth across different species, both immediately (in the same year as the extended season) and in subsequent years?
2. **CookieSpotters**: How phenological traits regulate tree growth in urban ecosystems?

1.5 Hypothesis

1. **Fuelinex**: Growing season extension modifies a tree's capacity to fill carbon and nitrogen storage pools and this could lead to increased growth in the following season.
2. **Fuelinex**: Species capable of accumulating nutrients after growth cessation while going through leaf senescence might exhibit growth increment in the following growing season
3. **CookieSpotters**: The magnitude of the growth response to longer seasons will differ between juvenile and mature trees.

1.6 Objectives and outreach

1. **Fuelinex**: Assess tree species' potential to prolong or stretch their activity schedule.
2. **Fuelinex**: Determine whether trees can absorb nutrients beyond their theoretical growing season.
3. **Fuelinex**: Examine if increased carbon pools translate into greater growth increment in the following growing season.
4. **CookieSpotters**: Investigate how the timing of phenological events affects growth across years for juvenile and mature trees

2 Methods

2.1 Fuelinex

1. Full factorial design (Figure 1. Experimental design)
2. 2-year experiment
3. Nutrient addition
4. Data: phenology, shoot elongation, diameter, height, biomass, tree rings
5. Analysis: TBD

2.2 Wildchrokie

1. Common garden from 2015 to 2023 (Table I. Species studied, and number of trees/species)
2. Data: phenology, height, tree rings
3. Analysis: Hierarchical model to understand how tree ring width relates to GDD

2.3 Treespotters

1. Citizen science project from 2015 to today (Table II. Species studied, and number of trees/species)
2. Tree coring
3. Data: phenology, tree rings
4. Analysis: Hierarchical model to understand how tree ring width relates to GDD

3 Timeline

Figure 2. Master's thesis timeline.