Assessment of Two Stands of Eastern Hemlocks in Black Rock Forest: Relationships between Vigor, Elevation, and Distance from a Water Source







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Abstract

Three stands of eastern hemlock trees in the boundaries of Black Rock Forest will be assessed for their health and damage from the woolly adelgid. This insect, originally from Asia, has infested eastern hemlocks from Virginia to New York. Unlike with other types of hemlocks in the United States, the insect has killed many eastern hemlocks on the East Coast. The data was gathered using the Point-Quarter method in an effort to find correlations between the trees' health and other outside factors. The data were plotted on a topographic map of the two stands to see what geographic features accounted for the difference in health.

A series of graphs was made in an effort to find any possible trends between the vigor of the eastern hemlock trees and the distance from the water sources or between vigor and the elevation of the stands. No definite trends were found in any of the graphs. The strongest trend was found for vigor versus distance from the water source at Mineral Spring Brook, with a trend line with a negative slope of -0.0059.

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Introduction

An infestation of a non-native invading organism can alter many aspects of a forests ecology, including forest structure, composition, productivity, and dynamics (Liebhold et al., 1995). Other major changes from the invading organisms can alter aesthetic conditions and natural resources (Castello et al., 1995).

This study asks the questions: what is the composition of the hemlock forest stands with woolly adelgid infestations, and how does the local environment affect the likelihood that the tree attracts the insect.

Description of Eastern Hemlocks

The eastern hemlock, *Tsuga Canadensis*, is a conifer with flat needles. It has a round top and the highest shoot droops. Its needles lie in flat sprays, are whitened underneath, and are attached by slender stalks. Cones grow up to an inch in length and have few scales. The tree's bark is dark and rough. The average height of the eastern hemlock is between sixty and seventy feet and the trees can grow up to one hundred feet tall. Their average diameter is between two and three inches.

Eastern hemlocks typically grow in mature forests and wooded ravines (Petrides, 1998). Other habitats for hemlock trees include exposed slopes and stream bottoms (Orwig, 1998). They grow with or without other trees or deciduous hardwood species. The trees provide a habitat for many

different species as well as a cool damp microclimate with low light levels, little understory cover, and relatively stable forest composition (Bezinger, 1994). The little understory vegetation is due to the shade created by the trees as well as the acidic litter (Godman and Lancaster, 1990).

Importance of Eastern Hemlocks

The eastern hemlocks' longevity creates stable ecosystems. They dominate stands and are late successional climax trees. Once, the trees made up twenty percent of the upland forest ecosystem but now their abundance is less than six percent. Part of their niche is to cover ruffled grouse, turkey, deer, snowshoe hare, and rabbit. Up to ninety percent of bird species in Connecticut use them as a food source, nesting site, roosting site, or as shelter in winter. The black-throated warbler, solitary vireo, and northern goshawk live in hemlock forest habitats as well. Many herbs and shrubs, such as leatherwood, rattlesnake plantains, bunch grass, gold thread, bluebeard, Canada mayflower, and wood sorrels live under hemlocks. The cooling effect of hemlocks attracts brook trout to streams where hemlocks border. They provide a different climate in forests than do hardwood trees. They cool the surrounding temperature in the summer by shading the area and warm temperatures in the winter by acting as a wind break (McClure et al., 1996).

Description of Insect

The hemlock woolly adelgid is a small, aphid-like insect that feeds on several species of hemlock. It is originally from Asia. The adult hemlock woolly adelgid is very small, less than a millimeter in diameter. It completes two generations of development per year on a hemlock. From the period of March through April, the adults lay their eggs in a mass on the hemlock twigs. Each mass has the appearance of a small bundle of cotton or wool, hence the adelgids' name. The eggs hatch in the period between April and May, with the nymphs (also called crawlers because of their mobility) settling on twigs near the needle base to feed on the tree and continue in their development. By the end of June they have matured and become adults. Some of the adults grow wings and fly off to search for another adelgid host, spruce. However, because there are no suitable spruces in North America, these adelgids soon die without reproducing (McClure, 1995).

The wingless adults are able to reproduce on the hemlocks at this time and in June lay egg masses on hemlock twigs. Those that hatch become dormant until October. Then they feed and mature by spring. While they are eggs or unattached nymphs, they disperse as eggs before attaching to twigs. They are dispersed by wind and birds, as well as deer and other mammals. Even humans can be agents for the dispersion through logging and recreational activities (McClure, 1995).

The woolly adelgid feeds mainly on the youngest hemlock twigs. They hatch in spring to take advantage of the previous season's growth. Woolly adelgids in the developing nymph stage suck the sap of the youngest available twigs on the tree and might also inject a toxic saliva into the tree as they feed (McClure, 1995). They have a stylet bundle composed of four stylets in a sheath. The stylet is inserted into the underside of the base of the needle. Then the adelgids work their way from the vascular tissue to the xylem where the plant's nutrients are transferred and stored. The saliva the insect injects hardens around the stylet bundle and forms a sheath. This remains even after the stylet bundle is withdrawn. When the insect molts the stylet cuticle is shed. When the adelgid's new stylet cuticle hardens, the stylet bundle is reinserted (McClure, 1987).

A woolly adelgid infestation can begin anywhere on the tree, although the progression of the infestation usually moves from the lower branches to the top of the tree. It takes only a year for the infestation to reach the crown of the tree. If a few trees become infested in a particular stand, it is almost certain that in time the rest will become infested as well (McClure,1995).

The woolly adelgid population can increase rapidly within a short amount of time, since they increase by two generations a year and females do not need males to produce offspring. When a tree looses enough nutrients, it can no

longer support the woolly adelgids. At this point the insects die and there is a crash in their population (McClure, 1987).

Description of Classification of Trees

The trees were classified by several factors that were then used in analysis. The vigor of the trees was measured visually on the spot by guessing the percentage of needles and branches left. The system had six categories, with 1 as the lowest and 6 as the highest. Trees that had 100-84% of their needles and branches were given a 6, 84-68% were given a 5, 68-52% were given a 4, 52-36% were given a 3, 36-16% were given a 2, and 16-0% were given a 1. The distance from the tree to the marker was taken in meters. The diameter of each tree was measured at breast height in centimeters. The measurements of distance were measured not from each individual tree but taken once from each plot. The elevation was also taken this way with one reading for each plot. The elevation data came from Figures 4a and 4b.

Methods of Lessening the Effect of the Adelgids

There is some hope for the eastern hemlock trees. Some trees can be protected by using an integrated pest management approach. This means monitoring the tree for the presence of the insect, following various practices to improve the health of the trees, and using mechanical and chemical procedures to kill the woolly adelgid (McClure, 1995).

To monitor the pest, it is best to inspect the trees often so detection will be made as early as possible. Once the adelgids are detected, cultural control methods are also necessary. The best method for prevention is to keep animals from coming in contact with the tree since they could be dispersal mechanisms. Moving items from an infested area to an uninfested area is discouraged as well, especially in the period from March through June when the adelgids are at their most active. And it is important to remove larger, infested trees, which contain a greater amount of adelgids than smaller trees, so that they do not serve as a "launching pad" for the insects to nearby trees (McClure, 1995).

To improve tree health, trees should be watered in times of drought so that they will be at their peak of health. Pruning and using fertilizer without nitrogen also helps. Nitrogen fertilizer enhances the insects' survival, so it is detrimental to the trees' health. These methods are probably most helpful for home gardeners, however, as they would be difficult to implement throughout an entire forest (McClure, 1995).

Other methods can help individual trees. Mechanically removing adelgids involves directing a strong stream of water at infested branches in their hatching and growth period from April through June. Clipping infested twigs lessens the number of woolly adelgids on the tree (McClure, 1995). Chemical methods involve completely spraying the tree with

horticultural oil, insecticidal soap, or a petrochemical insecticide.

At this time, there is no biological method that has effectively stopped the infestation on the eastern hemlocks. There is hope in the Pseudoscymnus beetle, a Japanese black ladybug that preys on the adelgids. Releases have shown that they can survive and reproduce for a reasonable amount of time after their release, and they can eat as many as 50 adelgid nymphs a month during their prime feeding months (McClure, 1995). Another biological method is the coccinellid beetle, also from Japan. It can eat adelgids at any stage and has shown to reduce the number of hemlock woolly adelgid (McClure, 1995). Coccinellid beetles have been released in Connecticut by the New York Department of Environmental Conservation in Putnam County and at Clermont State Historic Site, in Columbia County, Ulster County and Westchester and Greene. There is hope that this beetle will spread and do great damage to the woolly adelgid population (Shapley, 2000).

It has also been found that predators introduced against other insects, such as balsam woolly adelgids (McClure, 1996), native midges (*Cecidomyiidae*), flowerflies (*Syrphidae*) and lace wings (*Chrysopridae*) may also eat hemlock woolly adelgids. However, the numbers of these occurrences are too small to have an impact on the woolly adelgid population (McClure, 1987).

History of the Adelgid's Movement in the United States

The hemlock woolly adelgid was first noticed in North America in British Columbia in the 1920s. It was first noticed on the East Coast in Richmond, Virginia, in 1951, (Shapley, 2000) where it infested both eastern and Carolina hemlocks (McClure, 1996). Although the exact origin of the infestations is unknown, it is most likely that they resulted from an accidental transportation from Asia.

Once the tree has become infested with the insects, it undergoes a patterned series of stages. The insect densities on the trees vary from year to year. When the tree is first infected, the woolly adelgid population multiplies rapidly, gaining a peak density the first year of infestation. The second year of infestation is marked by a population decline because the damage to the tree results in reduced growth and therefore a reduced food supply. During the third year, the hemlocks typically produce a small amount of growth because the smaller adelgid population of the second year allows the tree to try to recuperate and grow, although this growth is usually stunted. The hemlock woolly adelgid population increases moderately due to the presence of this tree growth. In the fourth year, after the renewed attack by the adelgids, the tree cannot grow at all and the insect population crashes as the tree begins to die (McClure, 1996).

Several species of hemlock have shown themselves to be resistant to the hemlock woolly adelgid. Two species are Japanese hemlocks, which have had a longer amount of time to

become resistant to the adelgid. Two other resistant species are hemlocks found in western North America, with the western hemlock, *T. heterophylla*, the most similar to eastern hemlocks in appearance, growth, and usage. In general, despite the existence of hemlock woolly adelgids on the West Coast of the United States, western hemlocks do not die in the same large numbers as eastern hemlocks.

Eastern hemlocks grow in a region bordered by the Canadian Maritimes in the north, to the Great Lakes in the west, to northern Georgia and Alabama in the south. The hemlock woolly adelgid has infested a small part from northern North Carolina to southern New York and to eastern Massachusetts.

Location of Study

Black Rock Forest Consortium supported the research done in this thesis. The consortium is located in the Hudson Highlands 50 miles north of New York City. Its 4000 acres have been set aside for research and education. It has elevations from 330 to 1461 feet, many lakes and streams, and several rare and endangered plants and animals. Before becoming the consortium in 1987, it was part of the Harvard University System. Now the Consortium is comprised of twenty colleges.

The research was taken on three weekends in October. The first stand is located at Canterbury Brook and goes up the southeast branch. The second stand is beside Mineral Spring

Brook, a contributor to Woodbury Creek, in the southwestern part of the forest. These two stands were not fully plotted in this area because it went over the forest boundary and onto private property (Black Rock Forest).

According to Dr. William Schuster, director of Black Rock Forest, the infestation of hemlock woolly adelgids in Black Rock Brook was first documented in 1992, although they may have been present prior to that date. Dr. Schuster first documented the presence of the adelgid in Mineral Spring Brook in 1995, and in Canterbury Brook in 1994. "In particular," Dr. Schuster wrote in a letter, "the lower portion of the Canterbury Brook hemlock stand, just at the entrance of the forest, probably had adelgid by '92 or '93….If I had to guess the actual first date of introduction [for Mineral Spring] I would guess 1994."

Thesis Statement

The objective of this project is to assess the overall health of the two hemlock stands. The woolly adelgid started infecting trees over five years ago. This study measures their progress. It also tries to find other factors that can cause the trees to lose their health. The two most important factors studied were the distance of each stand from each stream and the elevation of each site. These were especially useful to analyze because the availability of the water source is important to hemlock growth because of the

hemlock's shallow root systems. The elevation affects the kinds of trees and other vegetation that grow at each site.

Methods

In Black Rock Forest, two stands of hemlock trees were deemed large enough for study by Aaron Kimple, the mentor who was assigned to work with me by Barnard Environmental Science professor, Peter Bowers. The two stands showed signs that the woolly adelgid had been living there for some years. Two stands were not fully measured because they extended onto private property. Additionally, a burned area in the stand along Mineral Spring Brook was avoided, because the fire damage made it unfeasible to determine whether the woolly adelgid or the fire had injured the trees.

To be able to get a random sampling of each stand in their entirety, we used the point-quarter method, also known as a plotless method. It is useful for sampling communities where the plants sampled are widely spaced, such as for shrubs or trees (Smith, 1990).

Within each stand, the stream that ran through it served as the point from which the plots were measured. Starting from the point believed to be the beginning of the stand, every 100 meters were measured using a measuring tape along the stream until the other end of the stand. Plastic tubes were hammered into the ground at these 100 meter intervals. Plastic ribbons were then tied to nearby trees as markers.

After the grid was completed, the transects and plots were measured. The transects were taken by measuring every thirty meters from the 100 meter mark along the stream, until the stand gave out. If the stand continued on the other side of the stream, another starting marker was placed on the side parallel to the first marker. (Refer to Figure 3).

A compass was used to ensure that the transect was perpendicular to the stream. The stand was considered finished if at the next plot there were no more hemlock trees within the marker and no hemlock trees were observed in the adjacent plot.

Starting at the 100 meter mark, each plot was measured, except for the parallel 100 meter mark on the other side of the stream. (Refer to Figure 3). The plots were measured from the plastic tube in the middle. Comments about the plot were made, its location and if it had any unusual features. Starting from the tube, the plot was divided into quadrants using the compass. The quadrants went from north to east, east to south, south to west, and west to north. In each quadrant, the closest tree to the tube was chosen to be measured (refer to Figure 3), whether it was a hemlock tree or another kind. A tape measure measures its distance from the tube. Then its diameter was measured at breast height. Trees that have a diameter at breast height too small to be measured by the tape are not included. The measurements were taken in centimeters to the nearest millimeter and then later in inches to the nearest tenth of an inch.

Next the health of the hemlocks was assessed. It is determined by the percentage of needles on the branches. It is divided up into five categories: (1) 0% to 20%, (2) 20% to 40%, (3) 40% to 60%, (4) 60% to 80%, (5) 80% to 100%. Hemlock trees that were dead were still counted and were evaluated as a 1.

The limitations with these evaluations are that it is possible for another factor to make some of the hemlocks lose their needles and mistakenly attribute it to the woolly adelgid.

The next step involved transmitting the data into map form. The computer program Adobe Illustrator was a useful tool for this process. A topography map of the two stands was pasted underneath the plots which showed the elevation and the relation of the brooks compared to the transects as well as the direction of the transects from the river.

Using this data and the data collected from the site it is possible to do analysis on the factors that may influence the health of the trees.

The graphs were made using Excel and an add-in of Excel called StatPlus 2.0. The add-in allows box plots to be made. Histograms were made using Excel.

To get an overall assessment of how many trees were healthy or unhealthy a histogram was made for each plot showing the frequency of eastern hemlocks with vigor in Figure 5a and 5b. Next, graphs were made comparing the different factors that might impact the health of the trees

with their vigor or health. Graphs 5g and 5h show the frequency of each tree by distance to each stream. Next in two scatter-plots Figures 5i and 5j, the relationship between vigor and distance from each stream. The last two scatter-plots compare vigor with elevation with elevation.

Boxplots show several descriptive statistics in one graph and graphically represent the variability of the data and the skewedness of the distribution. They show the first quartile, median, third quartile and interquartile ranges as well as the minimum and maximum values and the moderate and extreme outliners. The box area of each point on the graph shows the interquartile range of the distribution from the first quartile to the third. The median is the unbroken horizontal line somewhere in the middle of the box. The mean is shown by the dotted line in the middle of the box. The box shows where 50% of the data is located. The median shows where the data is clustered and to which range the data are closer to. Outside of the box the inner fences, the two unbroken lines on each side of the box, show the third quartile plus 1.5* interquartile and the first quartile minus 1.5* interquartile. The outer fences shown by the dotted line are located at the third quartile plus 3 * interquartile and the first quartile minus 3* interquartile. The outliners are shown by dots between the fences or above and below them. They are any values that fall between the inner and outer fences and are called moderate outliners or fall beyond the outer fences and are called extreme outliners. These are

shown by an unfilled dot. The whiskers are vertical lines that box the distribution that lie within the inner fence. They show the highest and lowest distribution which are not the outliners (Berk, pp. 157-162). the box-plot graphs compare distance from the stream and vigor (Figures 5c and 5d) and elevation and vigor (Figures 5e and 5f).

Results

The data we have collected shows the decimation of the woolly adelgid on the hemlock trees. The health is assessed through the needle percentage and how many trees out of the two stands have failing health. Taking the diameter of the trees will show if the stands are young or old and if there is a difference in health and if the woolly adelgid attacks one or the other.

It was important to observe how the eastern hemlocks were situated at the sites. The maps show the elevation, which is one of the factors that could influence the vigor of the trees.

First, the health of the trees was recorded as shown in Figures 5a and 5b. The first Figure shows the frequency of trees versus the vigor at Canterbury Brook. Next are trees with a vigor of 4. About 27% of the trees have a vigor of 4. Trees with a vigor of 6 make up about 14%. Close behind are trees with a vigor of 3 (about 13%.) 1% of the trees have a vigor of 2, and no trees have a vigor of 1 at this site. The

percentage of trees with a vigor of 5 is 45%, the most of any category.

The distribution of trees at Mineral Spring Brook is different from Canterbury Brook in several ways. At Mineral Spring Brook there is a higher percentage of trees that have a vigor of 3 than a vigor of 4. Also at Mineral Spring Brook there is a higher percentage of trees with a vigor of 1 and 2. Other than that the two distributions look similar. Mineral Spring Brook has most of its trees with a vigor of 5, about 39%. The percentage of trees with a vigor of 6 is about 13%.

Next, the distance from each stream was compared to the vigor. At Mineral Spring Brook the median was found at 100 meters from the stream. From this the data on each side was symmetrical. This is not surprising since only three such trees were found at the site. The median for trees with a vigor of 2 were found at 110 meters from the stream. The data for those trees were also symmetrical. The median for the trees with a vigor of 3 was at 75 meters, though the mean was higher at 105. The median was also in the lower half of the interquartile range. The top whisker was longer than the bottom whisker. This shows that the data was positively skewed. The trees with a vigor of four and five had a lower mean and median than the category 3 trees. They too were positively skewed. The category 6 trees were on average found to be farther away than the category 4 and 5 trees. These trees though are shown as symmetrical.

At Canterbury Brook (Figure 5d) looking at the same parameters, the first two categories, 1 and 2, were too small to measure. Category 3 has a mean of 55 meters and a median of 32 meters. This shows that the data are positively skewed. The category 4 vigor has a slightly higher mean than category 3 and a median at 45 meters. Having the median in the lower half of the interquartile range means that most of the data is clustered around this point. Category 5 has a smaller interquartile range and a mean and median close together at about 60 meters. This category is symmetrical. Category 6 has a mean of about 60 meters and a lower median of 30 meters. The data is negatively skewed.

Next, boxplots comparing elevation with vigor were made. Figure 5e. shows Mineral Spring Brook. Categories 1 through 3 show medians at a noticeably higher elevation than categories 4, 5 and 6. The mean and median for categories one and two are at 1145 meters. Category 3 has a mean and median at 1080 meters. The last three categories, 4 ,5 and 6, are not so symmetrical as the first three. Category 4 has a higher median than mean, with a median at 1045 meters, and a mean at 1025 meters. This category is positively skewed. Category 5 has a lower mean and median than category 4. Both are around 1000 meters. Category 6 has the same median as category 5 and a higher mean.

When measuring the same parameters at Canterbury Brook, categories 1 and 2 cannot be measured since there were too few number of trees with those health. Categories 3, 4, and 6

have similar means at about 825. Category 5 has a higher mean than the other categories at 900 meters. Categories 3 and 6 both have medians that are noticeably lower than their means, suggesting that much of their data is clustered in the lower part of the interquartile. Categories 4 and 5 have medians closer to their means, making their distribution more symmetrical.

Next at each stand the distance from the stream by the frequency was found. At Mineral Spring Brook (Figure 5g) most of the eastern hemlock trees were found at 30 meters from the stream. This was a number of 50 trees. A substantially smaller amount of eastern hemlock trees were found at 60 meters from the stream. Twenty-three eastern hemlock trees were found. The number of hemlock trees at 90 meters was even less with 11 trees found at that distance. The rest of the distances have about the same frequency of hemlock trees, at about seven trees at 120 meters to two trees at 300 meters.

At Canterbury Brook (Figure 5h), the highest number of eastern hemlock trees occur in the 30 meter range from the stream. At 60 meters the number of hemlocks drop to 26. There are almost as many trees at 90 meters as there are at 60. The number of hemlocks continues to decrease until only one is found at 210 meters. Three hemlocks were found at 240 meters from the stream.

Figure 5i is a scatter plot of vigor versus distance from Mineral Spring Brook. Each point shows the location of the tree and its vigor. The points can overlap. Most trees

are under categories 4, 5, and 6. They are situated mostly in the first 120 meters. The trees with a category one vigor are found in the first 60 meters or much farther back at 270 meters. The category 2 trees are more scattered. They are found at 90, 150, 180, and 270 meters from the stream. No category 3 trees were found on the river, they were found throughout the rest of the width of the stand. Category 4 trees were found up until 120 and then at 150 and 300 meters. Category 5 trees were found up until 150 meters and then at 250 meters. Category 6 trees were found up until 120 meters. The trend line has a slope of -0.0059. The regression R^2 value is 0.1289.

The scatter plot of Canterbury Brook (Figure 5j) showing the same parameters, shows that most of the data points fall under the healthier trees at the distances closer to the stream. There were no category 1 trees. There was one category 2 tree. It stands 150 meters from the stream. The category 3 trees are mostly in the first 120 meters. They are also at 240 meters. Category 4 trees are present until 150 meters and then at 210 meters. Category 5 trees are at each site from 0 to 180 meters. Finally, category 6 trees are present until 150 meters and then again at 240 meters. The trend line has a slope of -0.0001 and an R^2 value of 0.000005.

To look at the differences caused by changes in elevation, the two stands were combined and plotted against vigor. The first graph (Figure 5k), shows the lower

elevations from 520 to 720 feet. There are no category 1 or 2 trees at these elevations. Category 6 trees are only at 580, 620, and 660 feet. There are more hemlock trees with a vigor of 4 in these elevations. They occur from 520 to 550 feet, 590 to 620 feet, 650 to 670 feet, and at 720 feet. Category 5 trees cover the largest area. They are present from between 520 to 670 feet and at 720 feet. Category 6 trees start at 600 feet, then appear again at 650 to 720 feet. The trend line has a positive slope of 0.0047.

In the scatter plot of vigor with high elevation (Figure 5j) most of the data is in the area of 920 to 1190 feet. No trees were found at the area around 900 feet. The two category 1 trees were found at 1100 and 1190 feet. The category 2 trees had a larger area of 800 feet and again at 1100 to 1190 feet. Most of the category 3 trees were located from 1020 to 1190 feet, as with categories 4 and 5. Category 6 covered a smaller area, from 920 to 1160 feet. The trend line sloped negatively at -0.0014 and the R^2 value was 0.0248.

Discussion

In these stands where a foreign insect has invested the hemlock trees, it is necessary to find any trends between the health of the trees and other abiotic factors. Eastern hemlocks are grow well in ravines. An effort was made to find if the infestation of the woolly adelgid had damaged the

stand in such a way that had changed the conventional configuration of the trees.

The first parameters looked at were the frequency of eastern hemlocks versus vigor (Figures 5a and 5b). In both plots there was a high number of trees found in category 5. They had 68-84% of their needles. Due to the large number of trees in this category, the stand looks reasonably healthy overall, for a stand infested by an insect that can kill a tree in four years. Another example that the stands are reasonably healthy, is that the first two categories, 1 and 2, with a combined percentage of needles from 0 to 32%, have a very low frequency. But, an indicator that the stands are not quite as healthy as they ought to be is the poor showing of category 6 in the two stands. They have the fourth highest frequency. These trees have 84-100% of their needles.

In order to understand how distance from the rivers impacted the health of the stands (Figures 5g and 5h) the two graphs show how many trees are at each distance. The distance was measured from each marker, not each individual tree. The majority of trees occur with in 30 meters of each stream. By 60 meters the number of hemlock trees has decreased by half. While at Mineral Spring Brook the number of trees at the 90 meter mark are half as many as those at the 60 meter mark. It is different at Canterbury Brook with the number of trees decreasing slightly at each 30 meters. This shows a trend that the density of the trees decreases as the distance increases from the stream.

The two graphs (Figures 5i and 5j) were used to look for trends between vigor and distance. The results for the two stands were different. Mineral Spring Brook showed a slight trend between decreasing vigor and increasing distance. The slope of the trend line was -.0059 vigor/distance. Canterbury Brook showed no trend. Its trend line was almost a flat line. It has a slope of -.0001. This may have happened do the amount of water away from the streams. At Canterbury Brook, out of the ravine the land was wet and muddy in many places. While at Mineral Spring Brook the land dried out more. Slope did not seem to make much difference since both places had trees growing on the steep sides of the ravine.

In terms of the insect, this seems to show that it can not consciously attack where the trees are the healthiest. Since as expected the hemlock trees near the river tend slightly to be healthier.

In comparing elevation, the total change of elevation was taken and halved (Figures 5j and 5k). The low elevation graph shows the elevations from 520 feet to 720 feet. The high graph shows the elevation from 740 to 1220 feet. The Canterbury brook stand starts at 520 feet and ends at 1220. The Mineral Spring Brook stand starts at 940 feet and ends at 1190. The gap at 900 feet in the high elevation graph is caused by the Mineral Spring Brook stand not starting until 940 feet, and the Canterbury stand having a sparse area for hemlocks. The area did not have any noticeable features pointing out why hemlocks did not grow there. The low

elevation graph shows only the Canterbury Brook stand. The high elevation map shows both Canterbury Brook and Mineral Spring Brook. The reason hemlocks can be found at these elevations and not higher is that the terrain at Black Rock Forest gets rockier with worse soil at higher elevations. At other places hemlocks have grown to higher elevations. At low elevations there is a slight trend between increasing vigor and the increase in elevation. The slope of the line is 0.0047. At high elevations there is no trend. The slope of the line is -.0014. This could be because the two stands diverted from each other and cancelled each other out. A larger change in elevation is needed to get any definitive results.

Conclusion

The composition of the forest was found to have little sign of a huge infestation by only looking at the health of the eastern hemlock trees. Most trees were in the category 5 (68-84% of needle range). The most worrying aspect was the low number of category 6 (100%-84% needle range) in the two stands. These low numbers probably contribute to a lesser canopy in the two stands. A positive finding was the low number of category 1 and 2 eastern hemlock trees in the stands.

In looking at elevation and distance from the stream by vigor only slight trends or no trends were found. The Mineral Spring Brook stand showed slight trends in vigor versus

distance and vigor versus elevation. Canterbury Brook did not show even slight trends in these areas. One fact that was noted was the high frequency in both stands of eastern hemlock trees growing near the river and then sharply falling off as the distances grew. This reinforces existing data showing that plentitude of water is an important factor in the health of eastern hemlocks (McClure, 1995). According to Dr. Schuster, the infestation of the woolly adelgid is fairly recent to Black Rock Forest, with estimated arrival dates ranging from 1992 to 1995, therefore the amount of time needed for the adelgid to produce major damage is still to be determined. Given the slight trends from some of the data, it seems possible that the overall health of the tree due to proximity to water was able to combat the effects of the closeness of the trees, which have enabled the adelgids to move from tree to tree.

Recommendations

This was a cross-sectional study, completed over a period of a few weekends. It is unknown how much damage the woolly adelgid has caused and how much other factors have caused. A follow-up study is needed to learn if the number of category 6 trees decreases over time. With the description of the insect of killing the trees in four years it was expected the health of the hemlock trees would be much lower. Another abiotic factor that deserves attention along with distance from stream and elevation is the slope that the

trees are situated on. It changed from being almost flat in some areas to being very steep by the streams in some places. Another area of study would be soil analysis. Some places were very rocky, while others had a better soil.

In a future study, it would also be important to compare the soil at the two stands. Further study is needed to learn more about how distance and elevation impact the hemlock trees as well as the other factors, such as the impact of deer and insects on the hemlocks. Most importantly, the next study should include a close analysis of whether each tree was infected by the woolly adelgid, and how deeply the damage was sustained. This would facilitate finding out how much the other factors influenced the health of the eastern hemlock trees.

Acknowledgements

A special thanks to Prof. Bowers, Prof. Callahan, Mr. Kimple, Prof. McKesney, and Prof. Schulz.

Figure 1: Map of Black Rock Forest

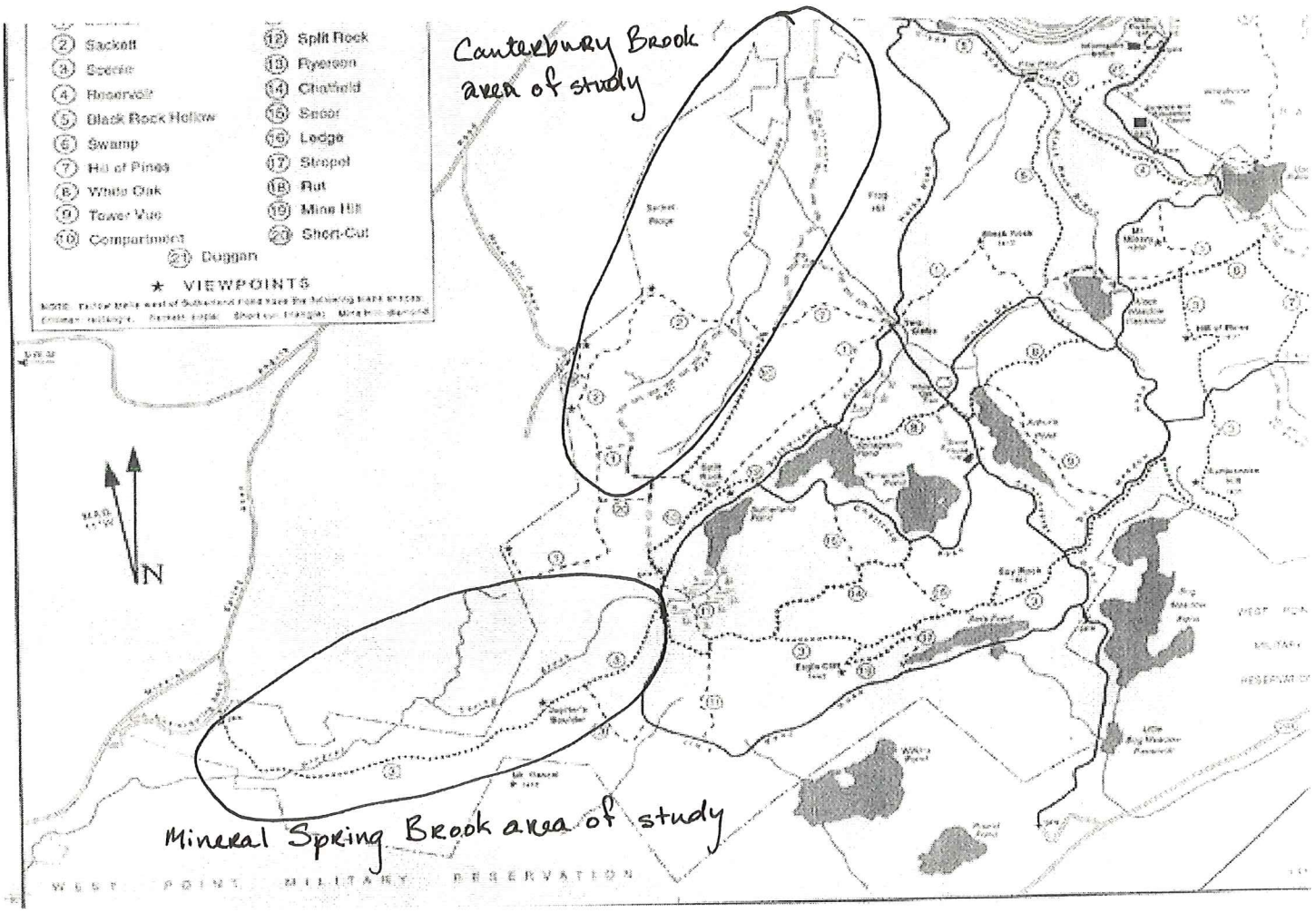


Figure 2 A Close-Up View of the Eastern Hemlock





Figure 3

Along the stream there is one plot every 100 meters. At this plot, 30 meters are measured perpendicular to it and another plot is placed. This continues until no more hemlocks are to be found. The transect can lie on either side of the stream. The four closest trees to the plastic tube in each quadrant are the ones that are measured.

Figure A.7 The point-quarter method of sampling forest stands.

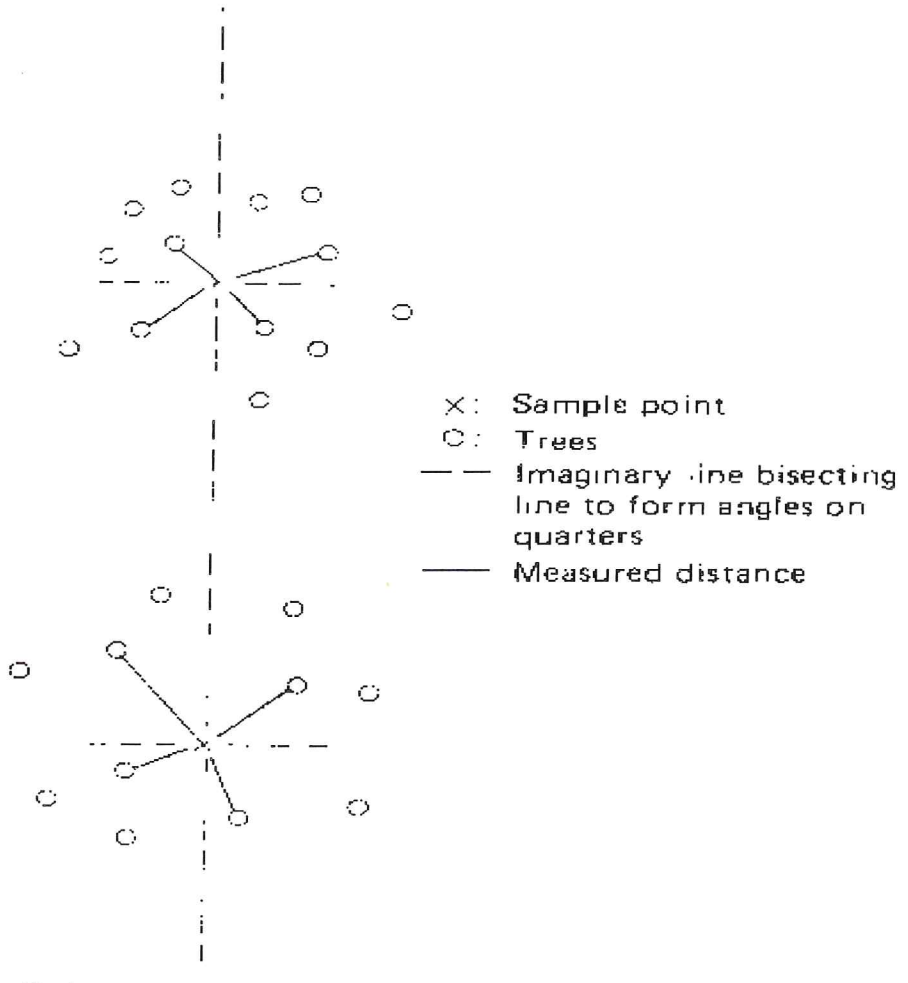


Figure 4a. Map of Stands at Mineral Spring Brook.

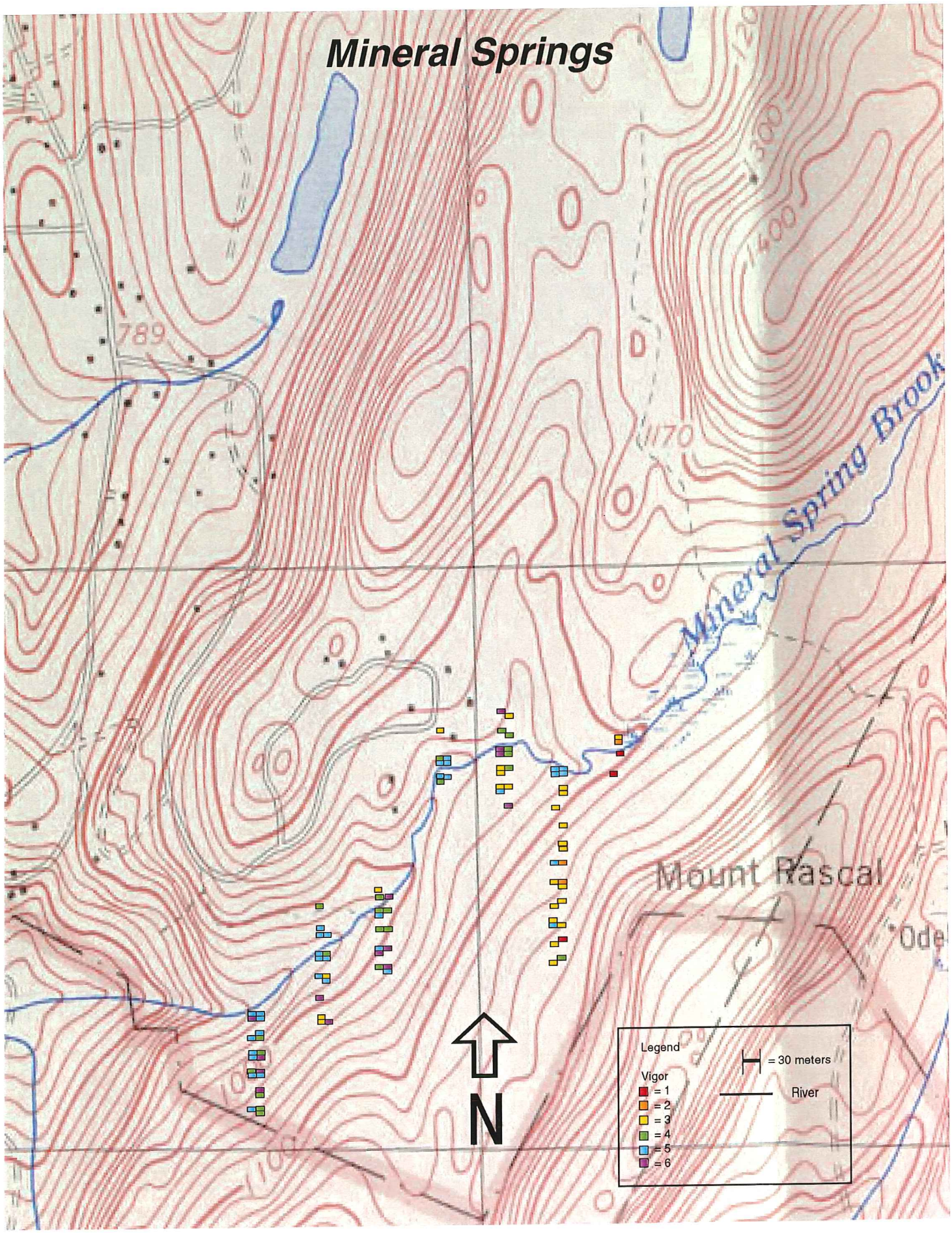


Figure 4b. Map of Stands at Canterbury Brook.

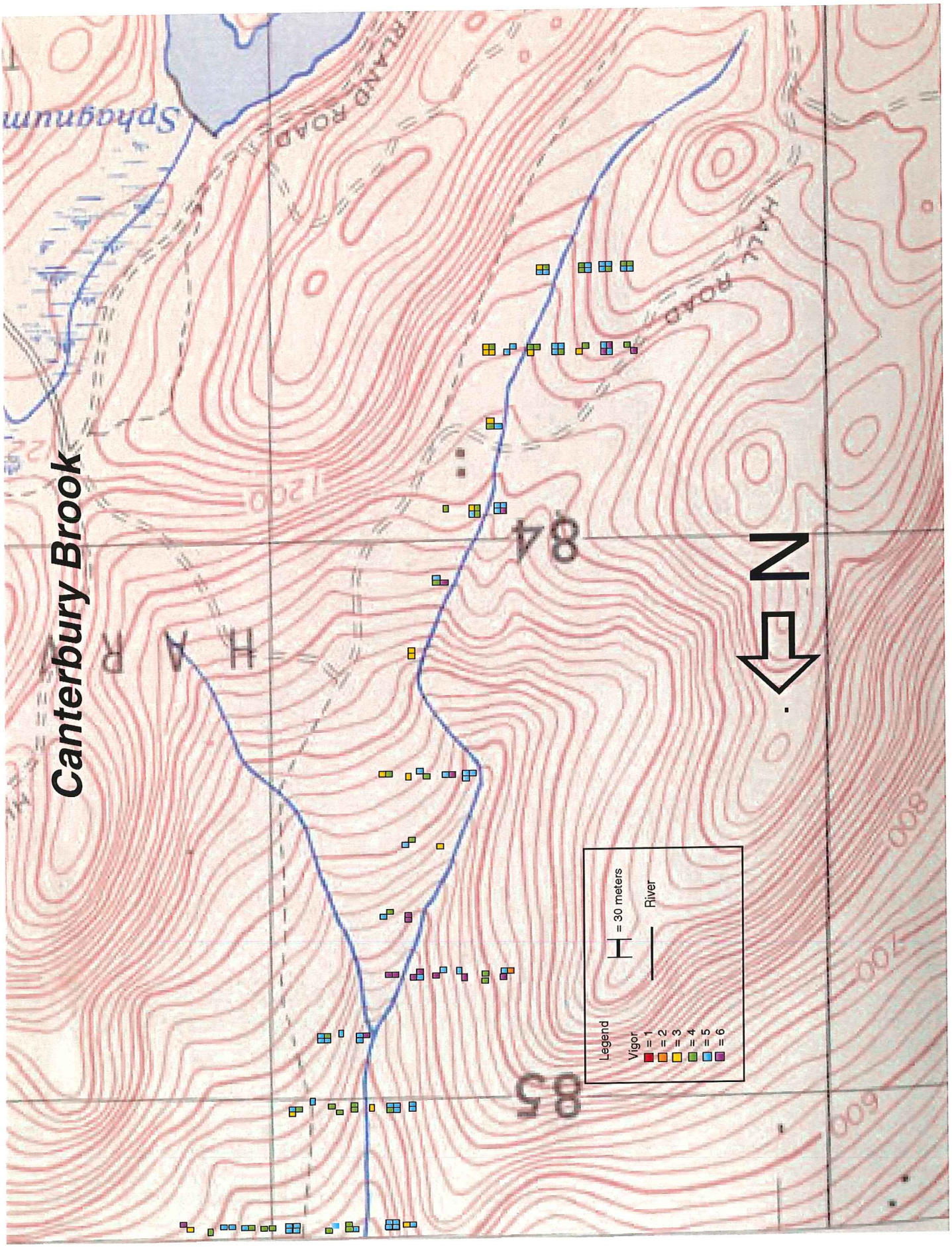
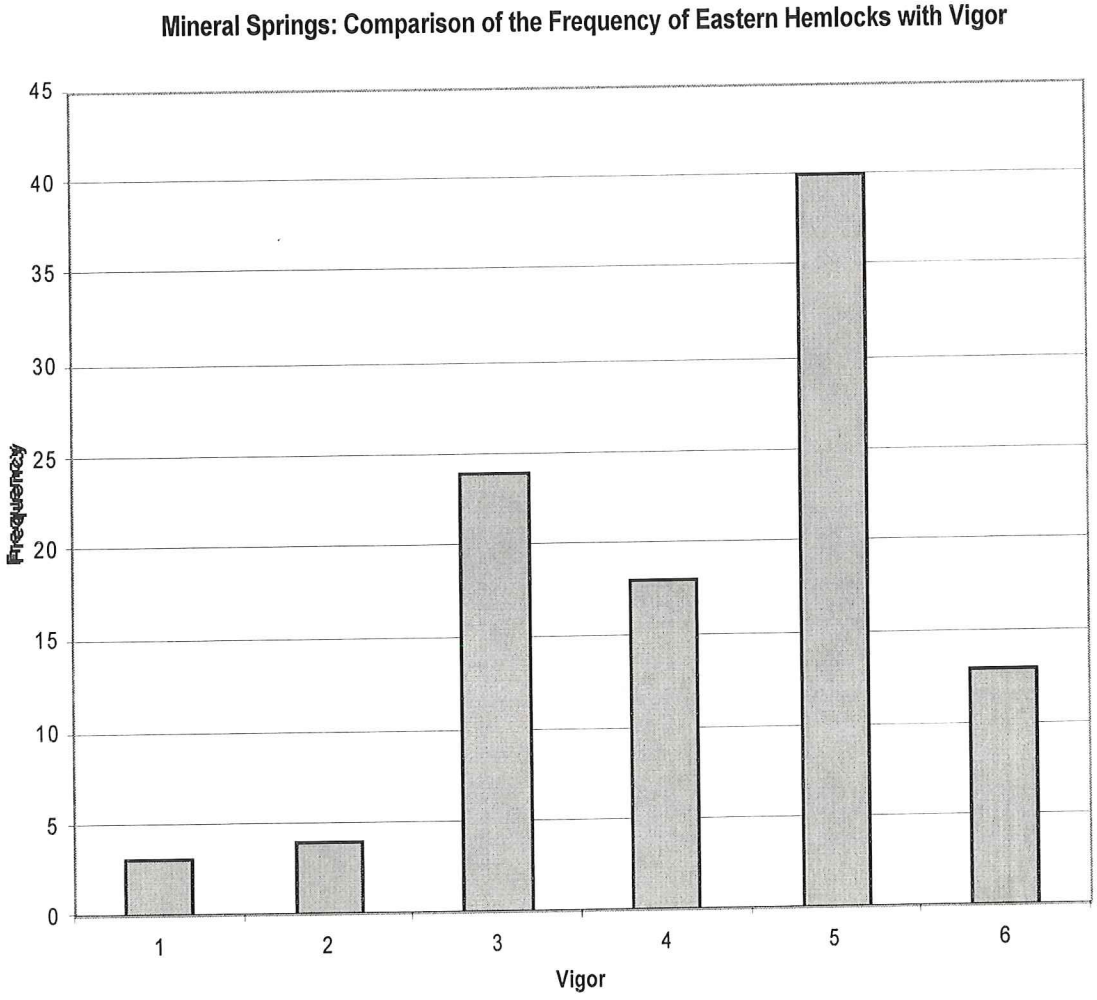
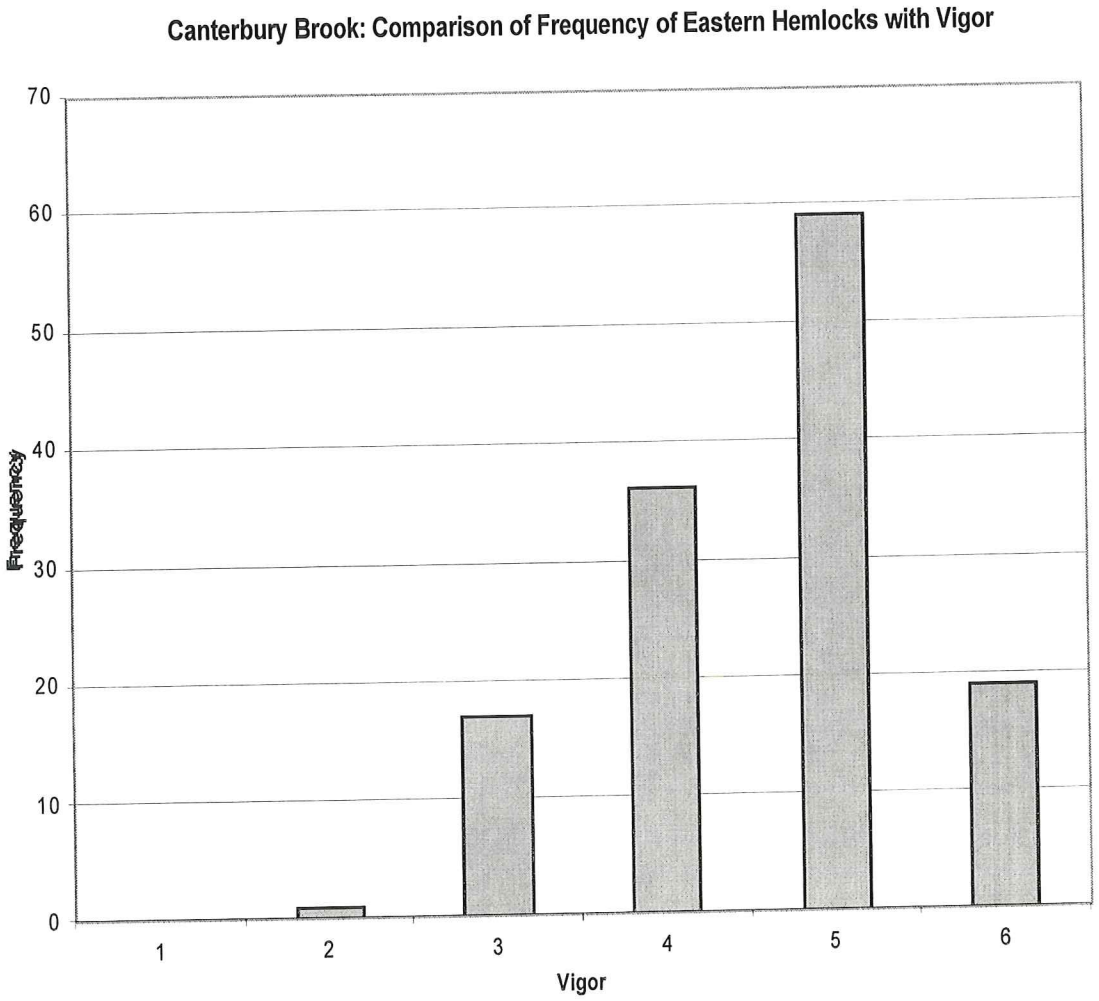


Figure 5a.



Vigor is measured by assessing the needle loss in each tree. Category 1 has the most needle loss, and category 6 has the least, and is therefore considered the healthiest. In the Mineral Spring Brook stand, trees in Category 5 were the most frequent, with 40 of the measured trees falling into this category.

Figure 5b.



In the Canterbury Brook stand, Category 5 was also the most prevalent, with almost 60 of the measured trees falling into this category.

Figure 5c.

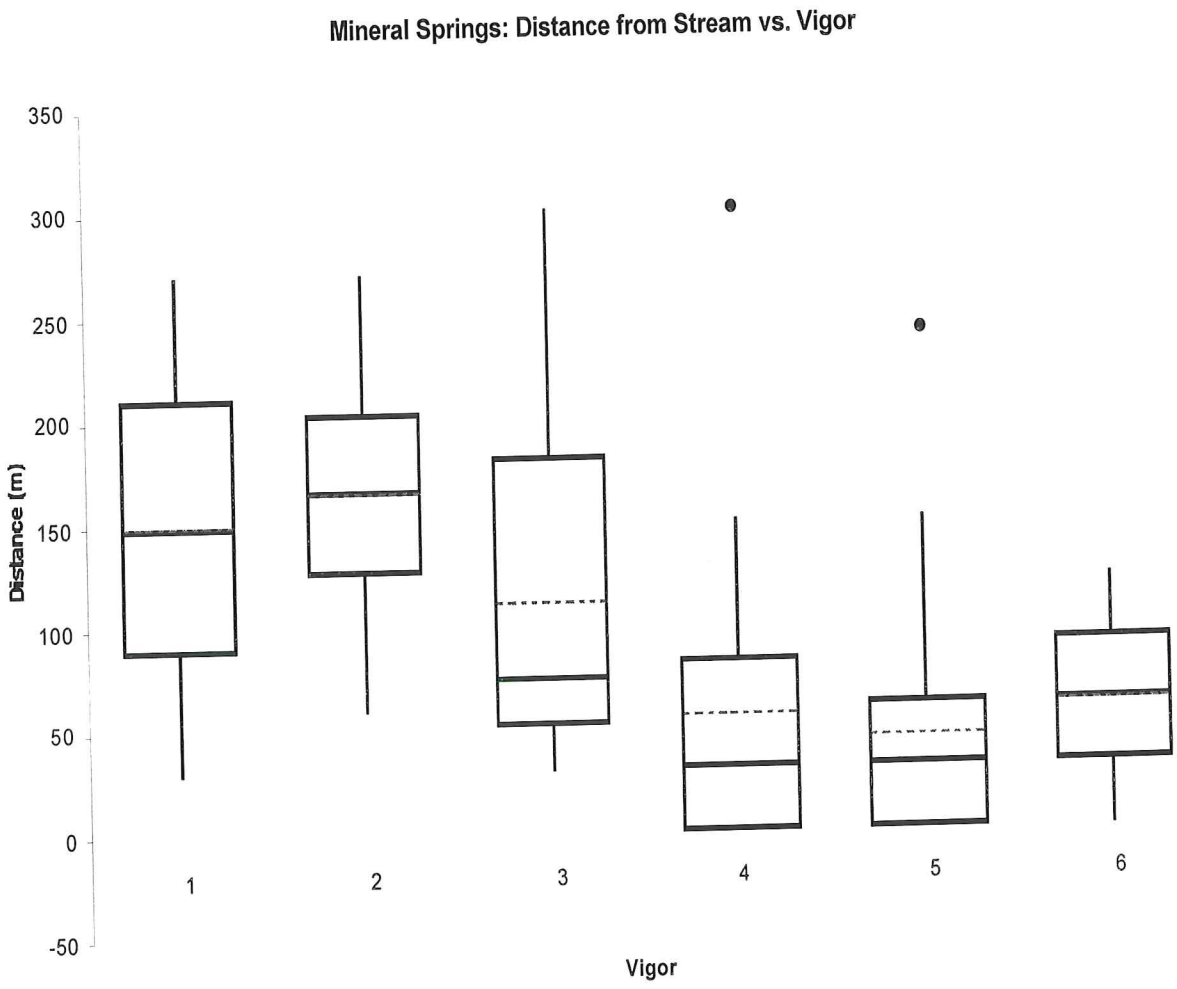
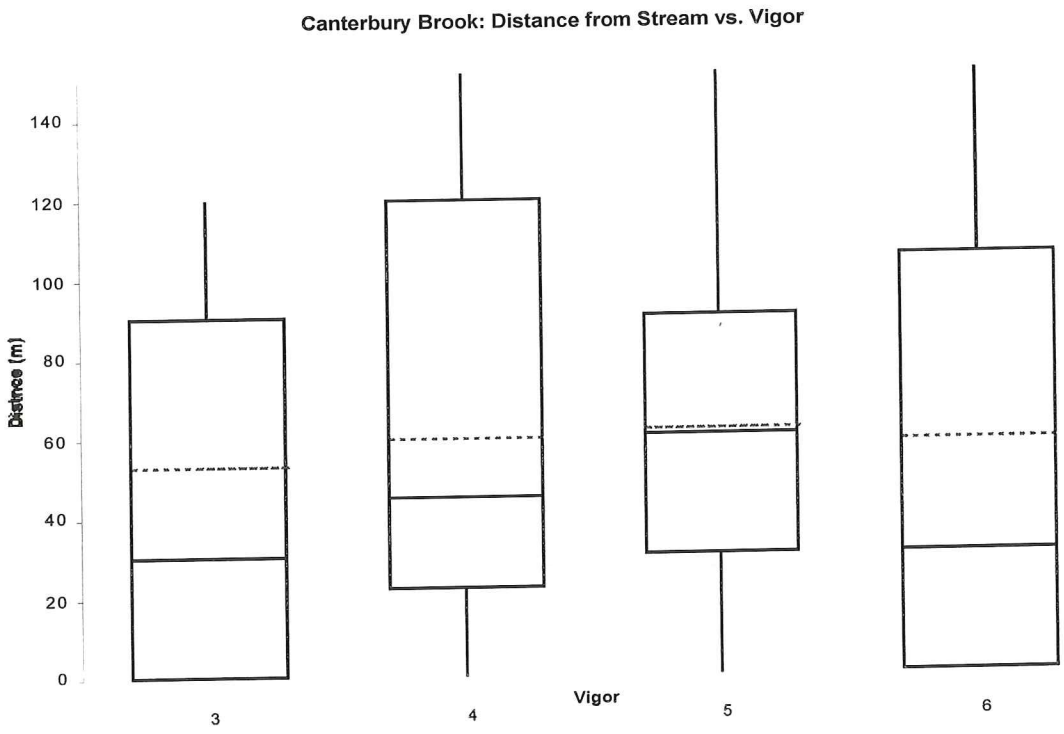


Figure 5c shows a possible trend between distance from the stream and vigor.

Figure 5d.



The graph is inconclusive. No trends can be found.

Figure 5e.

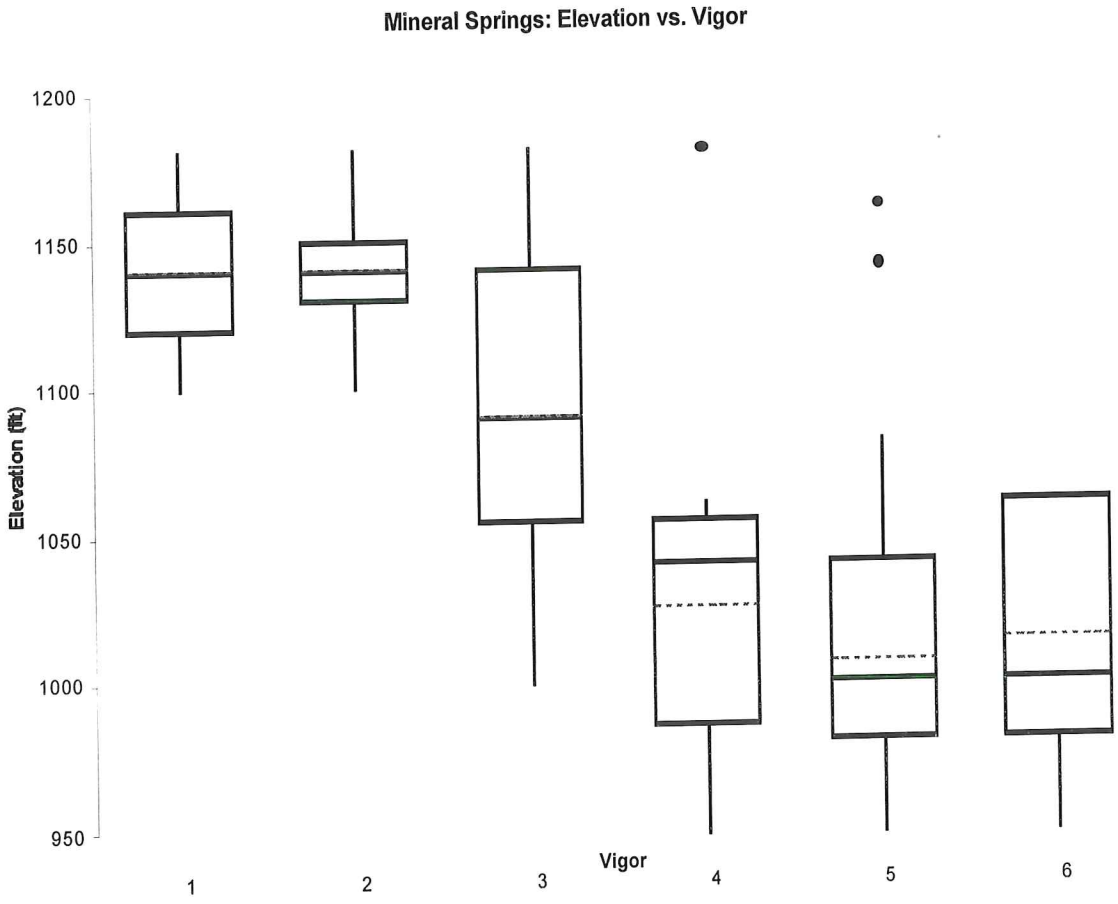


Figure 5e shows a possible trend between elevation and the level of vigor in the trees.

Figure 5f.

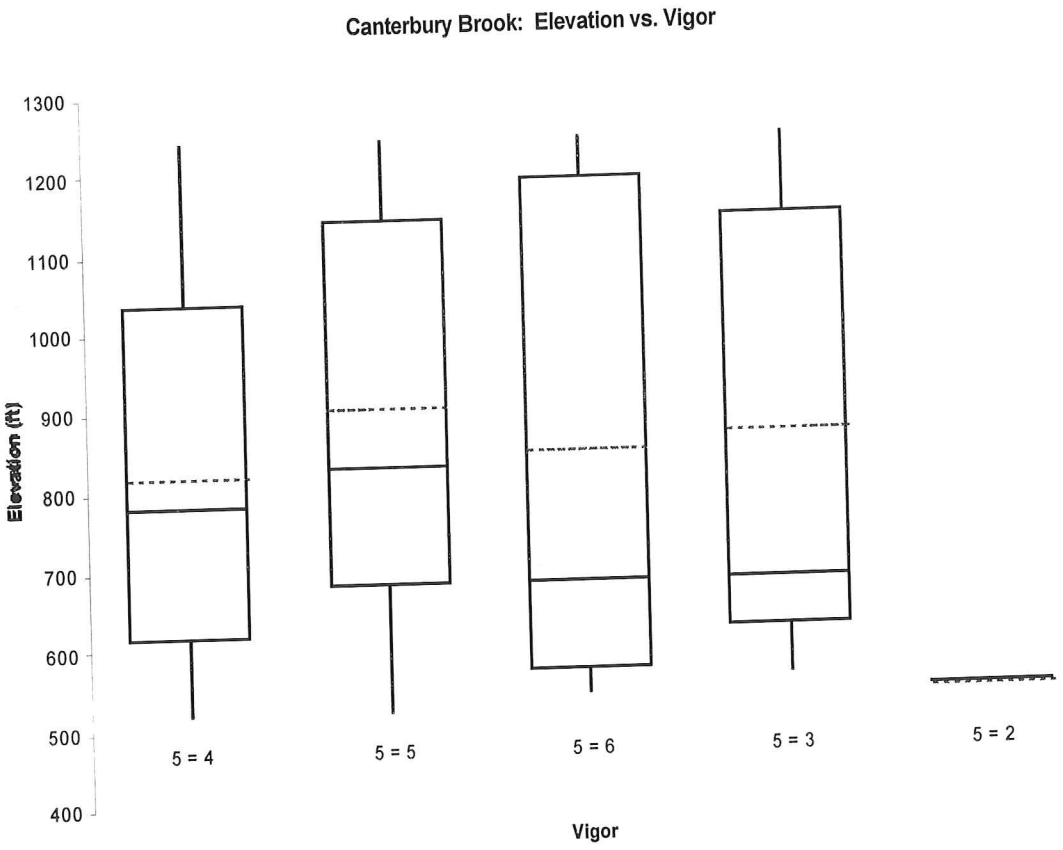
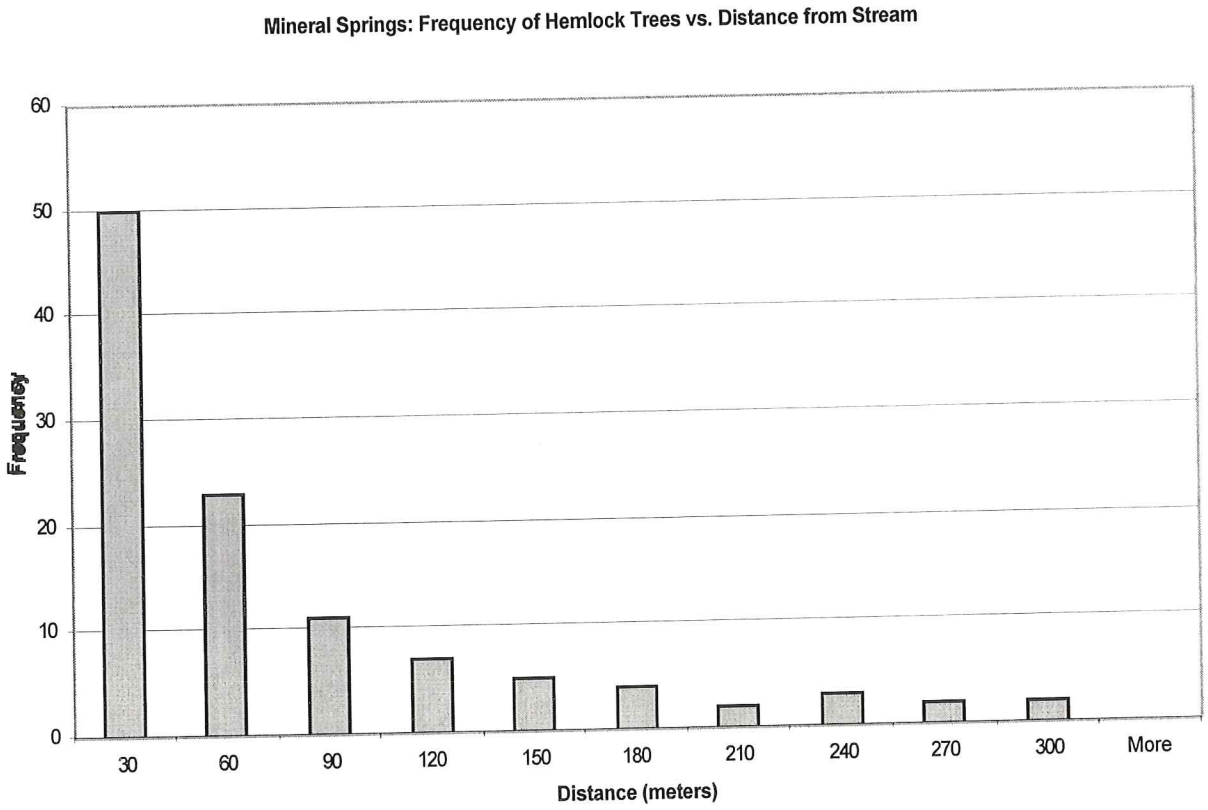
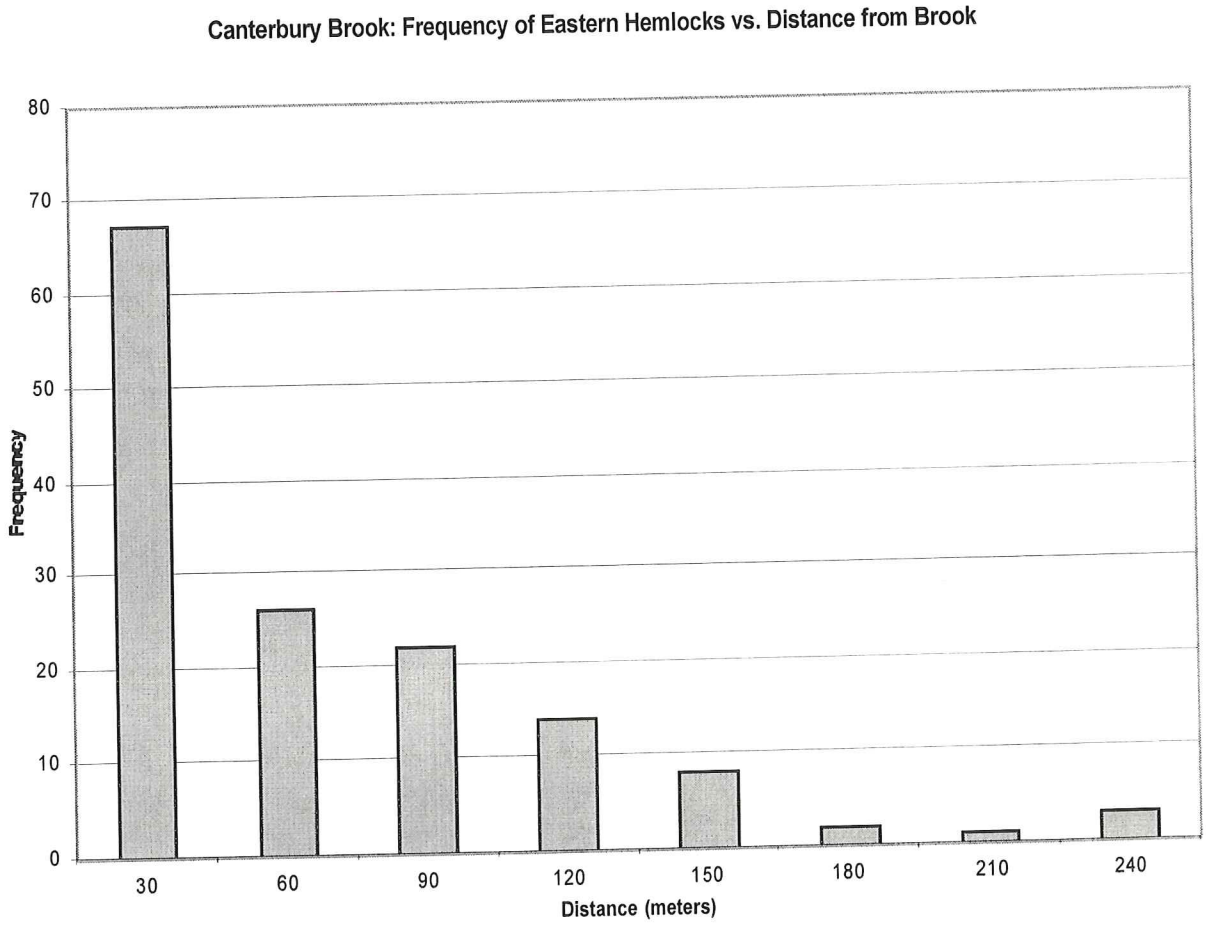

Canterbury Brook: Elevation vs. Vigor
Elevation (ft)
1300
1200
1100
1000
900
800
700
600
500
400
5 = 4
5 = 5
5 = 6
5 = 3
5 = 2
Vigor

Figure 5g.



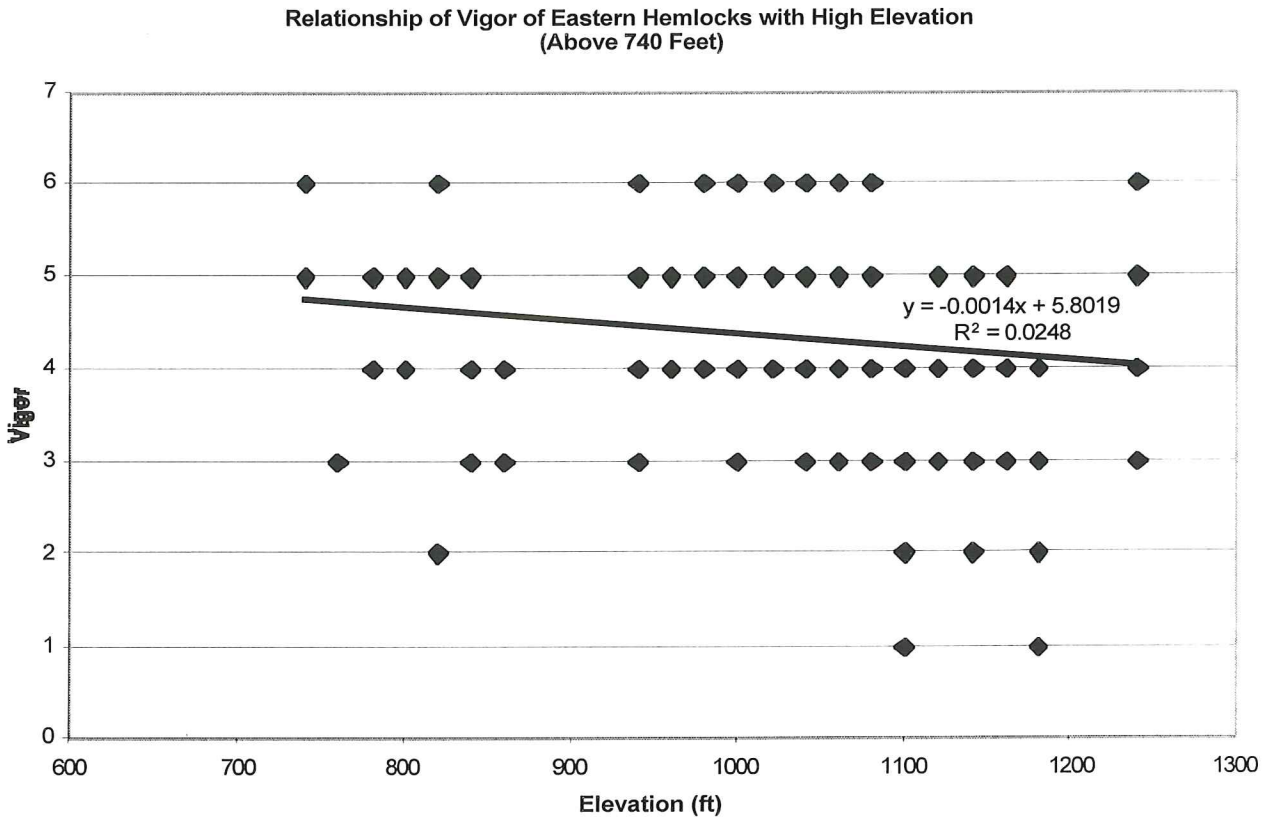
In this graph, the frequency of trees was compared to their distance from the brook (Mineral Spring). As can be seen on the graph, an overwhelming majority of the trees were within 60 meters of the stream, most within 30 meters.

Figure 5h.



At Canterbury Brook, the same pattern can be seen as in Figure 5g. The majority of the trees were found within 60 meters of the brook.

Figure 5j.


Relationship of Vigor of Eastern Hemlocks with High Elevation
(Above 740 Feet)
y = -0.0014x + 5.8019
R² = 0.0248
Vigor
Elevation (ft)
0
1
2
3
4
5
6
7
600
700
800
900
1000
1100
1200
1300

Resources

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