GROWTH RATES OF OAK TREES EXPOSED TO DIFFERENT MICROCLIMATE REGIMES RESULTING FROM TOPOGRAPHICAL VARIATION ON MARTHA’S VINEYARD

JAMIE HARRISON

Carleton College, Northfield, Minnesota, 55057 USA

Advisor: Dr. Christopher Neill

The Ecosystems Center, Marine Biological Laboratory, Woods Hole, Massachusetts 02543 USA

Collaborator: Hannah Kuhns

Franklin and Marshall College, Lancaster, Pennsylvania, 17503 USA

ABSTRACT. Frost pockets have been widely observed as a result of topographical variation, most notably from glacial influences. On Martha’s Vineyard, there are various instances of where the Buzzards Bay Moraine resulted in ridges along the southern end of the island. This study sought to examine the differences in the growth rates of oak trees located in these frost pockets, compared to their plateau, or upland macroclimate. The vegetation in these two areas consisted of the same species, but varied widely in composition. In the frost pocket areas, scrub oak dominated the site, with very few oak trees standing. The nearby upland macroclimates also consisted of scrub oak, but were dominated by mature oak stands. New temperature data was collected from different pairs of frost pockets and their macroclimates in addition to tree cores to examine growth rates. Previous data was also utilized to examine the effects of past temperatures on the trees. Temperatures revealed wide fluctuations in the daily temperatures in the frost pockets compared to the macroclimate. As a whole, the growth rates of oak trees in the frost pockets were faster than those in the macroclimates, probably due to the lack of competition for sunlight and nutrients. Past data on temperature could not be utilized to project temperatures in the past a result of the wide fluctuations in temperature. Past data was used for precipitation data, with accounted for 21% of the variation in growth rates in the frost pockets. A new direction for future studies would be to examine how climate, or specifically cloud cover, effects temperatures as it was observed on a small time scale that cloud cover limits the extreme temperatures of the frost pockets and upland macroclimate.

Key words: Martha’s Vineyard; frost pocket; oak tree growth rates; scrub oak.
INTRODUCTION. Frost pockets have been identified as having distinct microclimates, but the mechanisms by which they influence vegetation is not clearly known. The reason for these topographical microclimates, as described by Floyd Young is “[the] depressions [are] enclosed or with outlets so small that the cold air drains in to the depression faster than it can flow out” (Young 1940). Frost pockets can have up to a 10-degree difference compared to the hottest and coldest temperatures experience by the upland macroclimate, which is significant enough for one to experience frost and the other to not (Larsen 1922, Hough 1945, Barnes 1989, Aizen and Patterson 1995). In the 1940s, Hough noticed that the frost pockets he observed had sparse trees and shrub-like plants underneath compared to the thick forests in the macroclimates (Hough 1945). He speculated the sparse trees to grow were the individuals that were tall enough to escape browsing and avoid frost damage. However, the actual growth rates of these trees compared to the forest were not studied.

In a study by Motzkin et al. (2002), it was further established that frost pockets and microclimates have an effect on the vegetation of an area. This study looked specifically at a microclimate resulting from human disturbance, such as burning in a formerly agricultural area. Motzkin et al. (2002) researched an area primarily dominated by Quercus ilicifolia, or scrub oak, compared to an area with forested oaks, in a glacial outwash delta in central Massachusetts. Their findings were as follows, the few standing oaks trees in the microclimate experienced frosts, which resulted in chronically short growing seasons, reducing shoot elongation and slowing growth (Cochran and Bernsten 1973, Calmé et al. 1994, Motzkin et al. 2002). Frost sensitivity in oak trees has been greatly documented (Cochran and Berntsen 1973, Pilcher and Gray 1982, Calmé et al. 1994). In a study by Pilcher and Gray (1982), it was determined through tree cores that the growth rates of trees in frost pockets were slower than those in the macroclimate.

The Buzzards Bay moraine is a term describing the terminal moraine region off the coast of New England. This area includes parts of Block Island, Long Island, Cape Cod, Nantucket, and Martha’s Vineyard (Ogden 1959, Ogden III 1961, Sterling 1978). This moraine caused a series of “irregular and sub parallel ridges and hills” on Martha’s Vineyard (Foster et al. 2002). It has long been documented that the glacial outwash plains on Martha’s Vineyard exhibit characteristics of frost pockets with scrub oaks (Cochran and Berntsen 1973, Motzkin et al. 2002). The areas, as expected, contain scrub oak and few oak trees, compared with the upland areas that are oak tree stands (Figures 1 and 2).

These areas on Martha’s Vineyard are importantly managed areas for moths and butterflies endemic to the area. The reason for this is that the scrub oak buds out in June, slightly after the oak trees do (Grand and Mello 2004). In the event of a frost, the scrub oaks are more tolerant and survive the frosts better than the trees, which are less tolerant. When the insects emerge, the scrub oak leaves are young and tender, and they feed off of them. In the frost pockets, the scrub oaks are larger and more abundant, making these areas very important habitat for these species.
In this paper, I investigate the growth rates of oak trees as a result of temperature variation due to topographical frost pockets compared to those in the plateau, or upland macroclimate, on the southern end of Martha’s Vineyard. I asked the following questions: (1) Do the frost pockets experience more extreme temperatures than the upland macroclimates? (2) Are the growth rates of trees in the frost pockets slower than those in the upland macroclimates? (3) Are there trends in the growth rates of trees in the frost pocket and macroclimate?

Based on research from other studies I hypothesized that Martha’s Vineyard’s frost pockets would follow a similar trend with slower growth rates of oak trees in these microclimates. Additionally, I hypothesize that the temperature variation over a few weeks and also variation throughout the year from past data is enough to cause frosts in the frost pocket and not the macroclimate, especially later into spring. I initiated a detailed study of 4 sets of sites that include both a frost pocket and an upland macroclimate on the southern end of Martha’s Vineyard. The objective of this study was to evaluate the relationship between temperature and growth rates.

METHODS

Study Site. The 4 pairs of sites are located on the southern end of Martha’s Vineyard in glacial outwash plains (Figure 3). One pair is by Deep Bottom Road along the bike path about 8.84 m and 15.85 m above sea level for the frost pocket and macroclimate, respectively (41°48’N; 70°63’W, Figure 4). Two other sites are located off of Pohogonot Road, the first one in Hazy Acres with elevations of 7.62 m and 9.75 m for the frost pocket and macroclimate, respectively (41°37’N; 70°58’W) and one farther up the road with elevations of 6.71 m for the frost pocket and 10.1 m for the macroclimate (41°38’N; 70°58’W). The final site was located off of Barnes Road and the frost pocket had an elevation of 9.75 m and the macroclimate 15.55 m (41°39’N; 70°60’W).

Geological studies as well as my own investigations suggest that the soil consists of highly permeable sands, which renders the site drought-prone (Ogden III, 1961). The frost pockets have dense scrub oak (*Quercus ilicifolisa*) ranging from .5 to 1.5 m in height. All sites also contained blueberry bushes (*Vaccinium angustifolium*), ferns (*Dennstaedtia punctilobula*), huckleberry (*Gaylussacia brachyacera*), and wintergreen (*Gaultheria procumbens*). The Barnes Road site was dominated by black oak (*Quercus velutina*), while the others consisted of white oak (*Quercus alba*).

Temperature. To assess variation in temperature, temperature loggers were placed at every set of locations, one in the frost pocket and one in the upland macroclimate, for a total of 8 loggers. Hobo temperature loggers were placed in plastic waterproof casing and hung between 50 cm-100 cm off the ground and about 10 m beyond the start of the climate to avoid edge effects. They were all set on a delayed launch to begin collecting temperature data at 12am on
November 7, 2013. The loggers were set to collect temperature data every 30 minutes and were recollected on December 2, 2013.

Additionally, data on temperature and precipitation were collected from a NOAA base located in Edgartown dating back to 1946 and a base at the airport with data back to 1998. With this data, temperatures were looked at over a multi-year period to discern if there were years with a late spring frost. Additionally, precipitation was examined and adjusted in relation to a mean precipitation in order to see the fluctuations.

*Understory and Percent Cover.* At each of the sites, five .5 m x .5 m quadrats were randomly placed. Using a caliper, the diameters of the scrub oaks were recorded. Additionally, other plant species and their percent covers were recorded.

*Age Structure and Stem Height.* Tree cores were taken from at least 5 mature oak tree individuals. Individuals in the frost pocket were chosen based on availability, as there were fewer of them in an area. In the macroclimate, trees were chosen based on access to sunlight to be a good comparison with the frost pockets.

Trees were selected that were at least 10 m from the path or road to avoid the edge effect. Each tree was cored using a 16” Mora Sweden Increment Borer at breast height. Trees were cored up until the pith and then placed in straws for protection. For each of the trees, a clinometer was used to determine the angle to the height of the tree. The distance from the person taking the angle to the tree was also recorded to determine the height of the tree later. The DBH for each tree was also recorded.

*Data Analysis.* In order to calculate the height, the tangent of the angle of the height of the tree was multiplied by the distance. The height of the data collector was subtracted out and this resulted in a final height for the trees. The temperature data was downloaded from NOAA and the temperature loggers.

The growth rates and age of trees involved mounting the tree cores on 2 x 4 pieces of wood. The cores were mounted with wood glue and left to set overnight. The following day the cores were sanded first using 100 grit sanding paper followed by 150 and then 600 grit sanding paper. The tree cores were examined under a German Zeiss Stemi 2000 dissection microscope. The tree rings were measured using a digital caliper dating back to at least the pith.

The DBH for each tree was used to find the basal area of the trees. Then, using the growth rings, the basal area for each of the years was calculated. These values were subtracted from the following year to get the growth rate in terms of an increase in basal area per year. Years that all of the frost pocket trees experienced a decline in the growth rate in addition to the years where frost pockets experienced a decrease and the macroclimate trees remained the same were recorded.
RESULTS

**Understory Species.** In three out of the four sites, there were a greater number of scrub oak stems per m\(^2\) in the frost pockets compared to the macroclimate (Figure 5). On average, there were 3.6 more scrub oak stems per m\(^2\) in the frost pockets. Based on observational data, the scrub oaks were also taller in the frost pockets compared to the macroclimates. The basal area of the scrub oak ranged from .32 cm\(^2\) to 1.99 cm\(^2\) in the frost pockets compared to .01 cm\(^2\) and .76 cm\(^2\) in the macroclimate. There were no differences in the species composition of the understory of both the frost pockets and macroclimates. Both frost pockets and macroclimates contained blueberry bushes, ferns, huckleberry, and wintergreen.

**Age Structure and Stem Height.** In total, 42 trees were sampled. An extra tree core was taken at the frost pockets in site 2 and 3. The five number summary for the tree heights is .74 m, 2.95 m, 5.95 m, 8.49 m, 14.3 m (Table 2). The five number summary for the ages of the trees is 12, 43, 69, 78, 90. The five number summaries for each of the climates are also listed in Table 2.

**Temperature.** Based on the temperature loggers from November 7, 2013 to December 2, 2013, there is a great variation in temperature in both types of climates (Figure 6). There was a greater range in the temperatures in the frost pockets and the temperatures were also more extreme. For example, November 17\(^{th}\) at 1 pm had a temperature of 22.09 °C, plummeting to -11.7 °C three days later at 8 pm. Additionally, there was a difference in the frost pocket and the macroclimate on certain days. An example would be on November 17\(^{th}\) at 1pm where the frost pocket experienced temperatures of 22.09 °C and the macroclimate experienced temperatures of 17.14 °C, a 4.95 °C difference. Additionally, on November 20\(^{th}\), the frost pockets experienced temperatures of -11.7 °C and 8pm while the macroclimate experienced temperatures of -8.38 °C, a difference of 3.32 degrees. However, there are also some days where the range was negligible. From November 26\(^{th}\) at 5:30 am until November 27\(^{th}\) at 11:30 pm, the temperature differences were less than .4 degrees in the frost pocket and macroclimate.

**Growth Rates.** Overall, the increases in basal area per tree per year in the frost pockets were greater than in the macroclimate (Figure 7). There are specific years where the frost pocket and the macroclimate trees exhibit an increase and decrease together in the growth rates, such as 1992 and 2006. However, there are also some years that the trees in the frost pocket exhibit a decrease in growth compared to the macroclimate. Examples of these years are 1985, 1988, 1997, 1999, 2002, and 2004.

**Long-Term Temperature and Precipitation Data.** In order to properly assess the temperature variation over multiple years, the temperatures in the frost pockets and macroclimates were projected based on the long-term temperature records at the Martha’s Vineyard Airport and Edgartown site provided by NOAA. The way this was achieved was by using temperature data from May 2003 until December 2004 with measurements every 30 minutes. The daily maximum and minimums for May 2003 in each of the 8 sites were compared
to those recorded by NOAA. From this, delta values were calculated as an average of the entire month. These were then used to project what the temperatures would be in each of the sites back to 1980. However, this is not an accurate representation of the temperature variations in the frost pockets, as displayed in Figure 8. The reason for this is that the temperatures in the frost pockets are highly variable. Certain days, the frost pockets were 10°C higher than what was recorded by NOAA, and other times 10°C lower. This is consistent with what was displayed in the temperature records more recently, but also does not allow for an accurate prediction of temperatures in the past. Thus, the specific years that the trees experienced a decrease in growth compared to the macroclimate cannot be observed in terms of frost. Although this cannot be observed, based on the temperature data from 2003-2004, it is clear that the frost pockets experience frosts into June.

Based on the fact that the frost pockets experience extreme temperature fluctuations, these areas are drought-prone and experience precipitation stress. The changes in the growth rate were plotted against the adjusted precipitation (mm) for the growing season of April to October (Figure 9). Precipitation was adjusted around a mean value in order to accurately observe and increase or decrease in precipitation. In the frost pocket, 21% of the variation in growth rates can be attributed to the variation in precipitation. About 16% of the variation in growth rates can be explained by precipitation in the macroclimate. The relationship between precipitation and growth in the frost pocket appears to be stronger than in the macroclimate as displayed with the greater slope.

**DISCUSSION.** The fact that the trees are growing at a faster rate in the frost pocket compared to the macroclimate goes against previous hypotheses. A possible reason for this difference is that the trees in the frost pockets are not competing with other trees for sunlight and nutrients. The trees in the macroclimate are a part of a larger tree stand which probably has competition between trees. Although trees were specifically selected in the macroclimate to be in full sunlight in order to decrease the effects of this factor, it is possible that competition was still evident.

Looking closely at the temperature data from 2003-2004, it is clear that there is great temperature variation in the frost pocket. For example, on 5/19/2003, the daily minimum and maximum were -5.8 °C and 35.7 °C, which display a very large range. This is, however, very typical of a frost pocket that has an elevation difference compared to the plateau or macroclimate. On clear days, these frost pockets increase in temperature as the radiation increases. During clear nights, there is not any insulation to retain the heat and the frost pockets can lose all of the radiation, resulting in freezing temperatures. Additionally, this range is much larger than the macroclimate and has a lower minimum and higher maximum.

The same trend is observed from the temperature logger data from 11/7/2013-12/2/2013; there are times where the frost pockets are 5 degrees warmer than the macroclimate and also times where it is 5 °C cooler than the macroclimate (Figure 10). As previously mentioned, there
are also moments, like from November 26\textsuperscript{th} at 5:30 am until November 27\textsuperscript{th} at 11:30 pm, where there is little to no difference in the temperatures in the two climates (Figure 11). This is more recent data and was then compared to weather data from the Martha’s Vineyard Airport. From this weather data, it became apparent that from 11/26-11/27, the area experienced cloud cover.

There have been very few studies on clouds and their effects on frost pockets. In a study by Dorwoth et al. (1972), clouds were observed to prolong the growing season for a specific fungus. This is because the fog acted as insulation for the frost pockets, thus raising the temperatures and preventing frosts during the night throughout the spring and summer. More specifically, the clouds intercept the long-wave radiation that is being emitted from the frost pockets and re-radiates it back (Duffy and Fraser 1963, Dorworth 1972). So, compared to a completely clear night, the nightly temperatures are raised. A study by Duffy and Fraser (1963) also observed more extreme temperature variation in a frost pocket compared to the surrounding areas, just like preliminary observations on Martha’s Vineyard. The study looked at tree mortality and observed that mortality was attributed to frost during the growing season. However, as previously mentioned, when clouds occur, there is less of a chance of frost. Thus, the lack of clouds is most likely associated with more spring and summer frost events, which will result in a shorter growing season, thereby increasing mortality. We would also expect that years with a lot of cloud cover would not lead to many frosts, encouraging growth.

The lack of research on this topic leads to many ideas for future studies. Currently, there are only weather records back as far as 2006 at the airport on Martha’s Vineyard. What would be required is more data on the weather going forward including fog and cloud cover. After multiple years it will be better to study how the temperature varies with cloud and fog cover. It will also be easier to examine how weather affects the growth rates with a better record. Additionally, I would put temperature loggers back out into the 8 different sites for a longer period. As previously mentioned, the temperature variations in the frost pocket are too difficult to model back in time. A more detailed record of the differences in temperature for each pair of sites would be a better measurement in the future and would allow for more accurate analyses of growth rates.

Another part of a future study would look at tree mortality in the frost pocket compared to the macroclimate. The fact that the tree growth rates are faster in the frost pocket than the macroclimate are inconsistent with the fact there are so few trees there. It is possible that these trees are tall enough to escape the frost, as discussed by Hough (1945). In order to properly see the effects of the microclimate, mortality would have to be looked at for a longer period of time. Therefore, trees and saplings would be tagged in both of the areas. Over many years, the mortality of these tagged trees would be observed to see if there is a difference.

Monitoring how these frost pockets react to increases in temperature and changes in climate are important moving forward. These frost pockets are home to a diverse assortment of
butterflies and moths that are not found on the rest of Cape Cod or Massachusetts. Currently, the frosts act as a self-maintaining management program that keeps the scrub oaks abundant for the insects. However, with an increase in the temperature above a currently unknown threshold, the microclimates might begin to follow the successional pattern of the macroclimates. This would drastically alter the environment for the insects and affect their population number.

ACKNOWLEDGEMENTS. I thank my advisor Dr. Chris Neill for all of his guidance and advice throughout the course of this project. I thank my collaborator Hannah Kuhns for her assistance in the lab and in the field as well as Fiona Jevon, Megan Wheeler, and Rich McHorney. Also, Marina Lopez for her guidance throughout this project. This project was funded by the Semester in Environmental Science Program 2013 with lab space and equipment provided by the Marine Biological Laboratory.

Literature Cited

Young, F. D. 1940. Frost and the prevention of frost damage. US Dept. of Agriculture.
Figures and Tables

**Figure 1** An example of a scrub oak-dominated frost pocket on Martha’s Vineyard

**Figure 2** An example of an oak tree-dominated upland macroclimate on Martha’s Vineyard

**Figure 3** The elevations of the frost pockets and upland macroclimates of the 4 different pairs of sites

**Figure 4** The study sites located on the southern end of Martha’s Vineyard

**Figure 5** The number of scrub oak stems per m² in each of the 4 pairs of sites

**Figure 6** The results of the temperatures loggers placed in the frost pocket and upland macroclimate of site 1 from November 7, 2013 to December 2, 2013

**Figure 7** The actual yearly growth rates of trees in the frost pockets compared to the upland macroclimate

**Figure 8** A comparison of the daily minimum temperatures for the frost pocket and upland macroclimate of site 1 and Edgartown’s record for May 2003

**Figure 9** A comparison of the growth rates of trees and the adjusted precipitation for the growing season (April-October)

**Figure 10** Temperatures from November 18, 2013 to November 20, 2013 that indicate wide variation in temperatures of the frost pocket compared to the upland macroclimate

**Figure 11** Temperatures from November 26, 2013 to November 27, 2013 that indicate less variation in temperatures of the frost pocket compared to the upland macroclimate

**Table 1** The species represented in the understory of each of the frost pocket and upland macroclimate sites

**Table 2** The five-number summaries for the tree age and heights as a whole and also based on climate type
Figure 1: An example of a scrub oak-dominated frost pocket on Martha’s Vineyard
Figure 2: An example of an oak tree-dominated upland macroclimate on Martha’s Vineyard
Figure 3: The elevations of the frost pockets and upland macroclimates of the 4 different pairs of sites
Figure 4: The study sites located on the southern end of Martha’s Vineyard
Figure 5: The number of scrub oak stems per m$^2$ in each of the 4 pairs of sites
Figure 6: The results of the temperatures loggers placed in the frost pocket and upland macroclimate of site 1 from November 7, 2013 to December 2, 2013
Figure 7: The actual yearly growth rates of trees in the frost pockets compared to the upland macroclimate
Figure 8: A comparison of the daily minimum temperatures for the frost pocket and upland macroclimate of site 1 and Edgartown’s record for May 2003
Figure 9: A comparison of the growth rates of trees and the adjusted precipitation for the growing season (April-October)
Figure 10: Temperatures from November 18, 2013 to November 20, 2013 that indicate wide variation in temperatures of the frost pocket compared to the upland macroclimate
Figure 11: Temperatures from November 26, 2013 to November 27, 2013 that indicate less variation in temperatures of the frost pocket compared to the upland macroclimate
Table 1: The species represented in the understory of each of the frost pocket and upland macroclimate sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Frost1</th>
<th>Macro2</th>
<th>Frost3</th>
<th>Macro4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>Scrub oak</td>
<td>Scrub oak</td>
<td>Scrub oak</td>
<td>Scrub oak</td>
</tr>
<tr>
<td></td>
<td>Vaccinium</td>
<td>Vaccinium</td>
<td>Vaccinium</td>
<td>Vaccinium</td>
</tr>
<tr>
<td></td>
<td>Fern</td>
<td>Wintergreen</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site</th>
<th>Frost5</th>
<th>Macro6</th>
<th>Frost7</th>
<th>Macro8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Species</td>
<td>Scrub oak</td>
<td>Scrub oak</td>
<td>Scrub oak</td>
<td>Scrub oak</td>
</tr>
<tr>
<td></td>
<td>Vaccinium</td>
<td>Vaccinium</td>
<td>Vaccinium</td>
<td>Vaccinium</td>
</tr>
<tr>
<td></td>
<td>Wintergreen</td>
<td>Fern</td>
<td>Huckleberry</td>
<td>Huckleberry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fern</td>
</tr>
</tbody>
</table>
Table 2: The five-number summaries for the tree age and heights as a whole and also based on climate type

<table>
<thead>
<tr>
<th></th>
<th>Minimum</th>
<th>Lower Quartile</th>
<th>Median</th>
<th>Upper Quartile</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height-all (m)</td>
<td>0.74</td>
<td>2.98</td>
<td>5.95</td>
<td>8.45</td>
<td>14.32</td>
</tr>
<tr>
<td>Age- all (years)</td>
<td>12</td>
<td>43.75</td>
<td>69</td>
<td>77.75</td>
<td>90</td>
</tr>
<tr>
<td>Height-Frost pocket (m)</td>
<td>0.74</td>
<td>2.04</td>
<td>3.19</td>
<td>5.58</td>
<td>10.22</td>
</tr>
<tr>
<td>Height-Macroclimate (m)</td>
<td>2.87</td>
<td>6.45</td>
<td>8.19</td>
<td>9.85</td>
<td>14.32</td>
</tr>
<tr>
<td>Age- Frost pocket (years)</td>
<td>12</td>
<td>31.5</td>
<td>49</td>
<td>77</td>
<td>87</td>
</tr>
<tr>
<td>Age-Macroclimate (years)</td>
<td>40</td>
<td>66</td>
<td>75.5</td>
<td>79</td>
<td>90</td>
</tr>
</tbody>
</table>