# Demographic Structure of Eastern Hemlock and White Cedar Populations and Analysis of Growth Response to Climate

BIOS 35502-01: Practicum in Field Biology

Daniel Griffin

Advisor: Dr. Rose Marie Muzika

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## Abstract

This study was a survey of the demographic structure of eastern hemlock and white cedar populations in Northern Wisconsin. The growth response of each species to temperature and precipitation was also analyzed using climate data dating back to 1919. The species abundance in three size classes (canopy, tall regeneration, short regeneration) was measured. Balsam fir was also included in the species abundance analysis due to in-field observation of high abundance at each location. A chi-squared test demonstrated that differences in relative species abundance at each canopy class were significant ($p < 0.05$). Hemlock and white cedar were more abundant in the canopy, but balsam fir generally dominated the other species in the understory. This suggests that the species composition of the canopy may change in the future. No relationship was found between tree size and age for white cedar and eastern hemlock ($p > 0.05$). In addition, no relationship was found between growth of either species and climate conditions ($p > 0.05$). These findings are likely due to the fact that competition between individuals has the strongest effect on tree growth rate. An understanding of the population dynamics of hemlock and white cedar is important as climate change begins to have a stronger impact on forests in the Great Lakes region.

## Introduction

In the past 150 years, the forests of the Great Lakes region have changed dramatically. Years of intense logging, overbrowsing by vertebrate herbivores, and fire suppression have drastically changed the species composition of forests (Kassulke 2009). In the late 19th Century the forests in Vilas County, Wisconsin were equally dominated by sugar maple (*Acer saccharum*), yellow birch (*Betula alleghaniensis*), and eastern hemlock (*Tsuga canadensis*)

(Mladenoff 2009). White pine (*Pinus strobus*) was almost as abundant as these other species; some parts of the forests were even described as a "pinery with considerable merchantable timber" (Roth 1897).

The forests of Northern Wisconsin today are dominated by sugar maple. The percentage of white pine to total forest cover has dropped from about 12% to less than 2%, and the percentage of eastern hemlock has fallen from about 22% to less than 4% (Wisconsin DNR 2015). White pine and eastern hemlock were both logged due to their use in the shipbuilding and leather tanning industries, respectively. Eastern hemlock trees are also major targets of overbrowsing as they are a preferred food source for white-tailed deer (Borgmann et. al 1999).

More changes in species composition will occur in the future due to the onset of climate change. Average temperatures in the Great Lakes region are predicted to rise 3-11°C in the summer and 3-7°C in the winter by the late 21st Century (Duveneck et. al 2014). In addition, average precipitation during tree growing season is expected to decline (Reed and Desanker 1991). Tree populations will likely be unable to adapt to these changes due to their long life span and slow reproductive rate (Reed and Desanker 1991), and due to the inability of individuals to relocate to new climates. Given the impending changes, it is important to understand today's tree population dynamics in order to predict tree population responses to climate change. Hopefully, an understanding of today's tree population dynamics will inform tomorrow's management practices.

This study will focus on the populations of eastern hemlock in Northern Wisconsin. The eastern hemlock is a late-succession conifer that most commonly grows near the shores of lakes or rivers. Hemlock-dominated conifer groves are unique habitats characterized by their low levels of light and groundcover (Martin and Goebel 2012). Hemlocks are the foundational species in these ecosystems, meaning their presence has a strong effect on the microclimate and species composition of surrounding areas (Martin and Goebel 2012). Because these trees play a key role in ecosystem stability, it is important to understand hemlock population dynamics.

One study conducted in the central Appalachian region analyzed eastern hemlock growth over a period from 1896-2012 and found that hemlock growth had varied responses to climate (Saladyga, Maxwell 2015). Another study found that mountain hemlock (*Tsuga mertensiana*) populations may adapt to climate change by expanding northward as temperatures in North America increase (Johnson et. al 2017). There is still a knowledge gap in how eastern hemlock populations in the Great Lakes region respond to changes in temperature and precipitation, and it is unclear how these populations will fare due to future temperature increases.

Northern White Cedars (*Thuja occidentalis*) are another common canopy species that are found in the hemlock groves of northern Wisconsin. White cedars tolerate higher levels of moisture than hemlocks ((Boulfroy et al. 2012)), so they are often found right along the shores of lakes and streams. There is no consensus as to how the populations of white cedar interact with eastern hemlock. In one study, white cedar populations in the Great Lakes region were found to be increasing while eastern hemlock populations were decreasing (Zhang et. al 2000). Another study concluded that in conifer forests where both eastern hemlock and atlantic white cedar (*Chamaecyparis thyoides*) populations are present, the hemlocks were regenerating at a much higher rate than cedars and were likely to become dominant in the near future. (Gengarelly and Lee 2006).

This study will consist of a survey of the demographic structure of eastern hemlock and white cedar populations within three hemlock-dominated groves in Northern Wisconsin. The major questions being asked are as follows: (1) How are eastern hemlock and white cedar populations regenerating within these forests? (2) Is the size distribution of eastern hemlock and white cedar individuals in the canopy a good approximation of the age distribution? (3) How does the growth of these tree species respond to climate variables? The hypotheses being tested are that white cedar and eastern hemlock are regenerating at different rates, that size and age are not linearly related in either species, and that although both species respond to changes in temperature and precipitation, the response is not the same. The last hypothesis is based on the ecological differences between the species, namely that cedar might be found in a higher light environment along the edges of lakes, whereas hemlocks can grow in closed canopy, shaded environments.

## Methods

This study was conducted at the University of Notre Dame Environmental Research Center (UNDERC), located along the border between northern Wisconsin and Michigan. Data from the eastern hemlock and northern white cedar populations was taken from three different locations on UNDERC property. The three locations were positioned on the shorelines of Plum Lake, Tenderfoot Lake, and Crampton Lake where the two species co-occurred.

Two plots of 20 by 15 meters were created at each sampling location. Because white cedars primarily grow very close to the water, each plot was located with one of the longer sides along the lakeshore. This setup allowed for hemlocks and white cedars to be studied together on the same plot. In order to randomize plot selection, the total length of the conifer grove was measured along the lakeshore. This distance was used to find the midpoint of the grove. A random number generator was used to specify distance in meters from the midpoint that each plot would be located. One plot was made in either direction from the midpoint.

Within each plot, trees were separated into three different classes: canopy trees, tall regeneration, and short regeneration. Any tree that was part of the canopy at its highest point was included in the canopy class. Any individual that was greater than 1.4 meters in height and not in the canopy was considered a tall regeneration. Short regeneration included trees that were less than 1.4 meters tall.

Despite the fact that eastern hemlock and northern white cedar populations were the main focus of this study, a considerable amount of balsam fir trees (*Abies balsamea*) were found in the understory of these forests. As a result, balsam firs were included in the population surveys done at each site. In order to survey the populations, the number of individuals of each species were tallied on each plot. Separate counts were made for each class. Only eastern hemlock, white cedar, and balsam fir populations were tallied. Almost no other species were found within the conifer groves, with the exception of two black spruce individuals (*Picea mariana*) and one sugar maple.

For the size/age distribution and climate analysis, two eastern hemlock and two white cedar individuals were cored at each plot using an increment borer. The diameter at breast height (DBH) was also measured for each tree cored using DBH tape. While individuals were selected to be cored as randomly as possible, the trees needed to have certain qualifications. Individuals had to have a DBH of at least 20 centimeters, they had to be part of the canopy, and they had to be living. In addition, selected trees could not show signs of fungal growth or have any visible scars on the bark, and they could not have branches at the height from which the core would be taken. Each of these attributes could have a negative impact on the quality of the core taken from the tree. The process of taking cores from a tree can put the tree at risk of disease or fungal growth, so individuals were carefully selected, and every core taken from a tree was analyzed.

Once cores had been removed from trees, they were mounted, sanded and counted under a microscope so that the minimum age of the tree could be determined. The length of every ten rings was measured using a ruler and microscope, starting with the period of 2009-2018 and going through 1919-1928. These measurements were used to analyze the amount of growth that occurred in one decade for an individual tree.

For the climate analysis, data on annual precipitation and average temperature was downloaded from the National Oceanic and Atmospheric Association website. Data was combined from four different locations close to UNDERC property (Minocqua, WI; Ironwood, MI; Stambaugh, MI; Watersmeet, MI) because there were no close locations with complete records. Data was found for the years 1910 through 2018. For every decade counted on the tree rings, the average annual precipitation and average temperature per year was calculated.

Statistics were run on the data collected using R Studio software. Chi-squared tests were used to determine whether there was a statistically significant difference in relative abundance of species in each class across the three locations. Correlations were run to test whether a relationship existed between the diameter and the minimum age of the trees that were cored. Each tree cored was analyzed individually using correlations to see how it responded to changes in average precipitation and temperature. Because the data was found to be non-normal (Shapiro-Wilks test) and it could not be transformed, the Spearman method was used for every correlation run.

## Results

A significant difference in relative species abundance between eastern hemlock, white cedar, and balsam fir was found in the canopy class of conifer groves across UNDERC property

(X = 10.57, p = 0.03). Eastern hemlock and white cedar had a higher number of individuals compared to balsam fir (Table 1). Similarly, a significant difference in relative species abundance was found in the tall regeneration class (X = 50.745, p = 2.52e-10). In all three locations, the abundance of white cedars was lower than the abundance of eastern hemlock and balsam fir in this class (Table 2). The Crampton Lake location differs from the other two locations in this instance because it contains more hemlock regeneration, while balsam fir dominates this class at Plum and Tenderfoot Lakes. A significant difference in relative species abundance was also measured in the short regeneration class (X = 46.775, p = 1.69e-09). Once again, the abundance of white cedar regeneration was very low compared to the abundance of the other species studied (Table 3). Balsam fir dominated this size class at Plum and Tenderfoot Lakes, but hemlocks were more abundant at Crampton Lake.

No significant correlation was found between the minimum age and the DBH of eastern hemlock trees (t = 0.79, p = 0.44). Figure 1 represents a graphic depiction of the relationship between hemlock DBH and the minimum age calculated from the tree core. As evident by the extremely low R-squared value, no conclusions about the relationship between these two measurements can be made. Because the middle of the tree was not reached on some of the hemlock cores, Figure 2 represents the same relationship but with incomplete cores excluded. While the R-squared value in Figure 2 is slightly higher, there is still no observable correlation between hemlock DBH and minimum age. Results were also inconclusive for the relationship between white cedar minimum age and DBH (t = .34, p = 0.74). Figures 3 and 4 represent a graphic relationship between the cedar minimum age and DBH, with incomplete cores included and excluded respectively. The low R-squared values on both graphs indicate that very little of the data is explained by the trendline and that no relationship between the two measurements was observed.

No significant relationship could be found between tree growth, precipitation, and temperature for eastern hemlocks and white cedars. Of the twelve hemlock individuals tested, two displayed a significant correlation with precipitation ($p = 0.06$, $p = 0.06$) and one displayed a significant correlation with temperature ($p = 0.03$). Two out of twelve white cedars displayed significant growth response to precipitation ($p = 0.08$, $p = 0.02$), while four displayed significant response to temperature ($p = 0.06$, $p = 0.08$, $p = 0.08$, $p = 0.09$). In the case of a Spearman correlation test, a significant result means that as the independent variable increases or decreases, the dependent variable will correspondingly increase or decrease. A p-value of 0.1 was used as the standard for statistical significance because so many different ecosystem factors can alter the growth rate of an individual tree. Figures 5-12 represent the variety of relationships that were found between climate and the growth of hemlocks and white cedars. For each tree species, three individuals were selected and graphed so that examples of significant and insignificant relationships could be displayed. Figures 5 through 8 represent eastern hemlocks, while Figures 9 through 12 represent white cedars. While a few individuals of each species demonstrated significant correlations between growth and climate, no conclusions can be made about how eastern hemlock and white cedar species respond to changes in precipitation and temperature.

## Discussion

The population survey found that eastern hemlock trees are regenerating at a higher rate than white cedar trees, confirming the initial hypothesis. This finding supports the conclusion reached by Gengarelly and Lee (2006), in which eastern hemlock was regenerating faster than atlantic white cedar. Olsen and Wagner (1993) also recorded limited white cedar recruitment from seedlings into saplings. This result may indicate that white cedar has a lower tolerance of understory conditions than hemlock, as white cedars germinate best in disturbed soils with partial shading and constant moisture (Larouche and Ruel 2015). The groves studied were heavily shaded and undisturbed; it is possible that the environmental conditions favored hemlock development despite the fact that both species are relatively understory tolerant. The lack of white cedar regeneration observed suggests that, in the future, cedar populations in northern Wisconsin conifer groves are likely to decline.

Balsam fir was found to be the dominant species in the understory at the Plum and Tenderfoot Lake locations. This was not an expected result, as balsam fir was only included in the species analysis based on in-field observations of its abundance. The abundance of balsam fir is in part due to its opportunistic form of regeneration; it rapidly reproduces as a way to outcompete other tree species (Olsen and Wagner 1993). This strategy allows balsam fir individuals to take advantage of canopy gaps when they appear by growing more rapidly than other conifer species. The results of this study suggest that this process is occurring in the conifer groves of both Plum and Tenderfoot lake, as the abundance of balsam fir was significantly greater than that of either eastern hemlock or white cedar. This may mean that the balsam fir populations may overtake the populations of hemlock and white cedar at these locations.

Another explanation for the higher abundance of balsam fir is that both eastern hemlock and white cedar are preferred food sources for white-tailed deer (Palik et. al 2015, Borgmann et. al 1999). Browsing has been shown to have a significant negative impact on the development and success of white cedar seedlings (Larouche and Ruel 2015). Interestingly, balsam fir dominance in the understory can promote the development of hemlock saplings. One study found that the density and height of hemlock saplings significantly increased when they grew within balsam fir patches (Borgmann et. al 1999). It is possible that an abundance of balsam fir in the understory of hemlock-dominated groves will provide a “physical or visual barrier” that will protect hemlock saplings from browsing (Borgmann et. al 1999). The dominance of balsam fir in the understory will have mixed impacts on the hemlock populations, as it will both protect hemlock saplings from browsing and threaten hemlocks through competition.

The Crampton Lake location differed in understory composition from the other two sites. While balsam fir regeneration was very abundant at Plum and Tenderfoot, eastern hemlock dominated the tall and short regeneration classes at Crampton. There are a number of possible explanations for this difference. The hemlock grove at Crampton was more isolated—it was on a peninsula rather than the shoreline—so it’s possible that browsing had a lower impact on tree regeneration. This would put eastern hemlock at an advantage over balsam fir, but it would not explain the low abundance of white cedar. The Crampton Lake grove was also much larger than the other two groves studied; the hemlocks here may have stronger control over the microclimate (Martin and Goebel 2012) due to their higher population size. Finally, the most obvious explanation is simply that the Crampton grove is at a different stage of development compared to the other two groves. Given the species composition of Plum and Tenderfoot and the fact that balsam fir populations rapidly expand and regenerate into new regions (Olsen and Wagner 1993), the balsam fir population at Crampton may expand and dominate the understory in the future.

As hypothesized, no relationship was found between the diameter and age of hemlock and white cedar trees in the canopy. This suggests that size cannot be used as an accurate approximation of an individual’s age within this population. No relationship was found between these two measurements because competition between individuals leads to major differences in the growth rate. One study conducted on douglas fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), and western red cedar (*Thuja plicata*) found that competition over light and soil nutrients was the strongest growth-limiting factor for individual trees (Harrington 2006). In addition, the impact of browsing likely varied across the individual eastern hemlocks and white cedars tested in this study. Herbivore browsing limits tree growth because needle consumption reduces the amount of energy available to a tree by reducing the tree's ability to photosynthesize. While the hypothesis being tested was confirmed by the results in this experiment, further studies should be conducted with a larger sample size and greater variety of tree sizes. Because the guidelines were so specific for trees selected for coring, all trees analyzed were within 20-44cm in diameter. A larger and more diverse sample size would provide a more accurate correlation between tree size and age.

Contrary to the original hypothesis for the climate analysis, no significant relationship was found between climate conditions and the growth of eastern hemlock and white cedar. While a few of the individual trees analyzed did demonstrate a significant correlation, no conclusions could be made as to how temperature and precipitation affects the growth of these species. This may be due to the small sample size used in this analysis; however, there are a number of other reasons no significant relationship was found. As stated previously, competition between individuals has the strongest impact on tree growth, so changes in light and nutrient availability over time may have negated any effects that climate conditions had on tree growth. In addition, eastern hemlock's strong effect on habitat microclimate (Martin and Goebel 2012) may reduce the amount that the individuals experienced changes in climate. In future studies, a larger sample size may allow a relationship between temperature and precipitation to be seen. In addition, other climate measurements can be compared to tree growth, including the annual snowfall and maximum/minimum yearly temperature. Understanding how eastern hemlock and white cedar populations will respond to climate conditions—and how these populations interact with each other in Wisconsin conifer groves—is important because both populations are at risk from a number of different threats including overbrowsing and invasives (Martin and Goebel 2012). A better understanding of these populations may allow them to be better managed and protected as climate change begins to have an increasing impact on the species composition of Great Lakes forests.

## Tables

Table 1: Canopy Species Abundance by Location. Depicts the number of individuals of each species in the canopy at each location. Data was taken and combined from each of the two plots at each location. A chi-squared test found the differences in relative species abundance to be significant (X = 10.57, p = 0.03).

| | **Plum** | **Tenderfoot** | **Crampton** |
|---|---|---|---|
| **Hemlock** | **41** | **20** | **20** |
| **White Cedar** | **8** | **26** | **23** |
| **Balsam Fir** | **2** | **2** | **4** |

Table 2: Tall Regeneration Species Abundance by Location. Depicts the number of individuals of each species in the tall regeneration class at each location. Data was taken and combined from each of the two plots at each location. A chi-squared test found the differences in relative species abundance to be significant (X = 50.745, p = 2.52e-10).

| | **Plum** | **Tenderfoot** | **Crampton** |
|---|---|---|---|
| **Hemlock** | **35** | **1** | **71** |
| **White Cedar** | **1** | **5** | **2** |
| **Balsam Fir** | **70** | **70** | **22** |

Table 3: Short Regeneration Species Abundance by Location. Depicts the number of individuals of each species in the short regeneration class at each location. Data was taken and combined from each of the two plots at each location. A chi-squared test found the differences in relative species abundance to be significant (X = 46.775, p = 1.69e-09).

| | **Plum** | **Tenderfoot** | **Crampton** |
|---|---|---|---|
| **Hemlock** | **137** | **17** | **117** |
| **White Cedar** | **0** | **2** | **2** |
| **Balsam Fir** | **210** | **68** | **35** |

## Figures

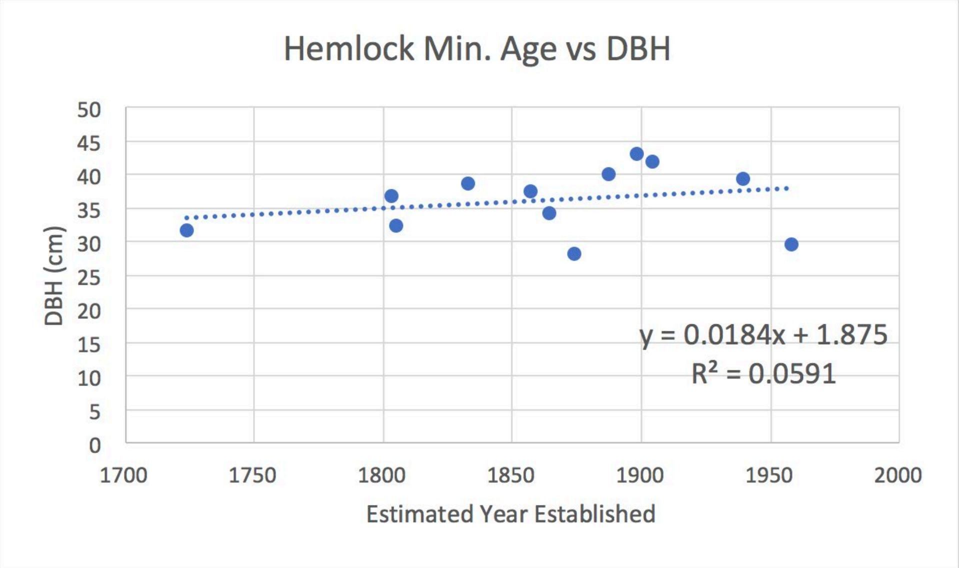

Figure 1: Relationship between Estimated Hemlock Age and Measured DBH. Trendline represents the linear relationship observed, but low R-squared value indicates that trendline does

not accurately explain the data. A Spearman correlation was run which determined that the relationship between these two measurements was not significant (t = 0.79, p = 0.44).

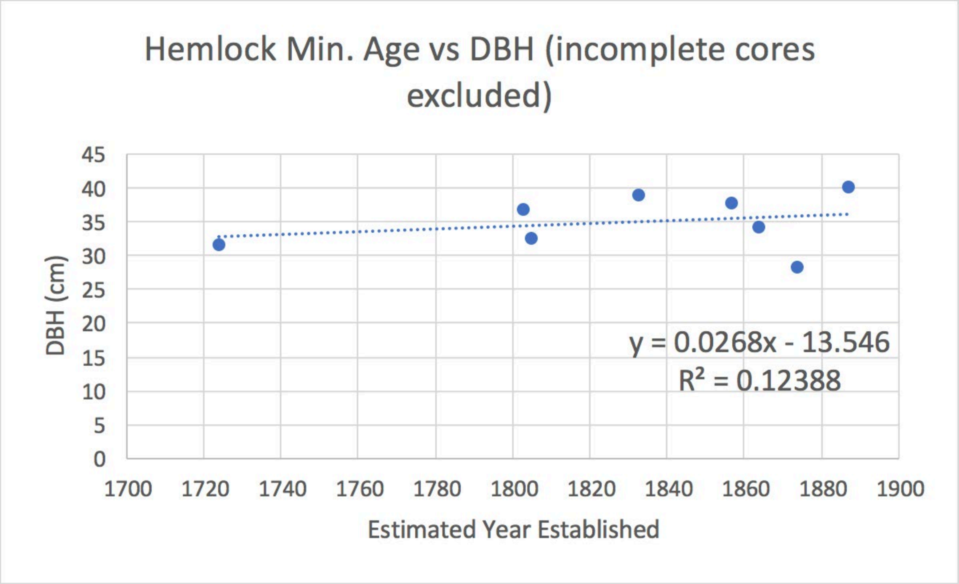

Figure 2: Relationship between Estimated Hemlock Age and Measured DBH, with Incomplete Cores Excluded. R-squared value is slightly higher than the value in Figure 1, but the trendline observed here still does not accurately explain the data.

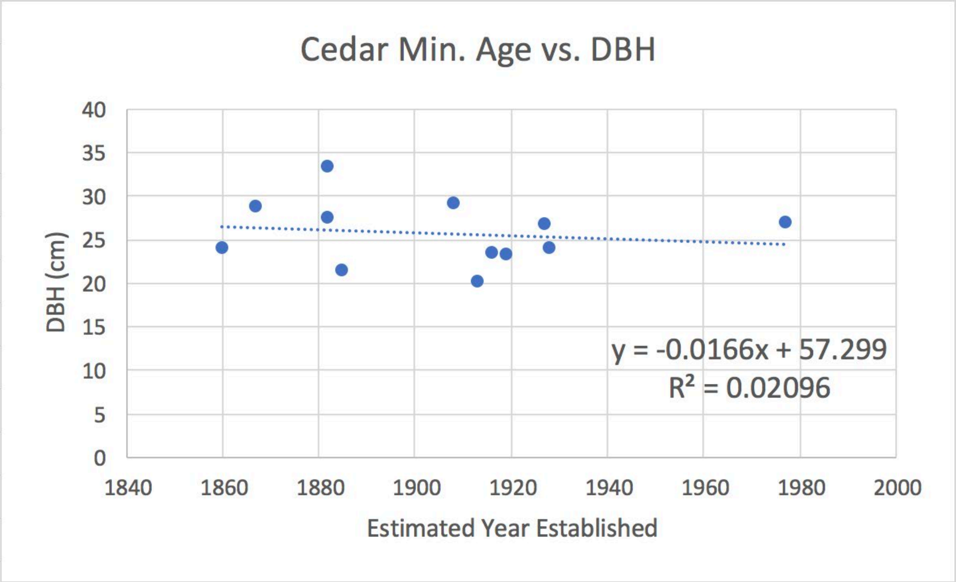

Figure 3: Relationship between Estimated White Cedar Age and Measured DBH. Trendline represents the linear relationship observed, but low R-squared value indicates that trendline does not accurately explain the data. A Spearman correlation was run which determined that the relationship between these two measurements was not significant (t = .34, p = 0.74).

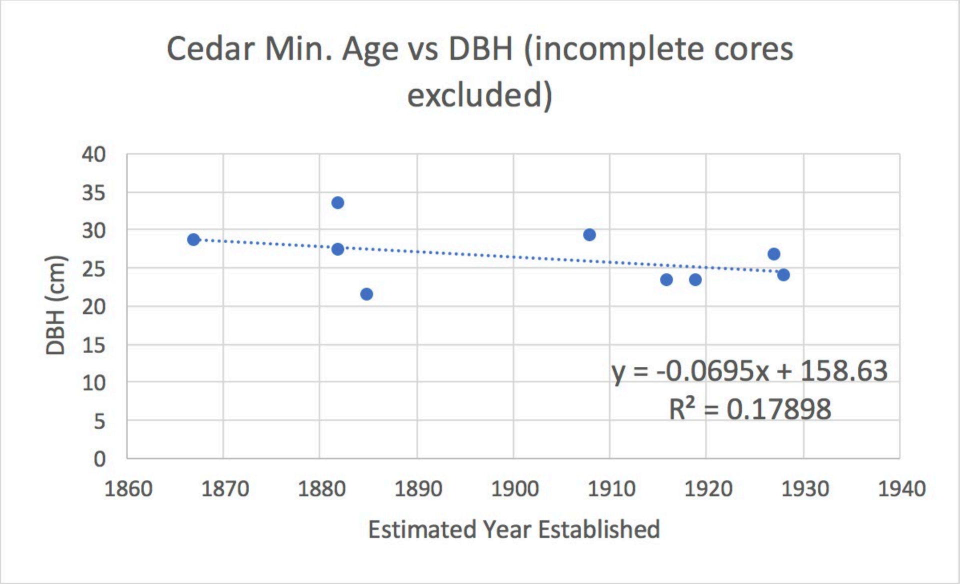

Figure 4: Relationship between Estimated White Cedar Age and Measured DBH, with Incomplete Cores Excluded. R-squared value is slightly higher than to the value in Figure 3, but the trendline observed here still does not accurately explain the data.

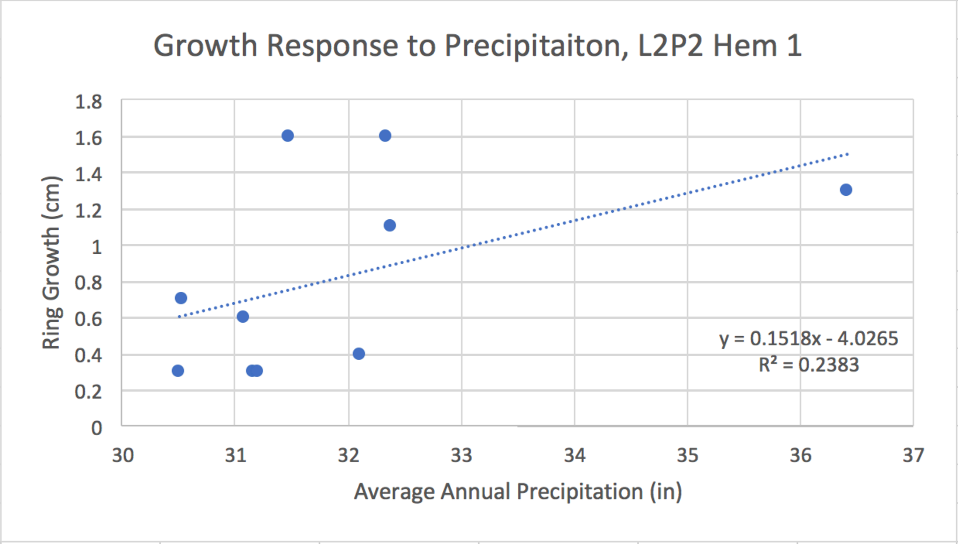

Figure 5: Graphic Depiction of Growth Response to Precipitation by Hemlock 1 on Location 2, Plot 2. An example of a strong correlation between hemlock growth and climate data. A Spearman correlation determined that this relationship was significant ($p = 0.06$). A visual relationship can be observed; as precipitation increases, growth generally increases.

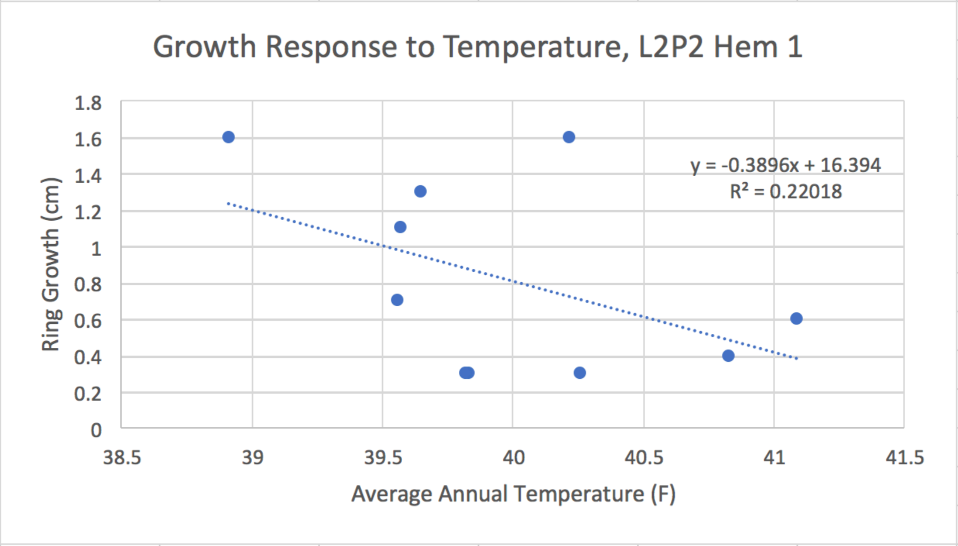

Figure 6: Graphic Depiction of Growth Response to Temperature by Hemlock 1 on Location 2, Plot 2. A Spearman correlation determined that this relationship was not significant (p = 0.17). However, a slight visual relationship between growth and temperature can be observed; as temperature increases, growth generally decreases.

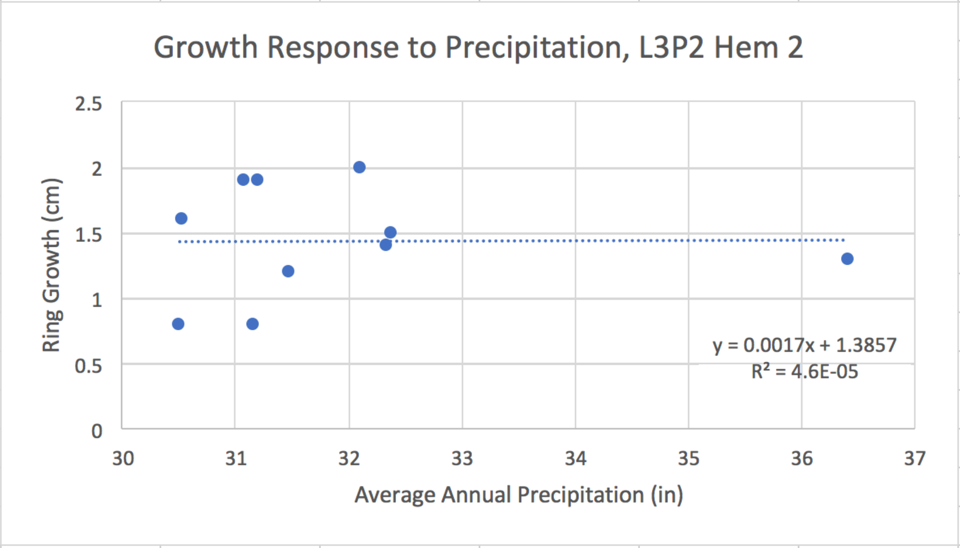

Figure 7: Graphic Depiction of Growth Response to Precipitation by Hemlock 2 on Location 3, Plot 2. An example of no correlation between growth and climate data. A Spearman correlation

determined that this relationship was not significant (p = 0.76). No visual relationship can be observed between growth and precipitation.

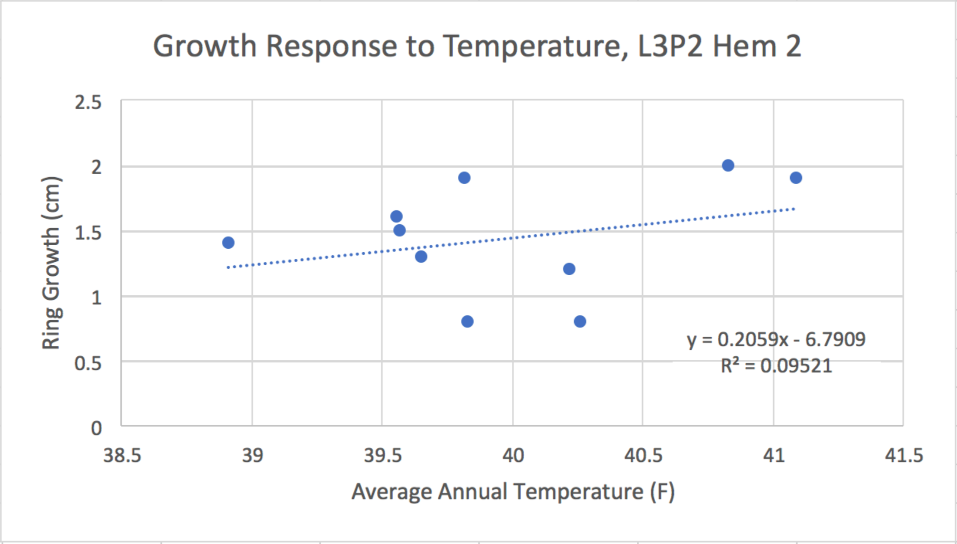

Figure 8: Graphic Depiction of Growth Response to Temperature by Hemlock 2 on Location 3, Plot 2. An example of no correlation between growth and climate data. A Spearman correlation determined that this relationship was not significant (p = 0.73). However, a slight visual relationship can still be observed between growth and temperature.

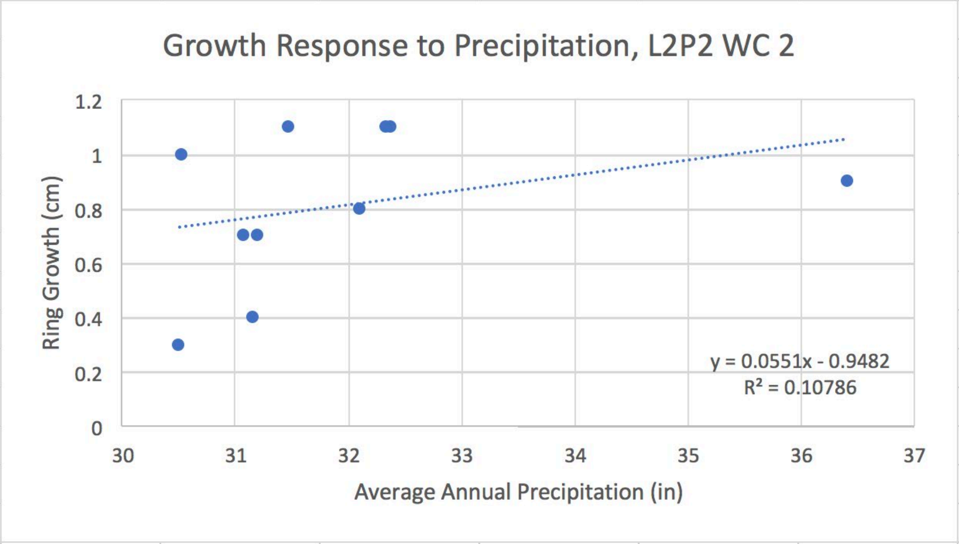

Figure 9: Graphic Depiction of Growth Response to Precipitation by White Cedar 2 on Location 2, Plot 2. An example of a strong correlation between white cedar growth and climate data. A Spearman correlation determined that this relationship was significant (p = 0.05). A visual relationship can be observed; as precipitation increases, growth generally increases.

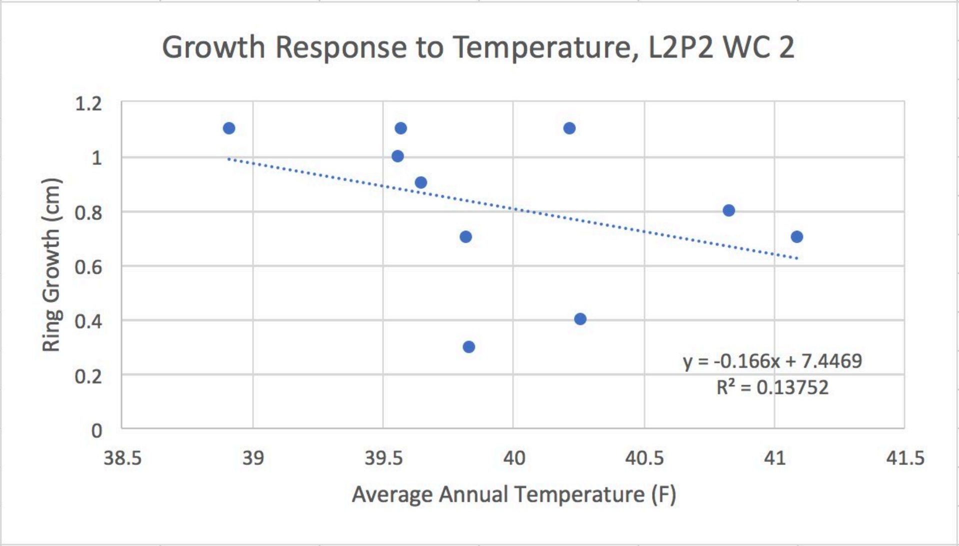

Figure 10: Graphic Depiction of Growth Response to Temperature by White Cedar 2 on Location 2, Plot 2. An example of a slight correlation between white cedar growth and climate data. A Spearman correlation determined that this relationship was significant (p = 0.08). A visual relationship can be observed; as precipitation increases, growth generally decreases.

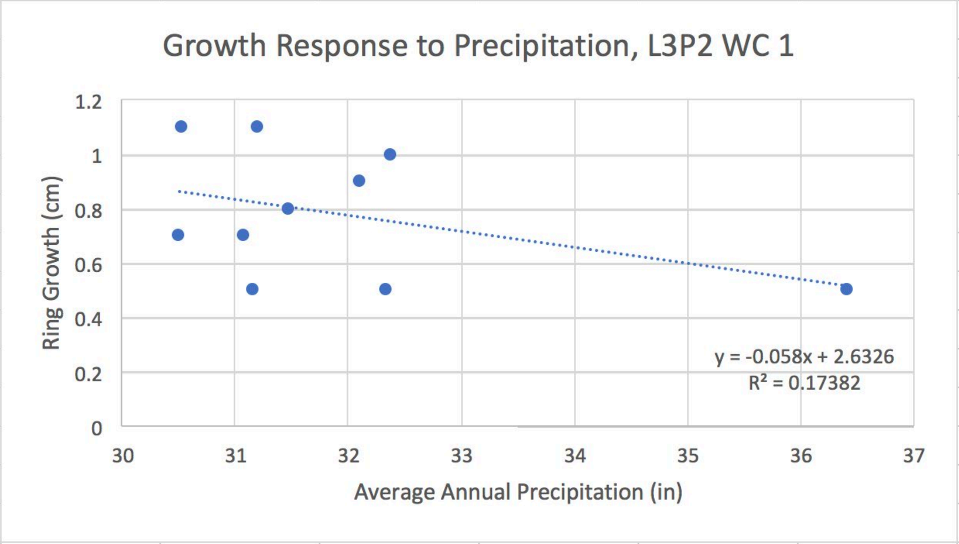

Figure 11: Graphic Depiction of Growth Response to Precipitation by White Cedar 1 on Location 3, Plot 2. An example of no correlation between growth and climate data. A Spearman correlation determined that this relationship was not significant ($p = 0.56$). However, a slight visual relationship can still be observed between growth and precipitation.

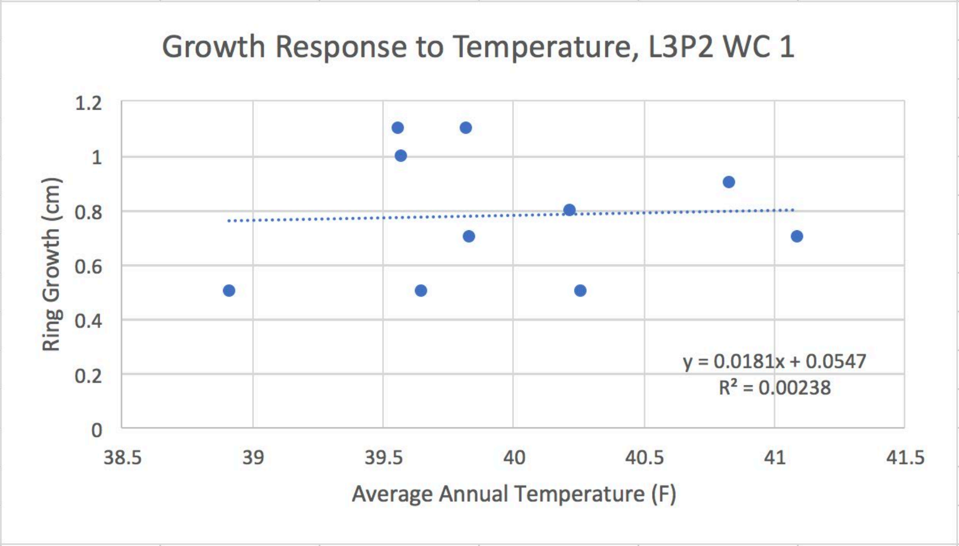

Figure 12: Graphic Depiction of Growth Response to Temperature by White Cedar 1 on Location 3, Plot 2. An example of no correlation between growth and climate data. A Spearman

correlation determined that this relationship was not significant (p = 0.75). No visual relationship can be observed between growth and precipitation.

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