Anthropogenic temperature increases and its effects on *Pinus resinosa* growth

Through the creation of research facilities, residential areas, and road building, humans have the potential to transform the surrounding environment. Our study focused on the impact that the construction and subsequent expansion of the Biological Station has had on the growth of Red pine, *Pinus resinosa*. To determine if the Biological Station has had any impact, we analyzed tree cores from the Biological Station and a site upwind at grapevine point that had the same soil type and was unaffected by humans. We developed a series of statistical tests to compare soil pH, soil organic material, light availability, and temperature, between the two sites to determine if any of these influences impacted tree growth. We found that growth is greater within the Biological Station and that temperature, soil pH, and light availability are sources of differing growth. The Biological Station is a small model of the possible changes that humans can induce on tree species, which may be amplified in a larger setting

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Projected climate warming will potentially have profound effects on the earth's biota, including a large redistribution of tree species (Iverson, 1998). According to the Intergovernmental Panel on Climate Change (IPCC), global mean temperatures will continue to increase by 1.4° to 5.8°C in the next one-hundred years (Xu, 2007). In the Great Lakes region Conifer forests have gradually been replaced by broad-leaf species due to logging, forest fires, and natural forest regeneration which have occurred over the last 100-150 years. Recent research shows that land use change legacies can have profound influences on the nature of regeneration that occurs (Foster et al., 2003). Under some environments, removal of forest cover and resulting alteration of the physical environment strongly inhibits forest regeneration (Mallik, 2005, Schulte et al, 2007). Activities such as building construction, logging, and increased habitat fragmentation due to road building, may degrade surrounding forest.

The University of Michigan owns approximately 10,000 acres dedicated to the study and understanding of a constantly changing environment, called the Biological Station. At the station, researchers, students, and staff constantly fluctuate in and out of the residential and research areas throughout the year. With the inception of the Biological Station in 1909, numerous changes were made to the surrounding landscape, including land clearance and building construction, to accommodate for people in the area. Building of research facilities and living accommodations could have changed temperatures, soil composition, or canopy coverage, all affecting the growth of Red Pine within the station. Consequently, the objective of this paper is to demonstrate the human interactions that could have influenced tree growth, more specifically Red pine, within the Biological Station compared to pine populations in the surrounding forest.

The Red pine, *Pinus resinosa,* is native to northern Michigan, and is a member of the Pinaceae family. When glaciers that once covered northern Michigan retreated, they left behind varying landscapes, many of which are outwash plains. Outwash plains are flat areas immediately downstream of a moraine where glacial run-off in meltwater streams have deposited larger particles carried from the moraine (Karowe, 2008). Outwash plains are often composed of sandy soils, and due to their large particle size, do not retain water or cations very well. These dry conditions help create a more acidic soil and are characteristic of soils with low to moderate fertility. These conditions are optimal for Red pine growth (Flannigan, 1998). The optimal soil pH range for red pine is from 4.5 to 6.0 and is a major determinate of growth (Rudolf, 1990). Soil acidity can be influenced by the amount of organic material overlaying the soil, which can be affected by the frequent clearing of debris within the Biological Station thus indirectly influencing growth if Red pines favor a certain soil pH range (Sheller & Mladenoff 2005). Red pine is intolerant of shade and requires easy access to sunlight to grow, as well as partial removal of the canopy for regeneration (Flannigan, 1998). In the Biological Station there exist many populations of Red pine, whose growth since the initiation of the Biological Station in 1909, may have been altered as a result of landscape modification, in the form of roads and walkway formations, and other disturbances. These factors invariably alter canopy coverage, soil pH and average temperatures within the station compared to the surrounding forest landscape.

Our study focuses on what impact the construction and subsequent expansion of the Biological Station might have on the local Red pine populations. We chose to study Red pine because they grow rapidly, are easy to core, and are native to northern Michigan. To determine differences in Red pine growth between the Biological Station and our control site, we compared (1) temperature differences over a period of five days, (2) the distance between tree rings and diameter at breast height, (3) canopy coverage, (4) soil pH values, and (5) soil organic layer. By using comparisons of growth patterns between Red pine within the Biological Station and in a nearby control site, we can determine what role the Biological Station may have on Red pine growth.

The objectives of the present study are: (1) to determine if differences exist between Red pine growth in the Biological Station compared to Red pine in the control site, (2) to test if temperatures within the Biological Station differ between those in the control site, (3) to measure whether light availability within the Biological Station differs from light availability in the control site, (4) to determine if soil pH in the Biological Station differs from that in the control site, (5) to measure the soil organic material and see if it differs from the soil organic material in the control site , and (6) to test if Red pine diameter at breast height (DBH) correlates with Red pine age within the Biological Station.

In order to answer if there is a difference in growth between trees in the Biological Station and trees on our control site, we tested several variables which are listed above. We hypothesize that these variables are directly or indirectly related to the construction and expansion of the Biological Station and its facilities. The first variable we tested was temperature differences. Optimal average winter temperatures for Red pine are -23^{o} C to -40 ^{o} C, with summer temperatures of 32^{o} C to 38^{o} C (Rudolf, 1990). We expect that there may be increased growth of Red pines within the Biological Station than in our control site since the buildings and roads within the station absorb more heat than the surrounding forest. The second variable we tested was differences in light availability between the two sites. A previous study found that the species is intolerant of shade and requires at least partial removal of the canopy for regeneration (Flannigan, 1998). We expect that trees within the Biological Station will have increased growth compared to those in the control site since previous land clearing practices exhibited by the Biological Station opened up the canopy allowing for increased light availability.

High acidity of soil materials is not conducive to growth and development of the root system of Red pine, which shows the importance of basic pH for growth (Mallik, 1994). We expect that Red pine growth will be enhanced in less acidic soils as the pH range is 4.5 to 6.0 (Rudolf, 1990) . The fourth variable that was tested was the soil organic layer above the soil. Outwash plains promote vegetation tolerant to low moisture and low nutrient availability (Kennedy et. al, 1996). Since our two sites are both located on an outwash plain, we expect that increased growth will occur in the site that has a thicker soil organic layer. The final variable that we considered was diameter at breast height (DBH) and how this value correlates to tree age. Normal Red pine growth shows that this species invests many of its resources into growing laterally at its early stages, but then reallocates its resources from lateral growth to vertical growth (Butson et al, 1987). Therefore we expect that there is not a significant correlation between the size of the tree and the age of the tree.

The main question of our experiment is: Are there differences in growth between Red pines within the Biological Station and trees within the control site? To answer our main question, we asked several sub-questions, each with their our hypothesis;

- Do temperatures differ between the Biological Station and the control site?

Ho: Temperatures within the UMBS do not differ from those in the control site.

Ha: Temperatures within the UMBS do differ from those in the control site.

- Does light availability within the UMBS differ from light availability in the control site?

Ho: Light availability does not differ between the two sites.

Ha: Light availability does differ between the two sites.

- Does soil pH within the UMBS differ from soil pH in the control site?

Ho: Soil pH does not differ between the two sites.

Ha: Soil pH does differ between the two sites.

- Does the amount of soil organic material within the UMBS differ from that in the control site?

Ho: The amount of soil organic material does not differ between the two sites.

Ha: The amount of soil organic material does differ between the two sites.

- Does the thickness of the Red pine (DBH) correlate with age within the UMBS?

Ho: DBH has no relationship with age.

Ha: DBH has a relationship with age.

Materials and Methods

Study Sites

In order to determine whether human influences within the Biological Station have an effect on Red pine growth we needed to establish a control site for comparison. Many factors contributed to the selection of a control site, beginning with soil composition. We looked at soil surveys of the Douglas Lake region to determine a site that had Rubicon sand, which is a soil that is characteristically dry, sandy and excessively drained, to ensure that both samples of Red pine are growing in the same soil. Not only did the soil have to be the same but the site needed to be west, upwind of the Biological Station, so that the control site was protected from biotic affects, such as humans, induced by the Biological Station. We found a site three-fourths of a mile west within the surrounding forest that met these two conditions. The Red pines found within the control site are in a more dense forest, split on either side of a walking trail, surrounded mainly by Sugar Maples and Birch trees. The topography of the control site is fairly steep and Red pines are the dominant species in the area.

Within the Biological Station we chose three spots that were all within 50 feet of buildings or human disturbances such as roads, parking lots, and residential living. Most of the Red pines within the Biological Station were surrounded by a mix of species of trees, but less crowded. The Biological Station was split into three sub- groups, East, West, and South (North is Douglas lake), to see if there were any localized affects on tree growth within the Biological Station. Ten Red pines from each of the East, West, and South regions were selected, a sample size of thirty distributed evenly throughout the site would give us the most accurate measure of growth in various regions. We were particularly interested in weather and if there were any temperature differences carried by the wind that could be detected. The wind of northern Michigan moves west to east, therefore, if the Biological Station is having affects on temperature it would be carried west and have influences on trees in the west. For this reasoning, we chose a control site in the west, as well as divided the Biological Station into sub-sites to see if there are localized affects within the Biological Station.

It was necessary to collect numerical data representing annual growth, which is represented by tree ring cores, which could be tested to determine if there was a difference in growth between the control site and experimental (UMBS) site. To chronicle tree growth, we used tree corers to acquire samples of cores to study the tree rings. Thirty cores were taken from the experimental site and 30 from the control, all of which were at breast height and all core samples reached the center the tree. Once the samples had been collected, they were glued onto cardboard and set to dry for four days. To make the rings easier to read, they were sanded and subsequently analyzed under a dissection microscope. Analysis includes measuring the distance between each tree ring in millimeters, starting from the center of the tree and working outwards, as well as counting the number of rings to gain an accurate estimate of age. The sample size of the experimental site dropped below five trees for each sub-site during the year 1970, as well as dropped below 18 for the control. We considered these numbers to be too small of a sample size to continue with tests on growth, therefore we only compared the tree growth from 2007 until 1970.

The mean growth of all trees within the control site needed to be compared to the mean growth of all trees within the Biological Station, as well as comparing the control site to each sub-site within the Biological Station, to see if there was a difference in growth of Red Pine. A Mann-Whitney U test was the most suitable test to use to make these comparisons since a non-parametric test is needed when the data is not normally distributed (giving a p-value less than .05). We decided to use absolute numbers in millimeters as our indicator of growth, instead of transforming the individual measurements of the distance between rings to percent growth of the tree. If percent growth was used, it would only take into account the amount of growth relative to the specific tree itself, and we would not be able to compare that value to trees from other sites, as this would further confound the variability of age. DBH (diameter at breast height) of each tree was measured to see if there was a particular growth pattern of Red pines that correlates to age. We narrowed our choice of trees to a DBH of 18-36cm range in order to reduce the effects of age. To account for the varying ages of the trees an ANOVA test was also used to better determine if the difference of mean growth was independent of age. This test corrected against the confounding effect of age that could be influencing growth differences.

To test our hypothesis that there is a difference in temperatures between the two sites, temperature readings were taken for two weeks using eye-button thermometers, beginning May 21st and ending June fourth. One thermometer was placed on a central tree in the control site, as well as one placed in the middle of our experimental site. After two weeks temperatures were recorded and graphed to show the comparison of each site. In order to see if there was a difference in temperature between the two sites, a paired-samples T-test was used. This statistical test was used because we were comparing specific times at which the temperatures were taken during each day, in the control and experimental sites. Further temperature readings were taken between June fourth and June eighth, with ten eye-buttons placed in each of the two sites at breast-height, facing north, in order to get more accurate measures of temperature variation. To compare the mean temperatures for each day in each site, we checked for normality of the temperatures from the three days using an ANOVA. An ANOVA test allows us to compare means of multiple variables, which was necessary since we had three days to analyze. All three days were considered normally distributed (giving a p-value less than .05), and showed a difference due to chance, therefore a T-test was used to compare the temperatures between the two sites at 8AM, 2PM, and 8PM, to see if there was a significance in the temperature differences. Temperatures taken in the morning, afternoon, and evening were chosen in order to give the largest sample size across the longest portion of the day, as well during the times in which the trees are actively photosynthesizing. Therefore, we can accurately test to see if there is a difference in temperatures between the control and experimental sites.

To test our hypothesis that light availability may differ between the two sites we needed to measure canopy coverage. To do this, a spherical densitometer was used at 4 locations (north, south, east, and west) in both sites. Each reading and each location consisted of four subreadings, measuring percent canopy coverage, which were then averaged to get total percent canopy coverage at the four different locations at each site. It was important to measure light availability because differing percentages could cause differences in growth between the two sites. The percentages of each site were evaluated using a Mann-Whitney U test, which allowed us to compare the means of canopy coverage.

Ten soil samples were taken from the Biological Station and the control site, which were dried, sifted, and tested for pH by using a duplex indicator, which dyes the soil to a particular color which is then matched to pH card. While acquiring soil samples, thickness of the organic layer was measured at the same ten soil sites. Organic layer measurements were also collected for comparison between the two sites. For both of these variables, we compared the means to see if either of these impact tree growth, hence another Mann-Whitney U test was used.

Results

Tree growth

Of the sixty trees analyzed, we compared the mean growth of all thirty trees in each site for each year from 1970 to 2007. Mean growth can be seen in figure 1. Stars above some years indicate p-values less than .05 for comparisons made between growth and each site using a Mann-Whitney U test. This non-parametric statistical test is used to compare means between two groups, as well as show which group has higher means, which is ideal for comparing mean growth. Having a p-value less than .05 allows us to reject our null hypothesis and show that there is a difference in mean tree growth between the Biological Station and control site. For years in which mean growth was significant, growth was consistently higher in the Biological Station. The arrows on figure 1 show the years in which age was significant, 1985, 1977, 1976, and 1974, or gave a p-value less than .05, none of which overlapped with the years that showed a difference in tree growth between the two sites.

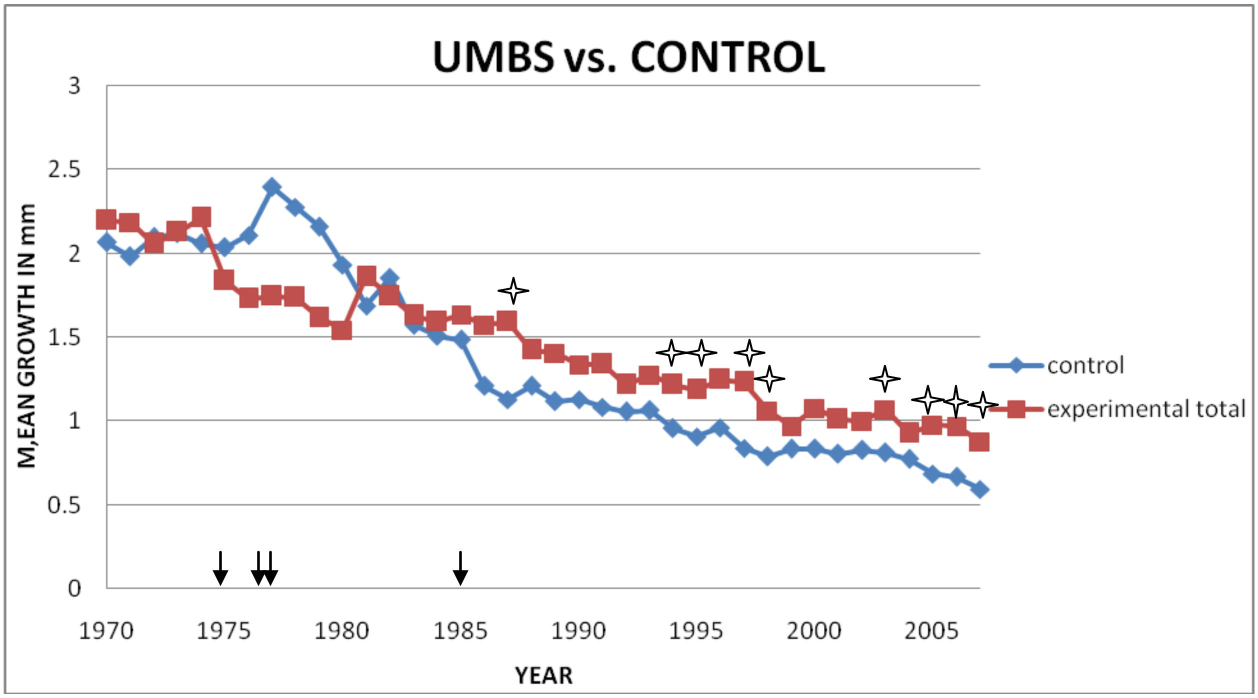

Figure 1: Biological Station tree mean growth vs. control tree mean growth (mm) from 1970 to 2007

Figures 2 shows the mean growth comparisons between the control and experimental west within the Biological Station. This graph is consistent throughout the sub-site and control site comparisons, with mean growth differing mainly in 2007, 1998, and 1997.

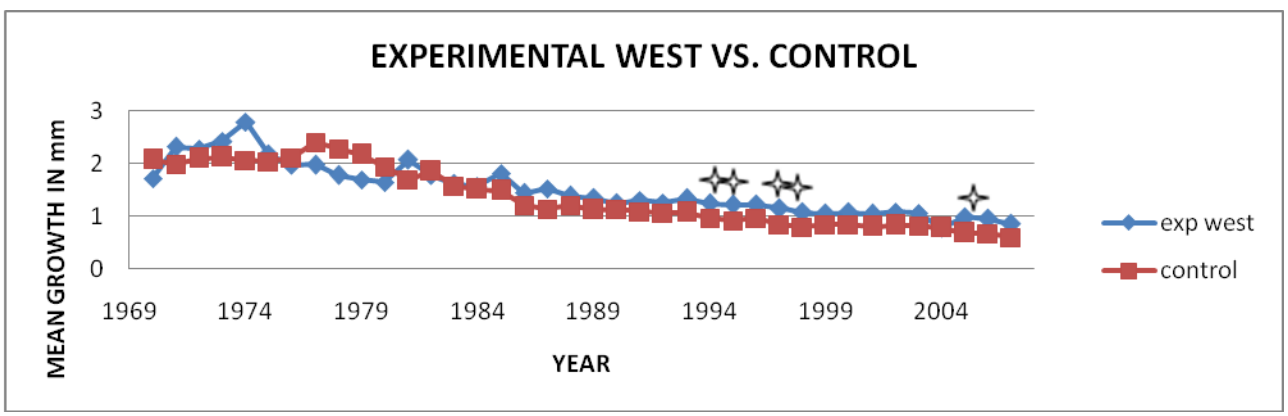

Figure 2: Experimental West mean tree growth vs. Control mean tree growth (mm) for years 1970-2007

Age differences both within and the two sites needed to be controlled to ensure that age did not play a significant role in observed differences in tree growth. An ANOVA test was performed to determine if age was a confounding variable in testing for a difference in tree growth. Figure 5 shows the average age of the experimental site (48.19) to the average age of the control site (41.8) with the average difference in age was about 6 years.

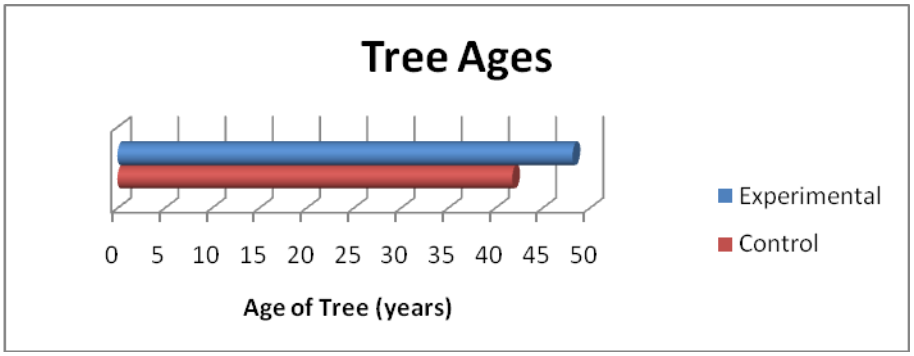

Figure 3: Average tree ages (years) of Experimental vs. Control

Temperature

Temperature readings of the control and experimental site were taken over two weeks, with average differences of 1° C. A paired samples T-test gave significant values ($p > .05$) for all readings taken over the 14 days taken at 8 AM, except for days 2, 4, 6, and 14, which gave a higher p-value. Generally, over the two weeks temperature was significant and does differ between the two sites (see figure 4). Ten eye-buttons were tested to see if there was variance between days by using an ANOVA test, which gave a p-value greater than .05; we accept our null hypothesis that the days do not differ in temperature at 8 AM, 2 PM, and 8 AM. Since there is no difference between the days, a T-test was run between the control and experimental temperature at the three different times (days being negligible). The temperature readings at 8 AM between the two sites on all three days showed no significant values, allowing us to reject our null hypothesis that there was no difference in temperature. Our 2 PM temperature readings also showed no significance and once again allowed us to reject our null hypothesis for all three days. For the last temperature readings at 8PM, comparing the temperatures of the three days showed no significance, and that the difference in temperatures was not due to chance.

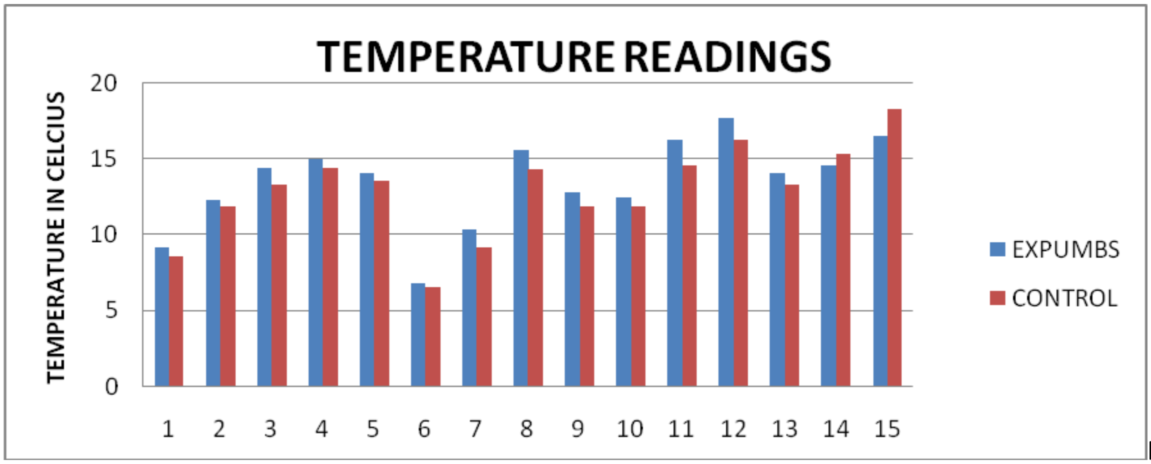

Figure
Figure 4: Daily temperature averages over two weeks in the Biological Station vs. the control site.

Light Availability

Percent canopy coverage of the control site was 91.6%, while the experimental site had 81% canopy coverage. It was necessary to compare the mean canopy coverage between sites, therefore a Mann Whitney-U test was used. This test gave us a p-value of .006, which allowed us to conclude there was a difference in canopy coverage and we could reject the null.

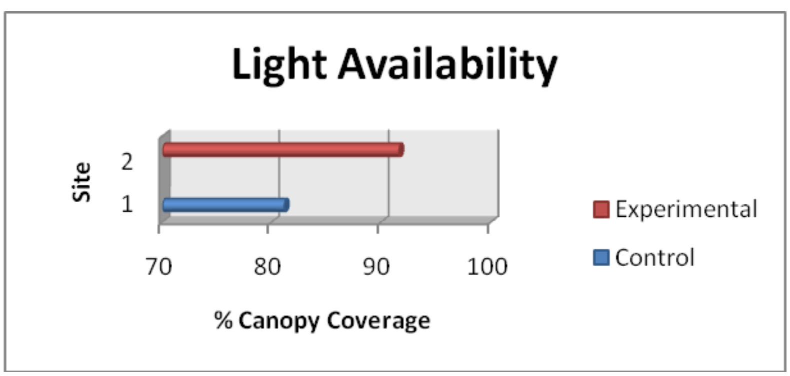

Figure 5: Percent canopy coverage

Next we wanted to compare soil pH between the two sites. Control group average pH was 4.6 and the experimental with average pH was 6.8. A Mann-Whitney U test was used to compare the means of soil pH between the control site and experimental site which gave a p-value less than .001. Therefore there is a difference in soil pH between the two sites and we can reject the null hypothesis.

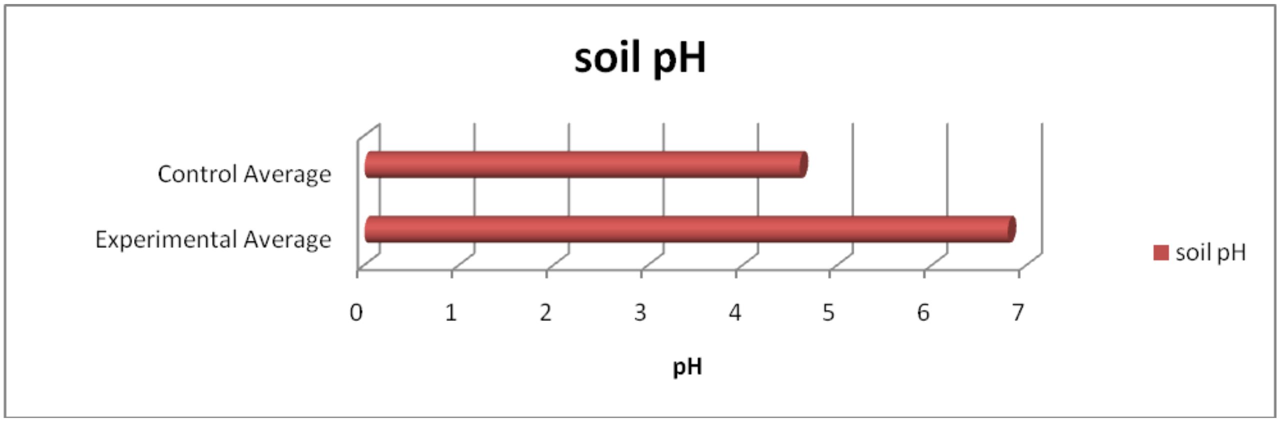

Figure 6: Average pH of control site (4.6) and experimental site (6.8)

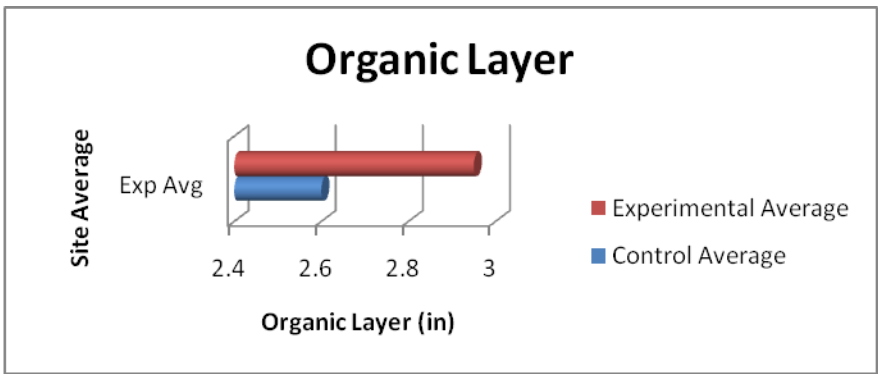

Figure 7: Mean organic layers of the control site (2.5) vs. experimental (2.9)

The means of the ten organic layer measurements were tested with a Mann-Whitney U to give a p-value of .739. We accepted our null hypothesis that there is no difference in organic layer thickness between the two sites. The experimental site averaged a 2.9 in. layer, while the control averaged 2.6 in. The differences in averages were not significant.

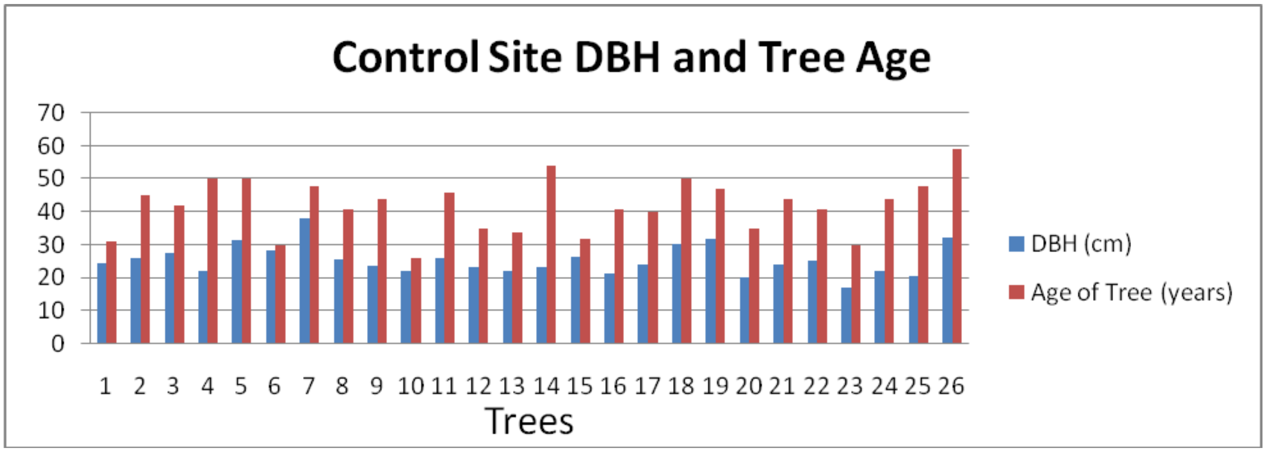

Figure 8: Differences in DBH (centimeters) and age of the tree (in years).

Our next variable to test was the relationship between DBH and tree age. As trees get older, the DBH slows and does not show a linear relationship to age (see figure 8). A Mann-Whitney U test was used to compare the mean DBH to the mean age of the control site. It yielded a p-value less than .001, therefore there is a difference between DBH and age and the null hypothesis was rejected.

Experimental Site

Once again, we needed to test the relationship between DBH and age in the experimental site by using a Mann-Whitney U test. The results of this Mann-Whitney U test showed values that were not significant. With this information, we can accept the null hypothesis that there is no correlation between DBH and age. Figure 9 shows the differences in DBH (in centimeters) and age of the tree (in years).

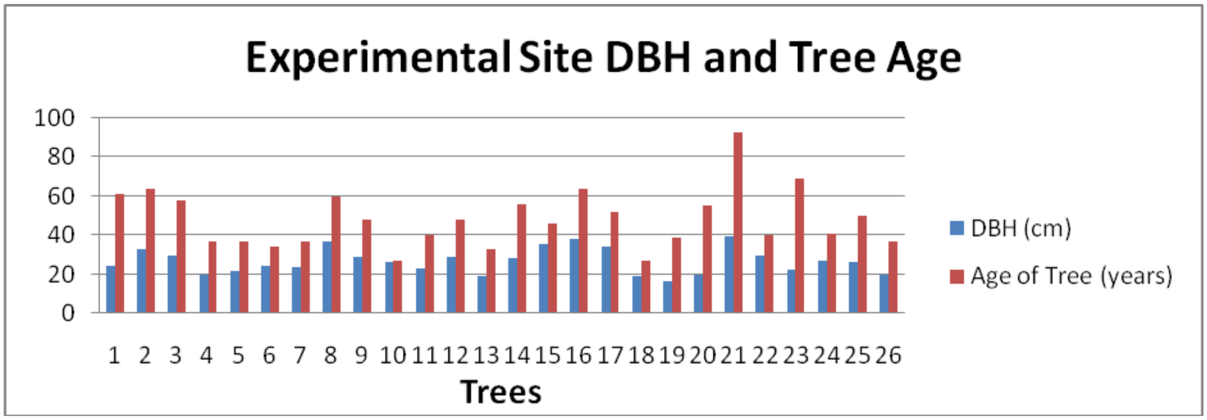

Figure 9: Experimental Site DBH (cm) compared to tree age (years) for all 26 trees

Discussion

The results of our research found a significant difference in tree growth between the Biological Station and the control site in the years: 2007, 2006, 2005, 2003, 1998, 1997, 1995, 1994, and 1987. When comparing the trees in our control site to the sub-sites in the Biological Station we found that the years 2007, 1998, and 1997 were significant in the East and West. In all nine years in which growth was significantly different between the two sites, the Biological Station Red pines had higher mean growth than the control group.

After determining that there were significant differences in tree growth, age needed to be controlled to ensure that it was not a confounding variable. Since all tree ages were not the same they could be at different stages of growth, in this case age could play a role in showing differing mean growth. For most years, age was not significantly correlated with tree growth, and the average difference in age between the two sites was only 6 years (see figure 3). There were four years, 1985, 1977, 1976, and 1974 in which age may have impacted tree growth (see figure 1). This may have occurred for the three years in the 1970's because in the year 1977 our sample size began to fall dramatically in our sub-sites from 10 to 5, due to the small number of Red pine trees present within the Biological Station. This drop in sample size causes age to be more prominent in the mean growth comparisons, and as a consequence, increases the significance of age in those years.

For the year 1985, age may have been significant because of the pattern of growth that is seen in Red pines. As age increases in Red pine, DBH begins to slow, which shows that as Red pines age the width between tree rings declines and they do not increase in diameter at a constant rate throughout their lives (see figures 8 and 9). In 1985 the observed tree ring growths may have been at an adolescent stage, where some trees were at the largest diameter expansions with maximum space in between tree rings, while others are slowing their rate of growth, and entering a time in which the space between their rings is decreasing. . Overall, between the years 1986 and 2007, our study found age was not significant in influencing growth of Red pines within the Biological Station.

Since growth showed a significance difference between the two sites for a number of years in the 1990's, we would like to know what happened in those years that would contribute to growth differences. From a previous study, we found that there was a severe gypsy moth outbreak in 1993. The prime defoliator in 1993 was the gypsy moth caterpillar, and a severe outbreak where 65% or more of the leaves are removed can cause a decrease in overall tree growth for up to three years following the outbreak (Chung et. Al, 1993). Following the gypsy moth outbreak, the Biological Station instituted leaf litter clearing, which could make the soil pH more basic since cations can no longer leach into the soil. Another factor that could have contributed to an increase in growth within the Biological Station could be the construction of a new research building in 2007, a year where growth between the two sites was statistically significant. This new building could have increased the amount of light available to the trees, or increased the surrounding temperatures by absorbing heat from the sunlight.

Our first temperature readings of a single eye-button in each site showed that temperatures significantly differ between the two sites, with the experimental site having higher mean temperatures. After finding that the two sites differ in temperature, it was necessary to take more specific temperature readings within the Biological Station and the control to ensure that temperatures within both sites are uniform. The ten eye-buttons set out for 3 days gave us a p-value less than .001, which means that our results were statistically significant, across uniform days and a uniform time period in which Red pines are most metabolically active. Due to the fact that all the experimental Red pines are within fifty feet of human influences, it is possible that these influences could be raising temperatures within the Biological Station and promoting Red pine growth.

In contrast to our findings, a previous study found that high temperatures are usually associated with low Red pine growth and low temperatures are associated with an increase in Red pine growth (Coile, 1936). In northern Michigan, we are at the southern temperature range limit, and if temperatures continue to increase throughout the region, Red pine populations may be forced to move farther north. Within the Biological Station, we found an increase in Red pine growth and also higher temperatures, which contradicts the geographical distribution of Red pine as we would expect higher temperatures to decrease growth since it is in the southern limit in this area. We believe that the other variables tested in our study may be more influential than temperature on Red pine growth. Raising temperatures are a serious concern for the distribution of Red pine populations, and previous research has attributed 58% of the mortality of red pine in plantations on the Huron National Forest to heat and 41% to the effects of drought (Rudolf, 1937).

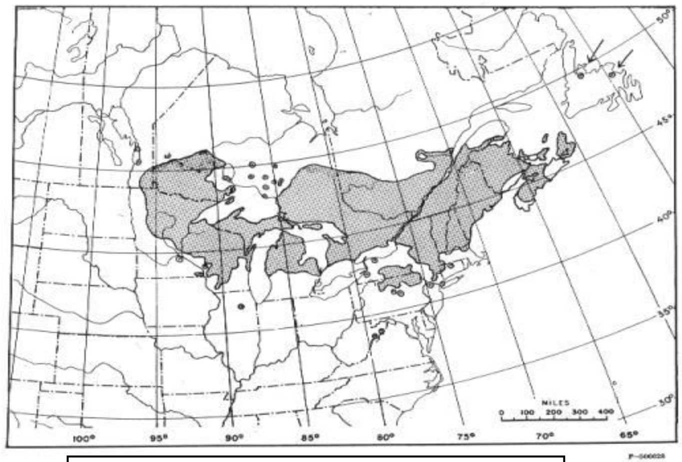

Figure 10: Range of Red Pine

Light availability differs between the two sites, and a previous study found that many northern species are shade intolerant (e.g. jack pine, red pine, paper birch) and even without climate change, these species are almost completely extirpated if adequate light for germination is absent (Scheller, 2005). The Mann-Whitney U test performed on correlating light availability between the two sites gave a p-value less than .05, allowing us to reject our null hypothesis that light availability does not differ between Red pines in the Biological Station and those in the control site. Our research found that the Biological Station has less canopy coverage than the control, with 81% and 91.6% coverage respectively (see figure 5). Due to the presence of buildings, housing, and roads within the Biological station, there is less available space for trees to grow, and therefore less canopy coverage. The control site is more densely packed with a mix of canopy tree species, and less disturbed by human influences such as buildings or roads, which allows for less light availability. The combination of human influences and less canopy competition seems to allow more light for the Red pines to allocate for growth within the Biological Station.

The acidity of the soil may be an aspect that could affect Red pine growth, but as shown in the Mann-Whitney U test comparing soil pH means between the two sites shows the difference in pH is not due to chance. The control site has a more acidic soil (4.6) while the Biological Station has a more basic soil (6.8). This difference may be because there is more leaf litter from other trees left on the forest floor in the control site, allowing for a more acidic soil through the leaching of cations into the soil, while the constant disturbance by people at the Biological Station does not allow for the same amount of leaf litter. Additionally, the lower pH of the control site is about 2 units out of the normal range of Red pine, which is 4.5 to 6.0, whereas the experimental site is on the most basic end of the Red pine's normal range, which suggests that the more basic environment due to human changes could be increasing Red pine growth (Rudolf, 1990).

Comparisons of soil organic material thicknesses in each site suggested there was no significant difference. We conclude that the difference of 0.3 in between the experimental and control is due to chance and has no influence on tree growth. One factor to consider in our sampling was that a majority of the measurements for organic layer within the Biological Station were taken from trees that were situated on top of a hill, which could contribute to the abnormal thickness of organic material overlaying the soil. We expected that the organic layer within the Biological station would be thinner than the control site due to the land clearing practices within the station, but perhaps the path that is in close proximity to our control trees has been heavily cleared of leaf litter, reducing the soil organic material thickness in the control site.

The final test that we conducted was a DBH to age correlation. We found that the two variables have no correlation with each other; older trees are not necessarily thicker. A previous study found that generally, much clearer responses to current season environmental fluctuations can be shown for diameter growth than for height growth, and after a certain age, the tree may begin to allocate its resources from diameter growth to height growth (Kozlowski et.al, 1962).

As stated previously, we attempted to control for age by narrowing our DBH range in the selected trees, but one can see that the ages of the trees varied anywhere from 25 to 93 years, which further validates our conclusion that the size of the tree does not necessarily coincide with the age of the tree (see figures 8 and 9). Varying growth patterns throughout a tree's life could be attributed to fluctuating nutrient availability from year to year, climatic differences in subsequent growing seasons, and various other factors, all of which have the potential to increase or reduce a tree's diameter by the end of its life.

At the conclusion of our study, we were able to answer our original main question; does growth differ between the two sites? We found that growth does differ between the two sites, and this growth could be due to a number of different factors. Our study found that age does not differ between the two sites and that tree growth was independent of age, with the exception of four years which do not overlap with years in which significant growth was exhibited. We also found no relationship between DBH and age, and this can be explained because trees do not consistently grow in diameter throughout their lifetimes. We found a difference in temperature between the two sites, and this can be attributed to the presence of humans, buildings, and roads within the Biological Station. Thus, temperature could affect tree growth. As a result of our study, we know that light availability differs between the two sites, and the most likely cause is the construction and expansion of the Biological Station, which cleared a large amount of land reducing the number of trees in the station. Hence, light availability could influence tree growth. We found that soil pH differs between the two sites, and we attribute more basic soil within the Biological station with leaf litter clearing practices demonstrated by the people in the Biological Station, and this could contribute to tree growth. Finally, we found that soil organic layer thickness does not differ between that two sites, and thus does not contribute to tree growth.

Conclusion

In conclusion, our study found that a few factors have the potential to influence Red pine tree growth. Relationships in growth between the Biological Station and our control site were tested against a variety of variables including canopy coverage, soil pH, soil organic layer, and the ratio between DBH and age of the tree. At the termination of this study, we conclude that the Biological Station has had a significant overall impact on Red pine growth within the station, due to human influences on these factors that affect Red pine growth. Humans living in the Biological Station indirectly affect temperature, light availability, soil pH, and canopy coverage, but as seen in this study all of these elements directly impact Red pine tree growth.

With a constantly changing environment, minute temperature fluctuations become magnified, which could disrupt the geological distribution of Red pine. As shown in the discussion, warmer temperatures may allow Red pine to move north in the United States. A future experiment could test which variable in our study has the most influence on tree growth. As temperatures might allow Red pine to expand its distribution, soil pH, light availability or organic layer thickness may prevent the species from doing so. A linear regression statistical test would be helpful in answering these possibilities.

The limits of our study were numerous. Although we considered fifty six trees overall to be a good representative of the surrounding Red pine populations, our sample sizes may have been too small to make any fully convincing arguments. In addition to increasing our sample size, we could expand the types of species that we study. By testing the growth of varying species, we could get a better idea of the patterns of tree growth that have occurred since the inception of the Biological Station, which would give more insight into whether or not the station impacts tree growth. Another improvement that could be made would be to expand our study by testing growth in more than one control site, allowing for broader insight into factors influencing growth of Red pine populations outside of the Biological Station.

Since Red pine is a commercially important species for purposes such as logging and use in construction, we would expect further studies to test the importance of human influences on tree growth and whether or not these factors enhance the growth and quality of trees. As we found that human influences do increase growth, it would be important to see if the increased growth positively or negatively influences the condition of the tree for their specific commercial uses. Future studies should also explore our test variables over a wider range. Specifically, soil pH and light availability should be further investigated, since the results from our study were significantly significant. Finally, continued research could be done in more heavily occupied areas to test for human influences on tree growth which could result in more significant and conclusive results.

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