Research Proposal for Master's Thesis
Oregon State University
College of Forestry
Forest Ecosystems and Society

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"Old Trees, New Climate: How Do Douglas Fir and Western Hemlock Respond To Heat Waves?"

Summary: Mature and old-growth (MOG) forests are at risk of climate change-related stressors and mortality. This is important because they are crucial for carbon storage, biodiversity, and cultural importance. My proposed project will study the short-term and long-term growth patterns of two dominant MOG tree species at the HJ Andrews Long Term Ecological Research site before, during, and after heat waves to quantify hypothesized negative effects of heat stress.

BACKGROUND, MODELS, AND BROADER SIGNIFICANCE

Forests all over the world are sequestering less carbon from the atmosphere due to stressors imposed by anthropogenic climate change, namely drought, heat, increased pathogens, and more (Davis et al., 2023). Climate change encompasses events such as acute periods of extremely high temperatures, also known as heat waves (Filewood and Thomas 2013). Heat waves and other climate change-related events like drought are often but not always co-occurring, and they are projected to increase in frequency, duration, and severity as time continues (Duarte et al, 2016; Dai et al. 2013; Salomón et al. 2022). Heat-related climate stress can severely negatively affect trees resulting in physical damage, increased vulnerability to pests and pathogens, reduced carbon uptake, hydraulic failure in leaves, water loss, and mortality (Rastogi et al; Kunert et al; Still et al. 2023; Allen et al. 2010). These effects have been globally identified and could completely reshape ecosystems and their functioning (Allen et al. 2010). Even under low emissions predictions, the Pacific Northwest specifically is expected to experience increased temperatures, heat waves, wildfire, and drought stress, thereby further reducing the potential for carbon sequestration despite this region being replete with forests relative to the rest of the country (Chang et al. 2023).

This is especially worrying for mature and old-growth (**hereafter MOG**) trees because they are unusually impactful as climate change buffers, disproportionately housing both carbon and a myriad of plant, animal, and fungal species (Swanson 2023). Mature forests are between 80-200 years and old-growth (**hereafter OG**) forests are older than 200 years (Cohen et al., 1996). Large, old trees store more carbon than their younger counterparts because in almost all tree species across all continents, the rate of above-ground biomass growth continually increases with tree size. One study went so far as to estimate that in western US OG forests, one-third of the forest's annual mass growth comes from *just* the large trees (with a diameter exceeding 100 cm) (Stephenson et al., 2014). What's more impressive is that these large trees only make up 6% of the total trees in these forests. Put another way, large trees add an average of 103 kilograms annually, which is equivalent to adding one 10-20 cm-diameter tree to the forest. Globally, the most potential for carbon storage exists in areas where forests could be restored into MOG conditions (Mo et al. 2023). This potential accounts for 139 metric gigatons of carbon. These details of OG growth are an important motivation to protect OG forests especially in an era where some scientists are still unsure whether younger forests are more productive in the long term (Cohen et al., 1996).

In addition to their photosynthetic productivity, OG forests are lauded for their contributions to biodiversity. Some wildlife species exclusively spend part of all of their lives in OG forests, most famously the now-threatened northern spotted owl of Oregon (Johnson and Swanson 2009). OG forests can additionally serve as living museums due to their advanced age in a way that cannot be replaced simply through plantation, adding a cultural and recreational value to MOG forests, thus further exemplifying the need to understand and protect them.

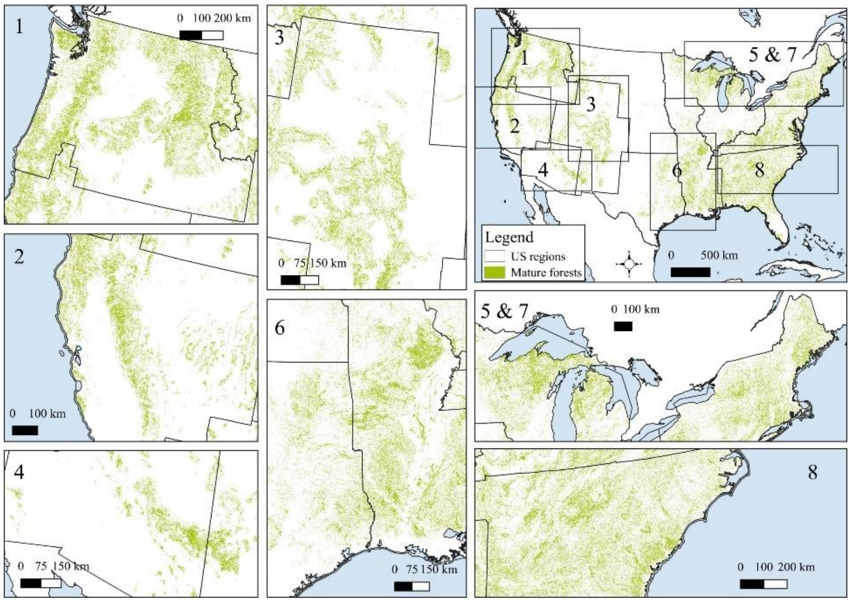

Figure 1: Spatial distributions of MOG forests in the contiguous US (DellaSala et al., 2022)

The distribution of MOG forests is shown in **Figure 1.** Note that the Pacific Northwest is depicted in box 1 of the figure (DellaSala et al., 2022). 25% of all remaining contiguous American OG forests exist in the Northwest part of the country (U.S. White House). This makes sense considering that most American MOG forests were removed with the influx of European colonization for settlement or agriculture, thus provoking federal protection for many remaining MOG forests by the time settlers made it to the Pacific coast (Johnson and Swanson 2009). As seen in **Figure 2**, the HJ Andrews Experimental Forest (also referred to as the Andrews Long-Term Ecological Research [LTER] Forest, Andrews Research Forest, Andrews LTER Forest, among others) contains several well-documented sites of continuous OG forests. LTER sites are unique in that they are typically protected to preserve undisturbed conditions. Research conducted on LTER sites are therefore novel for their holistic, interdisciplinary, and collaborative approaches to demystifying both short-term and long-term issues in ecology such as those proposed in this present project (Jones and Driscoll 2022). More information about the Andrews Forest is described below in "Proposed Methodology."

Figure 2: Map of the HJ Andrews Experimental Forest's location in western Oregon ("Maps").

Because of the mounting stressors climate change imposes on OG forests, it is important to predict the future of climate-tree relationships so that researchers can plan accordingly. The impact of warmer temperatures in Andrews is depicted in **Figure 3.** Data are from the Climate Toolbox and shows how three parameters vary from historical values under RCP 8.5 "business as usual" high emissions (Hegewisch and Rangwala). The three selected parameters are maximum daily temperature, number of days above 86°F, and vapor pressure deficit (original units hPa) times 100. Vapor pressure deficit (**VPD**) is a way to describe the relationship between a plant's stomatal opening and the amount of vapor present in the air. Increases in VPD are related to increases in drought stress, which decreases photosynthesis and therefore net carbon uptake. Especially when there is warming during already warm months such as the later spring or summer, VPD is the most dominant regional driver of drought-stress among forests (Williams et al. 2012).

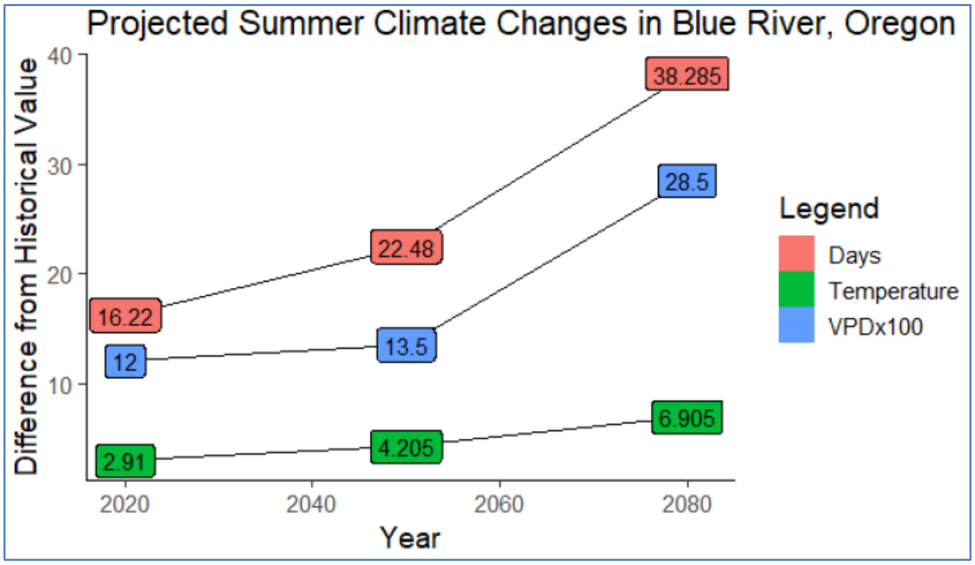

Figure 3: Projected changes in maximum daily temperature, number of days above 86 °F, and 100 times the vapor pressure deficit (original units hPa) in Blue River, Oregon (Hegewisch and Rangwala).

While increases in all three parameters have been observed since the start of the 21st Century, the above shows how these increases will continue to break historical records and potentially snowball beyond a point of return. The figure shows a distinctively sharp increase in VPD between 2050 and 2080. This will require special attention because VPD is associated with increased tree mortality and reduced canopy greenness, which are also affected by insect outbreaks and wildfires (Williams et al. 2012).

RESEARCH GAP

Despite their unique cultural, recreational, and environmental benefits, OG forests are scarcely studied relative to younger forests, likely due to a combination of factors including their challenging size and unequal geographic distribution. Moreover, the scientific literature is full of studies that use model simulations to predict forest responses to climate stress, but it is important to concurrently collect live data to methodologically ensure model accuracy and identify nuances between forest types and species. On this front, there is a severe lack of research on OG trees in the context of heat waves, specifically. Heat tolerance and the mechanisms that dictate it within both young and old trees are poorly understood because they are easily overshadowed by aforementioned co-occurring events such as drought (Still et al. 2023). Lastly, heat waves and their effects can vary widely by tree species and age (Wang et al 2023; Allen et al. 2010).

Therefore, use field methods to quantify their experienced physiology or real-time water use. Gaining such knowledge will be useful both for checking model accuracy as well as gaining insight into the more subtle mechanisms and strategies these trees rely on to adapt to our changing world.

Therefore, there is a need to **A)** use field methods to quantify OG trees' experienced physiology and water use amidst heat waves on a species level, and **B)** decipher whether the disturbances themselves are affecting those physiological mechanisms. Given the established value of OG trees and the dangers of heat waves, the ramifications of a study addressing the interactions between the two would be of great benefit to researchers, land managers, and everyday citizens alike. However, the interactions between trees and climate are often species specific. Because of the Northwest's unique position as a hub for MOG forests, the proposed study will focus on species commonly found there. Many parts of the Pacific Northwest, namely western Oregon and Washington, have mesic OG conifer forests dominated by Douglas-fir (*Pseudotsuga menziesii*) (**hereafter DF**) and western hemlock (*Tsuga heterophylla*) (**hereafter WH**) (Johnson and Swanson 2009). More information about these species and the proposed site are detailed below in "Proposed Methodology."

RESEARCH QUESTIONS AND HYPOTHESES

The following questions will dictate the proposed master's thesis research project. By its completion, we will gain a better understanding of DF and WH by combining short-term and long-term physiological data and climatological data all in one synthesis, which has not yet been done. Using dendrometers and tree cores to ask and answer questions related to barriers to carbon uptake is important because stem biomass accounts for 72-75% of a tree's biomass (Reich et al., 2014).

Dendrometers are relatively small sensors placed on tree trunks that measure changes in stem size. Automated point dendrometers can measure microscopic size differences as precisely as every thirty minutes. Stems change size in three phases: stem shrinking (due to water loss via transpiration), swelling or recovering (due to rehydration later in the day), and increment or growth (due to carbon assimilation into biomass) (Downes et al. 1999; Balducci et al. 2019). These dendrometers have been passively collecting data for years and therefore will show changes in tree diameter during multiple heat waves, the most recent being the 2021 Heat Dome (Still et al. 2023).

- Chapter 1:
  - How does short-term growth of MOG DF and WH change before, during, and after a heat wave event at the HJ Andrews Experimental Forest?
    - Hypothesis 1: growth of both DF and WH will slow or cease shortly after a heat wave, a stunt that will last throughout the growing season and perhaps into the next growing season
    - Hypothesis 2: WH will be more severely affected by heat wave-induced stress and growth cessation than DF will
- Chapter 2:
  - How has long-term growth of MOG DF and WH changed over the last few decades at the HJ Andrews Experimental Forest?
    - Hypothesis 3: In both DF and WH, latewood bands will be significantly smaller during heat wave years.
    - Hypothesis 4: Heat wave years will be easily distinguished in tree rings and will align with dendrometer data indicating growth changes as a temperature-mediated response.
  - (if time allows): Does the degree of foliar scorch from heat waves affect long-term growth of WH?
    - Hypothesis: Yes, and that the relationship between scorch and growth will be negative.

PROPOSED METHODOLOGY

The proposed study will take place at the HJ Andrews Forest. It is situated on the eastern side of the Cascade Mountains near Blue River in Linn County, Oregon (approximate coordinates: 44.1734° N, 122.1968° W). The area encompasses over 15,800 acres (6,400 hectares) and is jointly operated by the US Forest Service's Pacific Northwest Research Station, the Willamette National Forest, and Oregon State University (Swanson 2023). It is as diverse in its topography as it is in its biota. Elevations range from 380-1600 meters (1,247-5,249 feet), and the land sits atop the Lookout Creek watershed. Native forests can surpass 500 years in age while the younger plantations are the result of clearcutting practices of the 1960s (Swanson 2023). In the more mesic areas of the Andrews, the fire regime tends to be infrequent (fire return interval of 50-100 years) with high intensities.

DF trees rely on such infrequent yet intense fire regimes to establish new seedlings since they are shade intolerant. This is why they often occupy the peak of a forest overstory, standing 30 meters tall and taller. WH, on the other hand, is traditionally viewed as a shade-tolerant species occupying a forest overstory up to 30 meters in height (Johnson and Swanson 2009). WH and DF are both conifers. Conifers might be less likely to recover as quickly or completely from acute heat stress as broadleaf trees due to slower rates of rehydration. This could have dangerous implications for conifer trees because the year-long retention of their leaves means that prolonged hydraulic deficits could lead to further foliar stress and/or damage (Salomón et al. 2022). Directly comparing these species will provide interesting examples of how stress responses can vary based on location in the forest structure.

To answer the question reserved for chapter 1, I will use shrinking and swelling data (in microns or micrometers) from automated point dendrometers (brand TOMST or brand Ecomatic) already installed on DF and WH near the Discovery Tree Trail in the Andrews. This site is located in the moist valley of the Andrews and therefore has an elevation of approximately 1,475 feet. The OG trees in this area are between 450-500 years old and 60-70 meters tall. In order to have enough dendrometry data to track growth changes in an appropriate time frame relative to recent and intense heat waves at this site as dictated by available climatological data, I will have access to 3 dendrometers on OG DF trees and 1 dendrometer on an OG WH tree. If time allows, I could get more dendrometry data from a nearby site whose elevation is instead 2,130 feet. These dendrometers have been consistently collecting data since 2018, meaning that have captured one of the most recent and severe heat waves, the 2021 Heat Dome (Still et al. 2023). I will analyze dendrometry data using an R package titled TreeNetProc, which summarizes and cleans data while pairing it with temperature data (Knüsel et al., 2021).

To answer the question reserved for chapter 2, I will take tree ring cores from the same trees used in chapter 1 as well as others in the site to obtain a longer-term look into water use and stress among these trees, which—when paired with climate data at the area—can give key insights into heat wave responses. To ensure a viable data pool that can yield reliable results, I will aim to take 2-3 cores from 10-15 individual trees of each species for a total of 40-90 cores from the same site. A nearby weather station will provide the data necessary for analysis such as air temperature, canopy temperature, and precipitation. Some of these cores will also be used to answer a second question for this chapter, assuming time allows. The distribution of WH among this site results in varying levels of sun exposure due to gaps in the DF canopy, resulting in a clear gradient of foliar scorch of WH following a heat wave in 2018. I will take special and additional care when analyzing cores from these trees to assess whether the degree of foliar scorch affected growth patterns.

TIMELINE

My proposed timeline is available in **Figure 4** below. This timeline accounts for field work, laboratory work, thesis writing, course enrollment, and data analysis. I plan to have collected all relevant data by the end of the summer 2024 field season. I will spent the next year analyzing the data and writing my thesis chapters so that I may graduate by the summer or fall of 2025.

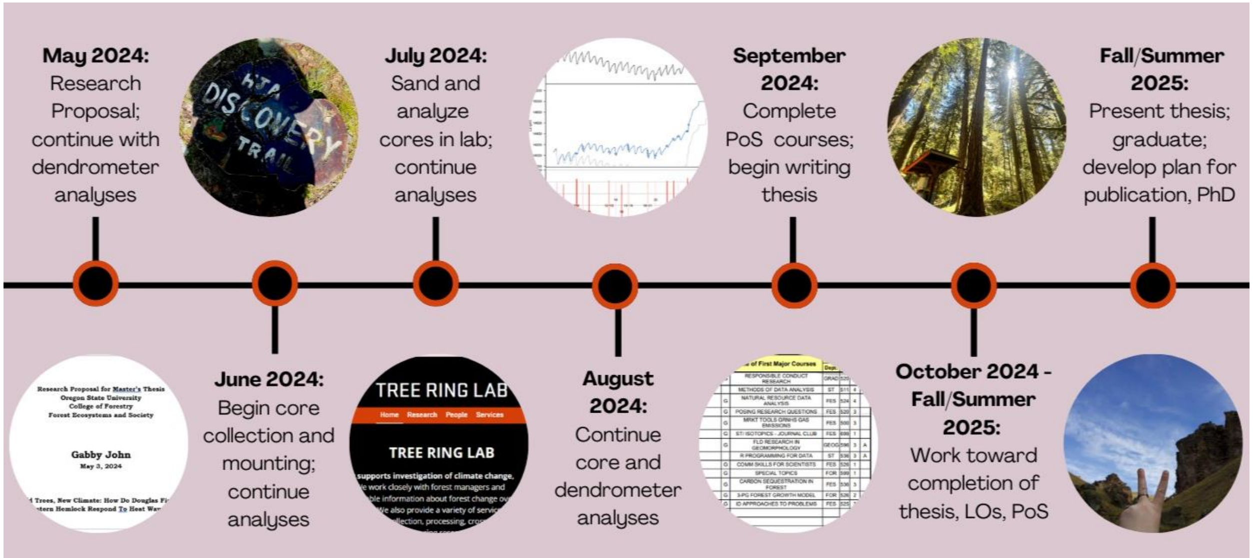

Figure 4: Timeline to achieve proposed thesis project. Made using Canva.com.

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