

1 Thesis outline

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4 **1 Introduction**

5 **1.1 Climate change impacts on tree phenology**

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

8 **1.1.1. Trends of spring and autumn phenological events and their drivers¹**

9 1.1.1.1. changes in phenology

10 1.1.1.2. Drivers of spring phenology (including forcing and chilling from paragraph of declining sensitivity)

11 1.1.1.3. Drivers of autumn phenology

12 **1.1.2. How these shifts translate into effects on trees/forests not totally clear – Pros and cons
13 of early/late start of season:**

14 1.1.3. Growing season shifts consequences on forest ecosystems and services

15 **1.2 Nature of the problem and to address it**

16 1.2.1. Past phenological trends can help (or not) predict future phenological changes

17 1.2.2. The assumption that longer seasons lead to increased growth is called into question

18 1.2.2.1. Absence of growth despite better conditions and strategies that can be used

19 1.2.2.2. Experiments

20 1.2.2.3. Ground based observations

21 1.2.3. Goals of my thesis

23 **1.3 Complexity of measuring growth**

24 1.3.1. Definition of growing season and growth

25 1.3.2. Traditional diameter measurements miss the resolution of the annual growth increment.

26 1.3.3. Dendroecology to analyses growth responses to changing growing season length

27 **1.4 Research questions**

28 1. **Fuelinex:** How do extended growing seasons affect tree growth across different species, both immedi-
29 ately (in the same year as the extended season) and in subsequent years?

30 2. **CookieSpotters:** How phenological traits regulate tree growth in urban ecosystems?

31 **1.5 Hypothesis**

32 1. **Fuelinex:** Growing season extension modifies a tree's capacity to sequester carbon and nitrogen,
33 and this could lead to increased growth in the following season.

34 2. **Fuelinex:** Species capable of accumulating nutrients after growth cessation while going through leaf
35 senescence might exhibit growth increment in the following growing season

36 3. **CookieSpotters**: The magnitude of the growth response to longer seasons will differ between juvenile
37 and mature trees.

38 **1.6 Objectives and outreach**

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

45 **2 Methods**

46 **2.1 Fuelinex**

- 47 1. Full factorial design (Fig. 1)
48 2. 2-year experiment over 2024-2025 (Fig. 2 and 3)
49 3. Nutrient addition
50 4. Data: phenology, shoot elongation, diameter, height, biomass, tree rings
51 5. Analysis: TBD
52 6. Studied species (Table 1)

53 **2.2 Wildchrokie**

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

58 **2.3 Treespotters**

- 59 1. Citizen science project from 2015 to today (Table 3)
60 2. Tree coring
61 3. Data: phenology, tree rings
62 4. Analysis: Hierarchical model to understand how tree ring width relates to GDD

63 **3 Timeline**

64 Fig. **

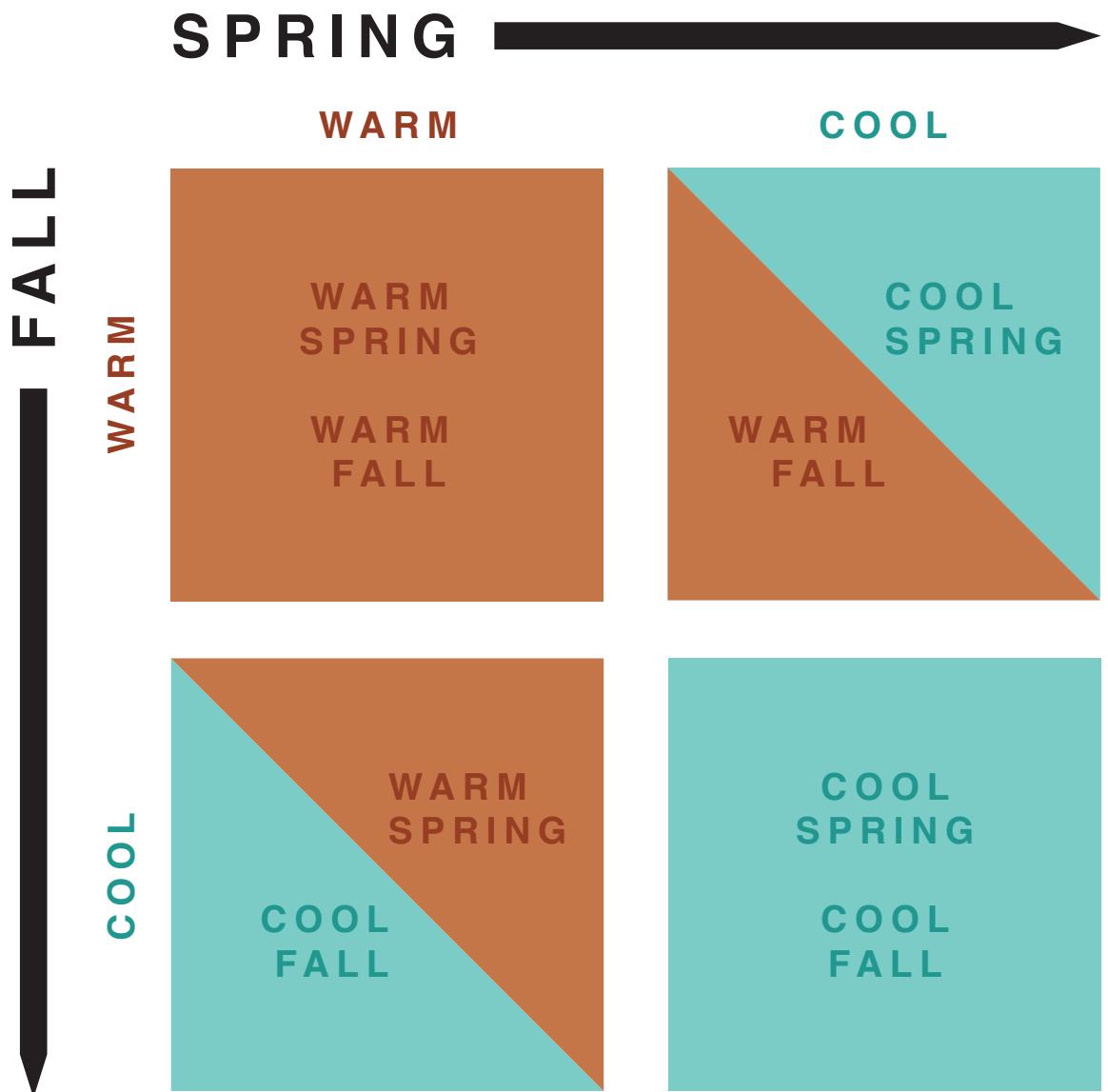


Figure 1: Full factorial design of Cool/Warm Spring and Cool/Warm Fall

2024 FUELINEX EXPERIMENTAL DESIGN

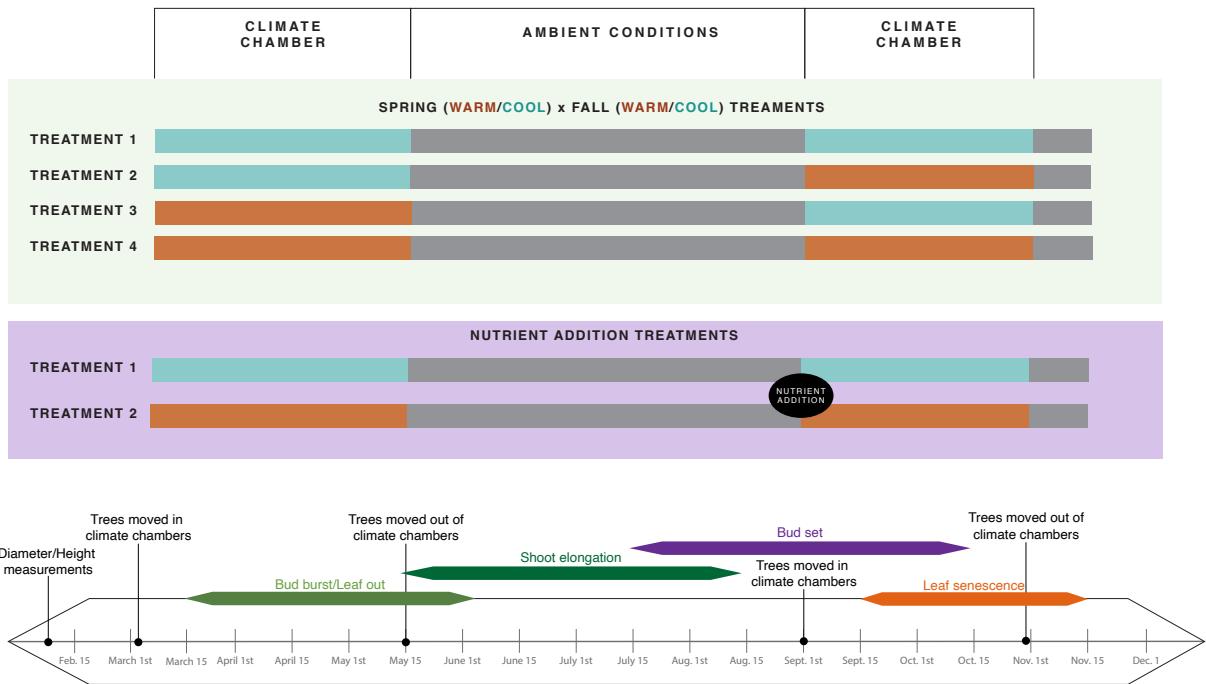


Figure 2: Experimental design of the different treatments that were performed during the growing season of 2024. The timeline displays the periods of the different measurements. Nutrient addition treatments are displayed by the black ellipses

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 (<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>Sequoia 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: Treespotters 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

65 4 References

66 References

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2025 FUELINEX EXPERIMENTAL DESIGN

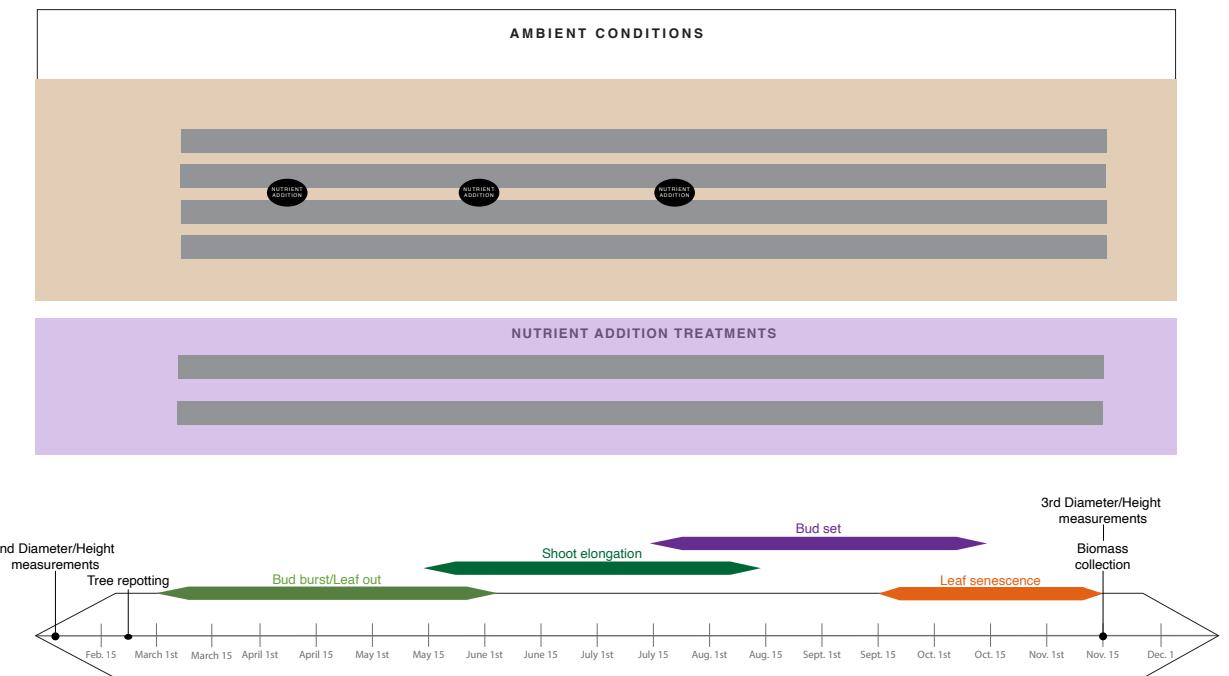


Figure 3: Timeline displaying the periods of the different measurements during the growing season of 2025

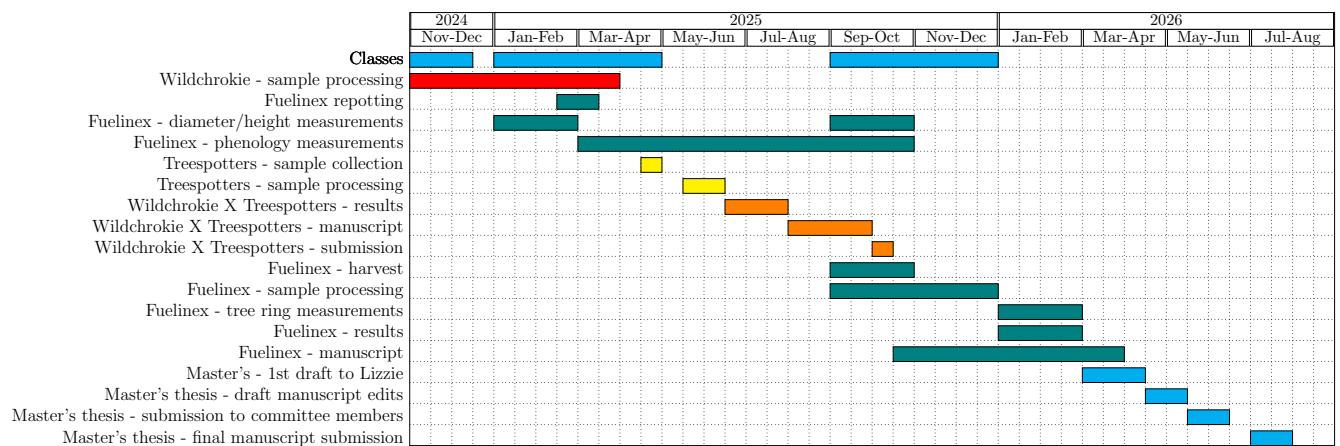


Figure 1: Christophe RD Master's timeline

Figure 4: Gant chart displaying the different milestones to be done over 2025 and 2026