# Tree Health and Productivity in the Context of Climate Change: Incorporating Eastern white pine (*Pinus strobus*) into an existing dendrochronology database

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**Abstract:** University of Vermont students enrolled in Dendrochronology (GEOG 244) collected Eastern white pine (*Pinus strobus*) tree core sampled from two sites in Chittenden County—Centennial Woods and Shelburne Farms. Using dendrochronology lab and field techniques, data and core samples were analysed and added to an existing dendrochronology database. White pine was selected in order to complement current research investigating potential impacts of acid deposition and/or climate change on red spruce (*Picea rubens*; DeHayes et al., 2016). Students compared regional climate data to ring width increment and basal area increment. Statistical analysis was conducted using Microsoft Excel, COFECHA, J2X, and ARSTAN. Several known historical disturbance events appeared to strongly correlate with RWI from both sites and climate variables correlated somewhat to BAI data from both sites. Overall increases in growth over the past few decades mirrored that of red spruce and may have suggested that red spruce growth rebounds were more closely related to climatic variables

**Keywords:** Dendrochronology, Tree rings, Eastern white pine.

## I. Introduction

The Dendrochronology Database, constructed by the U.S. Forest Service (USFS) and the University of Vermont Geography Department, contains data gathered from tree core samples from an array of species. Some data has already been used to assess temporal and spatial trends regarding red spruce (*Picea rubens*) growth (Engel et al., 2016). The study showed that the species is now growing much better than it has in decades; with growth trends showing a promising rebound from its previous decline. The researchers have two theories as to what could have caused the recent rebound in red spruce. They believe that it was caused either by the increased growing season brought on by increased temperatures, or a reduction in acid deposition, which red spruce is sensitive to. While evidence derived from red spruce tree cores indicates that this species is sensitive to acid deposition associated soil cation loss (DeHayes et al., 1999), additional data from other temperate conifer species could help to reveal if the increase in growth was mainly due to a change in climate or acid deposition.

Eastern white pine (*Pinus strobus*) is another locally available temperate conifer species. However, it is not known to be sensitive to acid deposition. Studying the recent growth trends of Eastern white pine could help determine if acid deposition was the main factor influencing the spruce rebound. If the Eastern white pine did not show signs of increased growth, then it would be more likely that the reduction in acid deposition was the cause of rebounded growth.

This information was gathered and analyzed using dendrochronological techniques. The Dendrochronology (GEOG 244) course at the University of Vermont sampled Eastern white pine (*Pinus strobus)* from two field sites in the Champlain Valley and prepared the tree cores so that the data could be incorporated into an existing database. This was necessary in order to bolster the current Dendrochronology Database. More samples must be added regularly in order to strengthen the chronologies in this region.

## II. Methods

### Study area:

Targeted sampling was used to identify two appropriate study sites due to access and time limitations. Sites in Chittenden County with a large number of mature Eastern white pines were selected because Eastern white pine was the targeted species and locations in Chittenden County were easily accessible to the students. The two sites sampled were Centennial Woods (CW), owned by the University of Vermont, and Shelburne Farms (SF), a local agriculture and education non-profit (Figure 1).  Cores collected from Centennial Woods were located within an Eastern hemlock (*Tsuga canadensis*) and Eastern white pine dominated stand with some hardwood inclusions on a roughly 30° northwest-facing slope. Five stands were sampled at Shelburne Farms in which Eastern white pine was primarily available for sampling along and near forest edges adjacent to fields rather than in the forest interior.

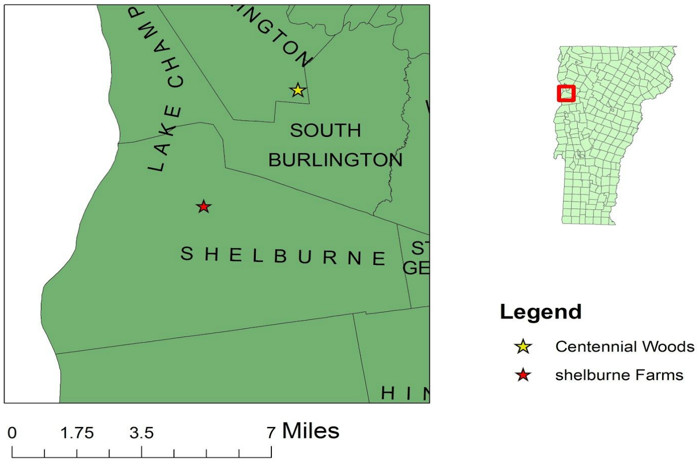

**Figure 1.** Locus map of study sites

## Field Methods

At each field site, trees sampled were selected based on crown class. Dominant and co-dominant trees were chosen because they had less competition than smaller trees so that growth would be less regulated by stand-level effects. Diameter (cm) was measured at breast height (1.3 meters above the ground) for each tree. Two increment cores were taken from each tree (Appendix 1) at breast height and perpendicular to the slope to prevent sampling of compression wood (Speer, 2010). Cores were placed in individual straws, labeled, and taped securely in the field.

## Lab Methods

In the lab, cores were dried in an oven for 24 hours, glued to wooden core mounts, and sanded to a flat surface using increasingly fine sandpaper (120-800 grit). Tree rings were then counted using a sliding scale Nikon 0.001mm resolution microscope. After that, the list method was used to preliminarily cross date the cores according to standard dendrochonological procedure (Speer 2010; Stokes and Smiley, 1968). Ring-widths were measured using a stage micrometer with a 0.001mm accuracy and Measure J2X software.

Analysis produced time series of raw ring width (RWI) measurements and basal area increment (BAI) data for each core and stand. Students compared the data gathered with local climate data, gathered from the PRISM Climate Group, in order to distinguish how important changes in weather patterns impact tree ring growth. Data were also compared to important historical disturbance events to identify any visually apparent links to tree growth patterns.

## III. Results

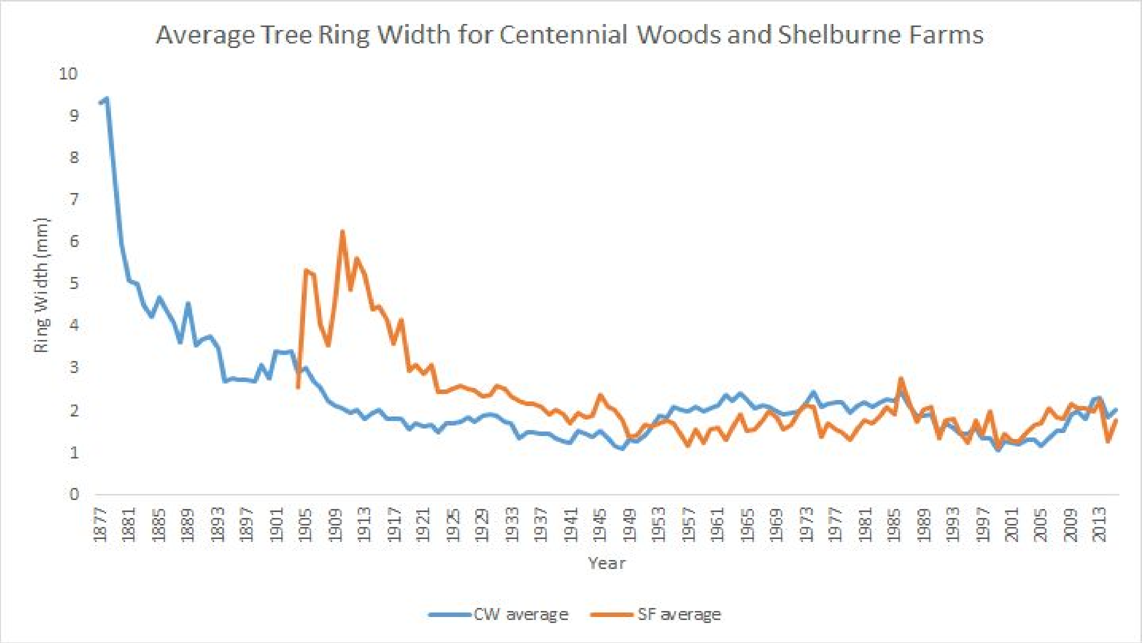

**Figure 2.** Average raw tree ring widths of both sites over time shown in millimeters.

Ring width index (RWI) is a measure of the width of every year's ring within a core sample, also known as "raw" ring width data. RWI data was collected for every core and averaged across both sites (Figure 2). This average RWI series was also detrended and standardized using ARSTAN to remove some long-term variation in growth, which was more likely due to tree age or stand-level effects rather than climatic variables (NCDC, 2015). Detrended and standardized RWI averages for both sites are presented in Figure 3, which presents the deviation from the mean of the chronology for each year's growth so that values above 1 represent above average growth, and values below 1 represent below-average growth (NCDC, 2015).

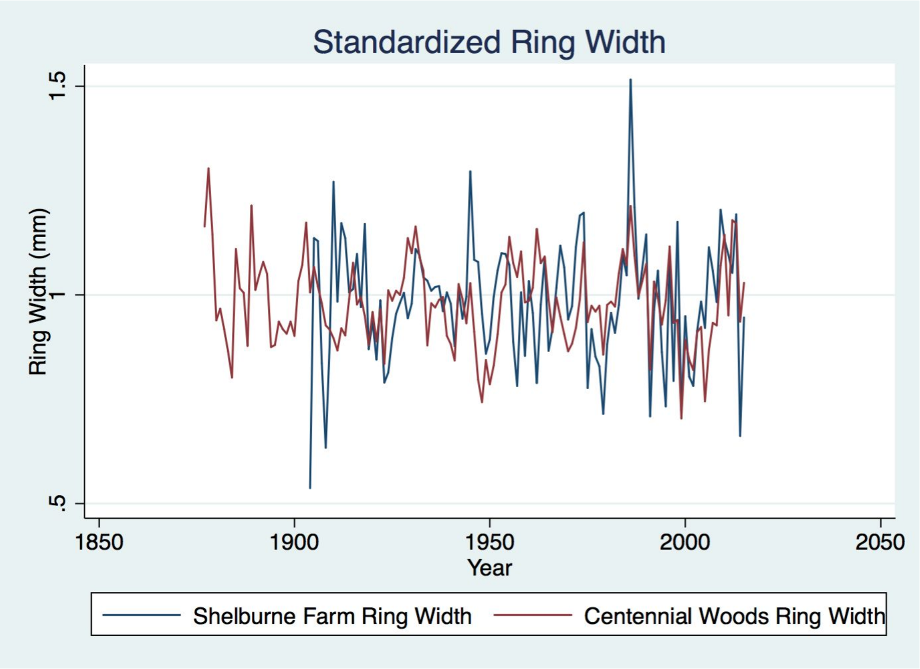

**Figure 3.** Standardized ring width indices for SF and CW averages over time.

Ring width indices for both chronologies, when averaged across the stand, showed wide variation over time. Figure 3, however, provides at least anecdotal evidence of correlation between the chronologies. Figure 3 also displays several locations where multiple years across both sites demonstrated marked growth trends, such as below-average growth at roughly 1915-1925, 1975-1985, and 2000-2010. Above-average growth trends also appeared at roughly 1930-1935, 1987-1993, and 2008-2013. In CW there was also dramatically productive growth at roughly 1875, which is potentially explained by the very young age of the trees sampled. Particularly unproductive years included roughly 1948, 1999, and 2007. SF demonstrated dramatically increased productivity around 1910, 1945, and 1985, and particularly unproductive years included roughly 1903, 1908, 1980, 1992, and 2014.

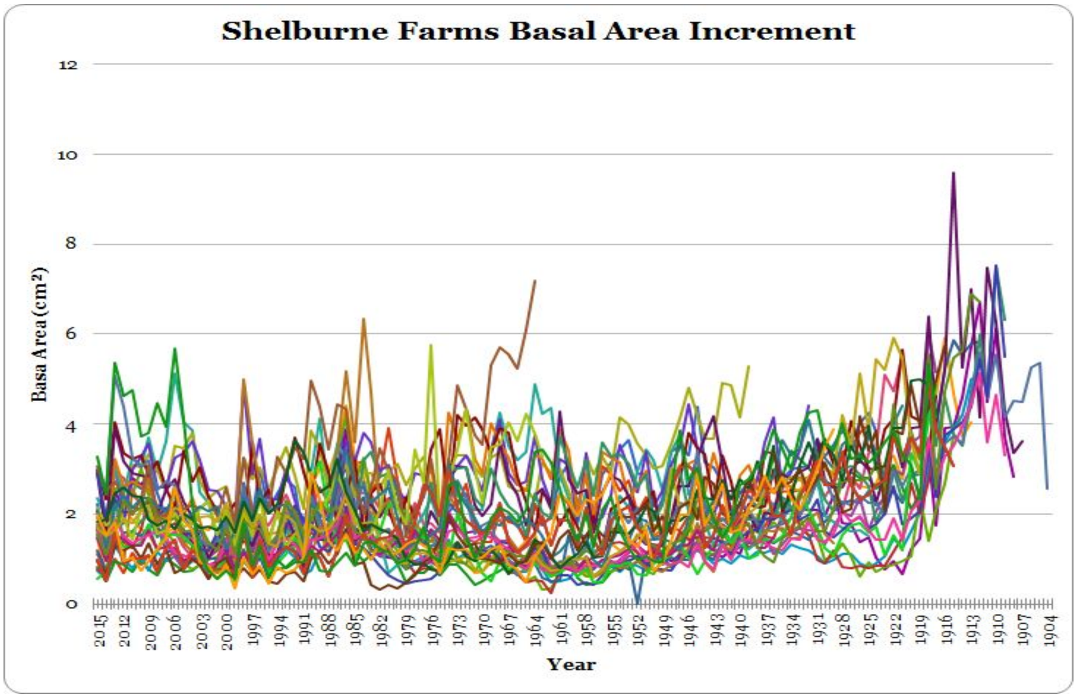

**Figure 4.** Shelburne Farms Basal Area Increment for all cores over time.

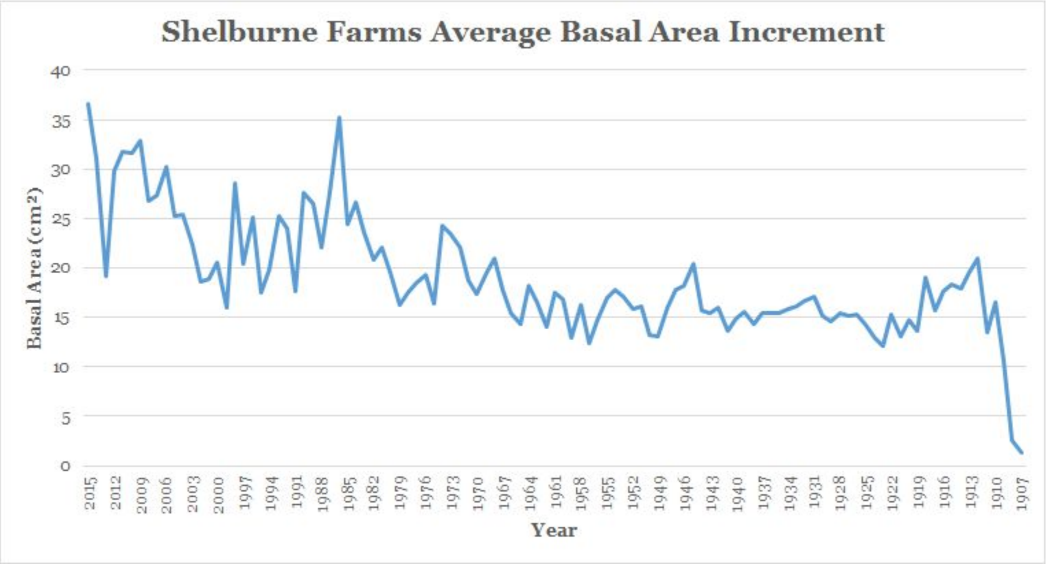

**Figure 5.** Shelburne Farms average Basal Area Increment over time.

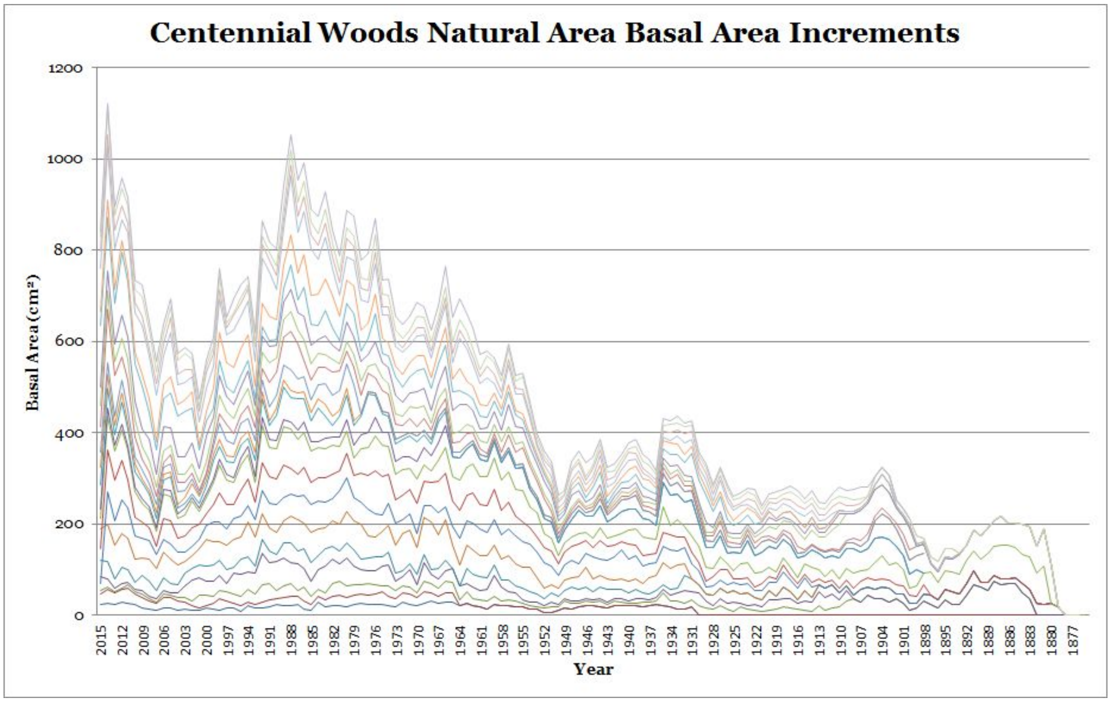

**Figure 6.** Centennial Woods Basal Area Increment for all cores over time.

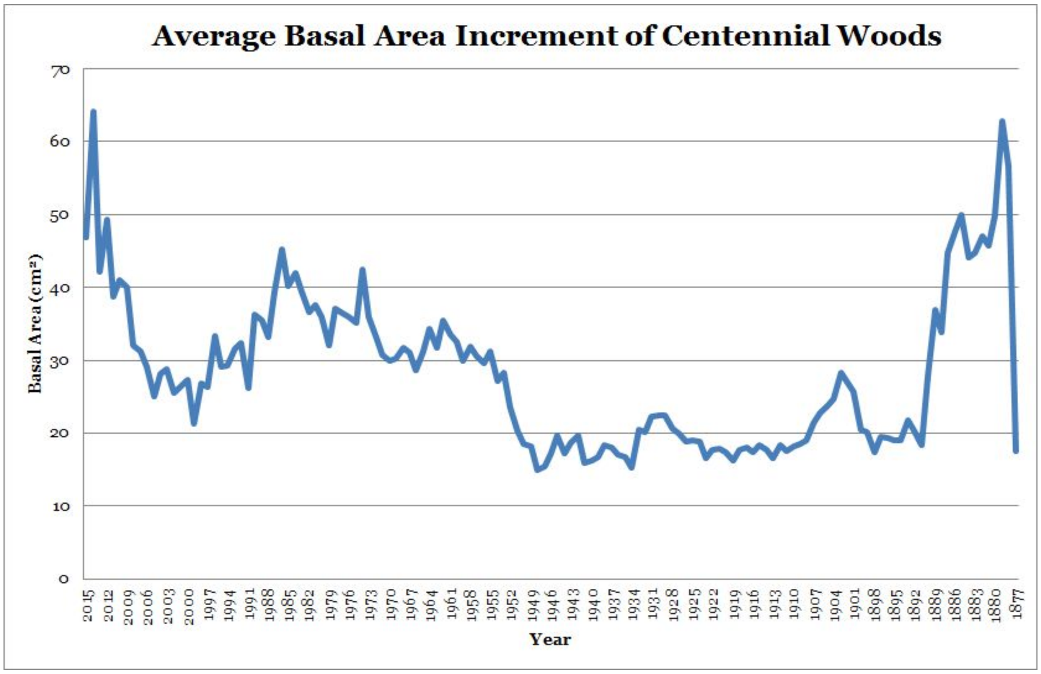

**Figure 7.** Centennial Woods average Basal Area Increment over time.

BAI was calculated for each growth ring in every core sample. BAI is a measure of the area (cm$^2$) added to the tree each year, based on the core sample's ring widths and the tree's DBH. BAI chronologies for all core samples in CW and SF are presented in Figures 4 and 6. Average BAI chronologies for each stand are presented in Figures 5 and 7 and were fitted to linear regression trend lines using Microsoft Excel (Figure 8.) BAI is used in further analyses, rather than RWI, because this measurement cancels out variation in ring widths occurring as a tree ages and wider girth causes the same amount of growth to be spread thinner over a wider trunk. BAI is a more accurate measure of volume added to the tree as a result of other variables including climate and exogenous and endogenous effects.

BAI trends are not very well correlated to RWI, but some years of dramatically increased or decreased growth in Figures 5 and 7 do match those in Figure 3, for instance an increase in growth in CW from 2010-2012 and a decrease in growth in SF before 1915. This disconnect is not unexpected considering the significant effect that tree diameter has on ring width. The decrease CW growth in 1999 is likely due, at least in part, to damage from the 1998 ice storm. Similarly, an increase in growth in 2010 and 2012 in CW could also be attributed to an ice storm in 2008, which may have released those trees that survived significant damage from competition.

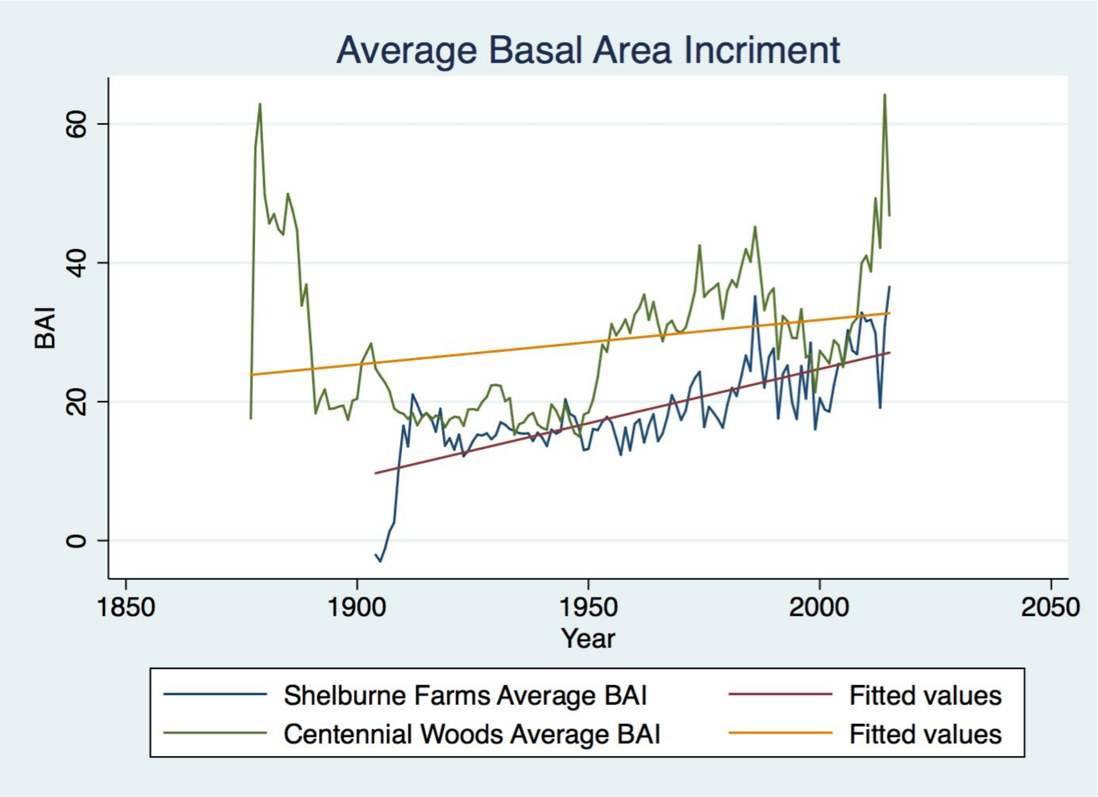

**Figure 8.** Shelburne Farms and Centennial Woods Average BAI with fitted linear regression line.

**Table 1.** COFECHA output statistics

| | Centennial Woods | Shelburne Farms |
|---|---|---|
| Total # Cores | 39 | 35 |
| Total Rings Counted and Measured | 4,157 | 3,327 |
| Date Range of Chronology | 1877-2015 | 1904-2015 |
| Total Years Covered | 139 | 112 |
| Mean Chronology Length (Years) | 106.6 | 95 |
| Series Intercorrelation | 0.415 | 0.549 |
| Average Mean Sensitivity | 0.261 | 0.218 |

Series Intercorrelation is a measure of the strength of the signal (typically the climate signal) common to all sampled trees at the site. It is the average correlation of each series (individual core) with a master chronology derived from all other series (entire stand). The lowest values for trees that can still be reliably cross-dated are around 0.400. Most chronologies have values between 0.550 and 0.750 (Grissino-Mayer, 2008). Average Mean Sensitivity is the relative change in ring-width from one year to the next and varies from around 0.650 (for very drought-sensitive conifers) to 0.150 for the most complacent trees (Grissino-Mayer, 2008). While mean sensitivity is not a measure of the chronology's utility for climate reconstruction, it is a good measure of the relative ease of cross-dating (Grissino-Mayer, 2008).

## IV. Climate Data

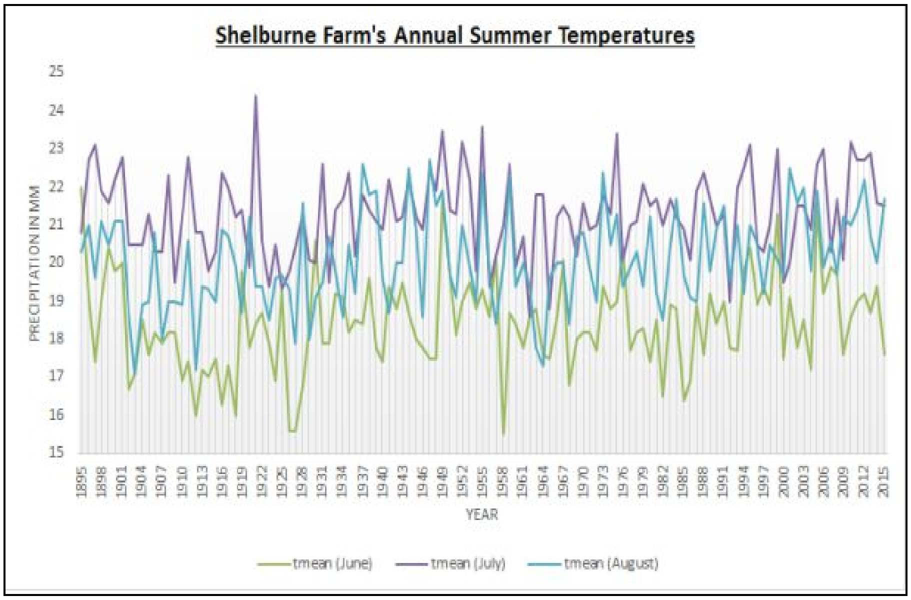

**Figure 6.** Graph of the annual average three month summer temperatures (°C) recorded for Shelburne Farms from 1895 to 2015.

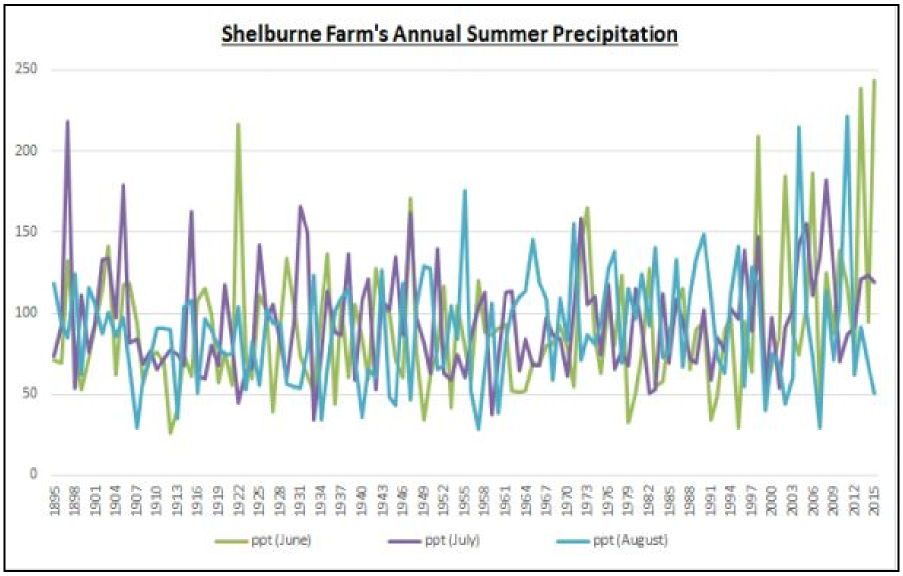

**Figure 7.** Graph of Shelburne Farm's annual summer precipitation from 1895 to 2015, y-axis is shown in millimeters.

**Table 2.** R values describe correlation significance between monthly measurements of climate variables and BAI values of study sites over the course of the chronology's time scale.

| SITE | CORRELATION | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEPT | OCT | AVG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SF | Mean Monthly Temperature | 0.126 | 0.061 | 0.149 | 0.290 | -0.036 | -0.272 | 0.012 | 0.038 | -0.004 | 0.033 | 0.040 |
| CW | Mean Monthly Temperature | 0.071 | 0.064 | 0.193 | 0.098 | -0.007 | -0.175 | -0.188 | -0.132 | -0.134 | -0.046 | -0.026 |
| SF | Monthly Precipitation | 0.089 | 0.095 | 0.031 | 0.039 | 0.331 | 0.262 | 0.220 | 0.036 | -0.023 | 0.028 | 0.111 |
| CW | Monthly Precipitation | -0.067 | -0.106 | -0.043 | 0.052 | 0.132 | 0.157 | 0.176 | 0.034 | -0.075 | 0.057 | 0.032 |

## V. Discussion

Centennial Woods and Shelburne Farms contained tree-ring chronologies that ranged from 1877 and 1904 to present (2015) covering a total of 139 and 112 years, respectively. Additionally, the mean length of individual cores within each site differed by nearly 10 years between CW and SF, 106.6 and 95 years respectively (Table 1). This is a direct result of land use and time of germination.

Temperature and precipitation patterns had a direct impact on tree growth from year-to-year. When environmental conditions were most optimal for tree growth, rings were wide. When disturbance events occurred, such as the 1998 ice storm, tree growth declined and resulted in the formation of narrow rings (Figure 2). The 1998 ice storm noticeably affected the growth trends of the tree stands. Overall comparison of the correlation between BAI and the growing months for the entire time series showed a few general growth trends. Positive R values showed a positive linear relationship between variables; this could be seen in most of the R values for SF, with only the month of September having a slight negatively correlated (Figure 2). In the month of April, both SF and CW had positive BAI growth trends during a time of increased precipitation. For both SF and CW the R value for September displayed a negative correlation between the temperature, precipitation, and overall BAI. The average R values for SF mean monthly temperature were slightly positive, at 0.040, while the average monthly precipitation was more positive, at 0.111. The average R values for CW signified a negatively trending monthly temperature, at -0.026; which implied a negative correlation between temperature and BAI. The R-value for monthly precipitation for CW was trending positive at 0.023. Overall, positive correlation values of BAI growth were associated with higher trendlines in temperature and precipitation during the growing season. It was unclear whether Lake Champlain had any effect on temperature or precipitation in the Shelburne Farms data.

Interseries correlation was not a measure of a chronology's utility for climate reconstruction. It could be possible that a chronology with a low series intercorrelation could contain a very useful climate signal. Series intercorrelation was an important consideration in assessing chronology quality. Chronologies with low interseries correlation required a larger sample size to maintain reliability (Grissino-Mayer, 2008). Internal stand variation in such a small bank of cores may have created outliers which dramatically affected the interseries correlation. Cores were carefully analyzed before disposing from the correlation and were only taken out for extreme measures. Six of the 40 cores sampled were removed from the chronology before running tree-ring widths through COFECHA due to the fact that measuring errors caused some cores to not correlate with the master chronology of the entire stand. As a consequence, the results remained unskewed through mitigation of human error.

Centennial Woods is an urban forest that is owned by the University of Vermont. The university acquired the site in pieces, from 1891-1968 (UVM Libraries). According to a guide published by the University, most of the Eastern white pine in Centennial Woods was established after farmland was abandoned in the mid-late 1800's. Therefore, the trees that were used from this site were likely the result of old field succession. Shelburne Farms was purchased by the wealthy Webb family in the late 1800's, who planted many Eastern white pine trees around the main farm building around 1900 (Huyler Donnis 2010). In addition to the planted individuals many of the trees that were sampled at Shelburne Farms probably also originated from old-field succession. Some of the differences between the two chronologies could be accounted for by the difference in the sites. Shelburne farms has been managed as an agricultural landscape for the past 120 years, whereas Centennial Woods has been treated as an urban forest since UVM acquired it. Natural stand dynamics would have less impact on the trees that were planted than those that naturally regenerated.

In analysis of aggregate BAI growth trends over the course of the sampling period, an apparent trend of increasing growth manifested itself following a decadal period of stasis. Around the year 1950, BAI seemed to adopt a sudden, steady trend of increase in both the Shelburne Farms and Centennial Woods samples. This contradicted the traditional school of thought for overall stand growth; wherein corroborative evidence suggested that forest ecosystem growth peaks during a period of successionary colonization and initial canopy development,  followed by collective stand decline with increasing age (Binkley et al., 2002). The data displayed in Figure 8 seemed to support the more recent evidence that while stand level growth may decline, individual tree growth increases with age (Stephenson et al. 2014). The decline in stand growth was attributed to individual resource-use efficiency, competition, and variable stand dynamics with time (Binkley et al., 2002).

In accordance with historic planting and establishment trends, it would appear that a portion of trees at both Centennial Woods and Shelburne Farms began a period of canopy establishment towards the 1950's in conjunction with age-related increases in growth rate of the larger trees sampled. This could signify that varied-age sampling led to the mitigation of statistical growth and productivity declines through conjunction of two different stages of increased growth. With changes in stand dominance and structure over time, growth trends may cycle back into decline.

## VI. Conclusion

Using the data collected we were able to accurately determine that Eastern white pine (*Pinus strobus*) responded to environmental and climatic variables. Temperature and precipitation demonstrated noticeable correlation with BAI growth during the growing season over the course of the chronology, with key anomalies pointing to direct relation. The 1998 ice storm was highly apparent throughout both site chronologies, leading to diminished growth over the decade following its occurrence. In regards to overall trends, physiological area acquisition seemed to increase dramatically near 1950 after a period of relative equilibrium. This could be attributed to the combinative effects of increased growth associated with canopy establishment and age.

This information could be used by industry or academic stakeholders (dendrochronologists, land-use managers, dendrologists, climatologists, etc.) to inform future research and to contribute to understanding changes to the health of northeastern forests. Better understanding the growth trends of various species in response to disturbance events and climatic variation can help researchers and land managers to predict future conditions in response to various climate change projections. Also, utilizing data from different species provides a certain kind of replication because each species will respond differently to environmental signals (Speer, 2010), so having a diversity of species represented within the Dendrochronology Database will be valuable in future research efforts.

Our contributions incorporated white pine into the existing Dendrochronology Database, which could be useful in future reconstruction research in regards to climate or other environmental variables. Correlations were assessed between climate data and basal area increments, and relationships derived between all acquired data.

The overarching culmination of this project successfully addressed the assumption that recent red spruce growth rebound could be more significantly related to climate change than changes in acid deposition. This assumption was supported by Figures 5 and 7, which demonstrate marked growth increases over the past few decades, similar to observed patterns in red spruce (Engel et al., 2016).

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## Appendix

Photo 1. Student, Jake, collecting an Eastern white pine tree-core.

Photo 2. Student-researchers in Dendrochronology (GEOG 244).

Photo 3. Student, Ethan Cross, collecting tree-core samples.