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. Trends of spring and autumn phenological events and their drivers (Walther, 2002)
2. Evidence of declining sensitivity to warming, predominance of winter temperature in spring phenological responses (Ettinger 2020)
3. Mechanisms that could limit growth despite having a longer growing season:
   (a) spring frosts (e.g.: Zohner 20)
   (b) extreme heat induced physiological stress (e.g. Salomón 22 ,Neuwirth 21, Stangler17)
   (c) increased drought frequency, intensity and duration (e.g.:Chiang 21, Choat 18, Li 23)
4. Pros and cons of early/late start of season:
   Early SOS
   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)

   Late SOS
   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 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

1.3 Tree rings measurements as a proxy for growth

Using tree ring data to investigate the relationship between phenology and growth

1. Triggers and mechanisms behind growth onset, duration and rate.
2. How radial growth is influenced by extreme weather events and their timing.
3. Which is more important? How fast a tree grows or how long it grows for
4. Methods to measure tree growth and why using tree ring images may better capture tree growth response than traditional diameter and height measurements.

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 sequestrate carbon and nitrogen, 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.