

**Soil texture, topography, and canopy effects on microclimate in scrub oak thickets
on Martha's Vineyard**

Laura Poppick
Department of Geology
Bates College, Lewiston, ME 04240

Advisor: Christopher Neill
The Ecosystems Center
Marine Biological Laboratory
Woods Hole, MA 02543

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ABSTRACT

The Massachusetts state government has historically supported scrub oak thicket management on Martha's Vineyard. To form the most effective and efficient future management plans, management agencies must understand where scrub oaks tend to naturally colonize, and why. Existing data suggest that scrub oak thickets congregate in topographic depressions formed by spring-sapping. Frequent late spring frosts in these depressions distinguish them from the surrounding level plains on which scrub oak also grows. Soil texture, topography, and canopy height all likely contribute to spring frost formation in the depressions. Our main objectives during this study were to verify that scrub oaks colonize spring sapping valleys with extreme microclimates more often than on level plains with less extreme microclimates, and 2) determine the predominant factor controlling microclimate in the thickets. We 1) used ArcGIS to assess the correspondence of scrub oak and spring sapping valleys, 2) collected and processed field samples to characterize soil texture within two spring sapping valleys on Martha's Vineyard, and 3) launched temperature loggers within and outside a spring sapping valley, and at additional sites in which we tested each of the three microclimate-controlling factors independent of one-another. We found that scrub oak growth significantly corresponds with topographic depressions, spring sapping valleys do have extreme microclimates, and canopy height and topography, not soil texture, drive microclimate fluctuations in the valleys.

Key words: microclimate, soil texture, spring sapping valleys, scrub oak

INTRODUCTION

Scrub oak thickets on Martha's Vineyard, MA represent an uncommon community of the northeastern U.S. and support several rare moth species (Motzkin et al, 2002). As a result, Massachusetts state agencies have historically managed scrub oak thickets with prescribed burns and mechanical removal of tree oaks that would eventually over-shade scrub oak in a natural succession (Foster and Motzkin, 1999). Existing data suggest that extreme microclimate fluctuations in scrub oak thickets imperil competing tree oaks but do not alter scrub oak growth (Fisher and Mustard, 2007; Swain and Kearsely, 2001). Because the natural impairment of tree oak growth in scrub oak thickets ameliorates management needs, understanding the factors driving microclimate fluctuations in scrub oak thickets in different locations can guide future scrub oak managers in establishing efficient management sites.

Scrub oaks tend to form dense communities within elongate topographic depressions on Martha's Vineyard (Foster and Motzkin, 1999). Uchupi and Oldale (1997) attribute the formation of these depressions to spring sapping during the late Wisconsinan retreat of the Laurentide Ice Sheet. Glacial meltwater created proglacial lakes dammed by thrust moraines formed during intermittent readvances of the glacier. These proglacial lakes had high hydrostatic heads and forced the water table to rise. The high pressure and elevated water table forced groundwater through the permeable outwash sands and gravels, forming groundwater seeps downslope. With time, erosion at seepage sites developed headward, forming amphitheater-shaped heads and fairly consistent downstream valley widths. Once the proglacial lakes drained, a decreased hydrostatic head caused the water table to drop below the level of the valley floors and stream flow

ceased (Uchupi and Oldale, 1997). The coarse texture of the modern soils within spring-sapping valleys results from these past glaciofluvial processes.

Motzkin et al. (2002) suggest that scrub oak's dominance within spring-sapping valleys is, in part, a result of its ability to cope with the extreme microclimate of the valleys. In particular, scrub oak growth persists through the late spring frosts that are characteristic of spring-sapping valleys. While the precise cause for extreme microclimate variation in the valleys is poorly understood, existing data suggest that soil texture, topography, and canopy height are the three most important factors in controlling microclimate in general (Motzkin et al. 2002). In particular, the variation in water content and thermal conductivity of soil with different textures, cold-air drainage in topographic depressions, and the variation in wind-speed and pattern in areas of different canopy heights all control microclimate (Geiger 1965; Geieger 1955). The coarse soils, topographic lows, and low canopies common of spring sapping valleys make them likely places for extreme temperature fluctuation and thus places in which scrub oak may outcompete tree oaks susceptible to late spring frosts. If this were the case, spring sapping valleys would be prime locations for effective and efficient future management projects.

The purpose of this study was threefold. First, we sought to verify that coarse-textured soils with low field capacity compose spring sapping valleys. Second, we sought to determine which one of the above listed three factors predominately influences microclimate fluctuation. Third, we sought to verify that scrub oak growth positively corresponds with the determined predominant factor. Ultimately, we expected to prove that the microclimate of spring sapping valleys makes them prime locations for scrub oak management.

Study sites

We collected field samples in two spring sapping valleys on Martha's Vineyard, Deep Bottom and Willow Tree Bottom (Figure 1). We sampled along transects at N41° 24' 18.6" from W°70 38' 20.0" to W°70 38' 22.5" and at N41° 23' 58.4" from W°70 38' 32.6" to W°70 38' 33.7" in the Willow Tree and Deep Bottom heads, respectively. We sampled two additional southerly transects at N41° 23' 13.6" from W°70 38' 37.0" to W°70 38' 33.7" within Willow Tree Bottom and at N41° 23' 03.9" from W°70 38' 50.2" to W°70 38' 47.7" in Deep Bottom.

The valleys are eroded into the late Wisconsinan outwash plains (Uchupi and Oldale, 1997). Soils within both bottoms are part of the Carver series, a coarse or loamy coarse sand. Soils along the banks of Deep Bottom are a sandy loam classified as the Riverhead series, while soils along the banks of Willow Tree Bottom are a very fine sandy loam classified as the Haven series (Fletcher and Roffinoli, 1986).

METHODS

We collected soil samples along transects in two spring sapping valleys on Martha's Vineyard to characterize soil texture. We assessed the extent that soil texture, topography, and canopy influenced microclimate variation using three combined approaches. First, we inferred thermal conductivity of different soil types by measuring the field capacity and porosity of soils within and adjacent to the valleys. Second, we used ArcGIS to assess the significance of the correspondence of scrub oak, low topography, and coarse soil types. Third, we logged temperatures within and outside a

spring sapping valley and at locations in order to assess the relative importance of soil type, canopy height, and topography on microclimate independent of one-another.

Soil Analysis

Throughout the northerly and southerly transects in Willow Tree Bottom and Deep Bottom, we sampled from 0-10cm and 20-30cm at three sub-sites: in the bottom of the valley, at the edge of the valley, and on the bank framing the valley. At each depth, we used an auger to collect samples for textural analysis and a 5-cm diameter metal corer to collect undisturbed cores for laboratory analysis of porosity and field capacity.

For textural analysis, sub-samples from each site were dried at 60 degrees Celsius and weighed. The dried sub-samples were wet-sieved in a 4 phi sieve, and the remaining material was dried at 100 degrees Celsius. The difference between the dry sample weight before and after wet-sieving was calculated to be the percent mud of the total sample. The remaining coarse material was then sieved through 9 sieves with phi sizes ranging from -4 to 4 to determine percent sand and gravel. Results from the textural analyses were plotted on a Folk diagram to classify sediment type.

Field capacity of undisturbed cores was measured by saturating cores with water in a tub lined with Scotch-bright pads. Upon saturation, cores were transferred to a dry tub, capped to prevent evaporation, and drained for 24 hours. Once drained, all samples were weighed, dried at 60 degrees Celsius, and weighed again. Field capacity (F_c) was calculated as a percent of the dried weight following the

$$\text{equation } F_c = \left(\frac{D_{\text{rainedweight}} - D_{\text{ryweight}}}{D_{\text{ryweight}}} \right) * 100.$$

I calculated bulk density of dry soil after drying samples of known volume for 48 hours at 60 degrees Celsius. I calculated porosity (%P) from bulk density following the

$$\text{equation: } \%P = \left(1 - \frac{B_{\text{ulkdensity}}}{P_{\text{articaldensity}}} \right) * 100, \text{ where particle density was assumed to be } 2.65$$

grams/cm³, the value of the dominant mineral in the soil, quartz (Brady and Weill, 1996).

For purposes of discussion, results from northerly transects are called ‘upstream’ and southerly transects are called ‘downstream’. I averaged all results from both valleys so that I considered one set of upstream results and one set of downstream results for all analyses.

GIS Analysis

We used ArcGIS to assemble maps that allowed us to assess the correspondence of scrub oak vegetation, coarse soils, and topographic lows. We collected a vegetation map, soil map, and a 5m resolution digital elevation model (DEM) of Martha’s Vineyard from the Nature Conservancy, the Dukes County Soil Survey (Fletcher and Roffinoli, 1986), and Mass GIS, respectively. We clipped all three maps to the area of the 21,470 hectares of Manuel F. Correllus State Forest in order to confine our study area to a region of minimal human disturbance.

We divided the soil layer into a Carver series (coarse soils) layer, a Haven series (fine soils) layer, and a layer of all other soils. We chose these particular soils because they represented the two texture extremes of the State Forest. We divided the vegetation layer into a scrub oak layer, and a layer of all other vegetation. We divided the DEM into

a low elevation layer and a high elevation layer. Because the terrain has a regional southeasterly dip and we sought to define local changes in elevation, we divided the State Forest into an east region and west region and defined topographic lows as land below 16m in the former and below 18m in latter.

In order to test the correspondence between scrub oak and coarse soils, we executed the following four intersections: scrub oak on Carver soils, scrub oak on Haven soils, all other vegetation on Carver soils and all other vegetation on Haven soils. Similarly, we created four new layers to investigate the correspondence of topographic lows and scrub oak topographic highs, scrub oak, and all other vegetation in the same way, creating four layers. Finally, we tested the correspondence of topographic lows, topographic highs, coarse soils, and fine soils. We assessed the statistical significance of each case by applying a Chi-square test to the areas of each of the four intersected layers.

Microclimate Analysis

We deployed ten HOBBO H8 temperature loggers from November 11, 2008 until December 3, 2008. We tested for variation in temperature extremes within and outside a spring-sapping valley by deploying four loggers in Deep Bottom, two in the upstream middle and bank and two in the downstream middle and bank. We tested for the effect of canopy cover on microclimate variation by launching two temperature loggers within a scrub oak thicket and two within a tree oak forest, while elevation and soil type, as designated by the Dukes County soil survey, remained constant. We tested the strength of topographic control on microclimate by deploying a logger within a topographic low and a topographic high, where soil and canopy cover remained constant. We then compared the average daily temperature minimums, maximums, and ranges of each case and defined the predominant factor as the case of the widest range.

RESULTS

Soil analysis

Soil samples collected upstream at 0-10cm depth from the middle, edge, and bank of the valley classified as slightly gravelly muddy sand on Folk's diagram (Figure 2). Among these three sites, the middle had the largest sand component and the bank had the largest mud component. A total of approximately 75% of each of these samples fell fairly evenly within phi sizes <4, 2, and 1 (Figure 3a).

Downstream at 0-10cm depth the middle, edge, and bank soils sorted as gravelly sand, slightly gravelly sand, and gravelly muddy sand, respectively (Figure 2). Middle and edge soils sorted most heavily into phi values 1 and 2, while bank soils maintained the highest percentage of material <4 phi (Figure 3b).

Soil samples collected upstream at 20-30cm depth from the middle, edge, and bank of the valley classified as gravelly muddy sand on Folk's diagram (Figure 4). Among these three sites, the middle had the largest gravel and sand components, and the bank had the largest mud component. These soils were poorly sorted (Figure 5a).

Downstream at 20-30cm depth, middle and edge soils classified as slightly gravelly sand while bank soils retained their upstream classification of gravelly muddy sand (Figure 4). Middle and edge soils sorted most heavily into phi values 1 and 2, while banks soils maintained the highest percentage of material <4 phi (Figure 5b).

Upstream and downstream soils at 0-10cm retained an average porosity of 60%, with values varying only slightly in the middle and on the bank, and shifting from 68% upstream to 50% downstream on the edge (Figure 6a). Percent porosity decreased with depth at all sites but did not vary greatly between upstream and downstream soils. Percentages increased slightly from the middle of the valley to the bank (Figure 6b).

Field capacity in soils upstream and downstream at 0-10cm did not show distinct trends across the width of the valley. Porosity decreased by approximately 20% with depth at all middle sites and upstream edge sites, and decreased by approximately 10% in downstream edge sites and all bank sites (Figures 7a and 7b).

GIS Analysis

A significant positive correspondence existed between scrub oak and carver soils in the Correllus State Forest on Martha's Vineyard (Figure 8a). Topographic lows positively corresponded with carver soils and negatively corresponded with haven soils (Figure 8b). Topographic lows did not significantly correspond with scrub oak vegetation within the entire state forest (Figure 8c). However, topographic lows highly significantly corresponded with scrub oak within a designated study site of a smaller area (3,954 hectares) (Figure 8d).

Microclimate Analysis

The average daily temperature range was wider within the middle of Deep Bottom than on the bank of Deep Bottom, with values of 18 and 13 degrees Celsius and an average minimum of -4.8 and -1.9 degrees Celsius, respectively (Table 1). When we assessed canopy height independent of soil texture and topography, the average daily temperature range was wider in sites with a low canopy by 4.3 degrees Celsius. We did not detect a great difference in temperature range in sites in which we assessed soils independent of canopy height and topography. Sites in topographic lows had a temperature range 1.2 degrees Celsius wider than sites on topographic highs.

DISCUSSION

Soil Analysis

The downstream loss of mud in middle and edge soils is likely evidence of their fluvial deposition in a process by which seeping groundwater entrained sediment from upstream material, deposited coarse material downstream, and carried the finest material further south and into the sea. We do not see a loss of mud in soils from the valley bank because they were not subjected to this fluvial environment (Figures 2 and 4).

Despite the likelihood that fine material transport to the sea can account for the loss of mud we found downstream, our observed coarsening of sediments downstream (Figure 2) contradicts the typical downstream fining of material in glaciofluvial environments (Reeding, 1996). This contradiction likely resulted from processes unique to spring-sapping. For example, when the water table falls below the base of the valley head during spring-sapping, outflow and grain movement cease locally but may recur farther downstream where the water table still intersects the channel (Higgins, 1982). This process disrupts typical fluvial sediment sorting patterns, and complicates our analysis of our soils and the paleoenvironment of Martha's Vineyard. Still, because middle and edge soils were better sorted downstream than they were upstream, and bank

soils were well sorted both upstream and downstream, we can infer an over-arching occurrence of downstream fluvial sorting within the valleys (Figures 3 and 5).

The absence of a width and length-wise trend in field capacity and porosity despite the differences in texture suggests either the difference in texture were not large enough to impact the soils water holding capacity, or that our methods of measuring field capacity were flawed. Fletcher and Roffinoli (1986) list a moderate available water capacity in Haven soils and a very low water capacity in Carver soils, suggesting that the difference in grain does significantly influence the water content of the soils. Had we measured field capacity in situ rather than in the laboratory, we likely would have collected more accurate measurements.

The decrease in porosity with depth correlates with an increase in grain size (Figures 2, 4 and 6), and is thus likely the result of compaction due to overlying weight and grain interlocking.

GIS Analysis

GIS analysis confirmed that scrub oak tend to colonize Carver soils, and that Haven soils tend to exist more frequently on topographic lows than on topographic highs. We attribute our inability to detect a significant relationship between topographic lows and scrub oak vegetation within the state forest to the crudeness of our topographic definitions within the DEM. Bennie et al. (2008) addressed the challenges of gaining high resolution topographic data from DEMs by creating a model that divides the landscape into a number of slope angle categories. Dividing slope angles into discrete categories can produce a slightly “stepped” distribution that lessens with increased categories. We modified this modeling approach by clipping layers to a smaller (3,954 ha) study area that contained Willow Tree Bottom and Deep Bottom. We successfully detected local topographic lows within this smaller study area, and found a positive relationship between scrub oak vegetation and topographic lows. We expect that, had we assessed relative elevation change by dividing the land into increasingly smaller and more numerous sub-plots, we would have found more accurate and significant relationships between soil type, vegetation, and topography throughout the entire state forest.

Microclimate Analysis

We found that canopy height had a larger impact on microclimate variability than did topography, and that topography had a slightly larger impact than did soil texture (Figure 8). Motzkin et. al (2002) also found that canopy cover was the most important of the three factors controlling microclimate. We can attribute this tendency to the canopy’s ability to reduce incoming and outgoing radiation, diminish wind velocity and eddy diffusion, increase humidity, and reduce evaporation (Geiger, 1955). Russel and Hamilton (1955) note that the canopy height’s influence on wind velocity is especially important in controlling local temperature fluctuations.

Topographic influence on temperature can arise from topographic differences of only a few tenths of a meter. In the absence of wind, nighttime increase in density of cooled air causes it to drain into topographic depressions and form more extreme temperature fluctuations than would occur on a level plain. However, such an effect only occurs under stable atmospheric conditions (Geiger, 1955). With unstable atmospheric conditions, overcast skies, and strong winds, the terrain has little effect on the surface air

temperature. Also, as the slope of the terrain increases, airflow increases and pooling of cold air becomes less common. The relatively shallow slope of the spring sapping valley walls creates an ideal environment for cold air drainage and pooling.

The water content of soil impacts the air temperature near the ground, as heat capacity and thermal conductivity increases with soil water content (Geiger 1955). In a four year study of annual soil-moisture variations in Germany, Unglaube (1952) found water content in loess was always higher than in coarser soils. While this would suggest that the heat capacity of loess was greater than that of coarser soils, Unglaube found that annual temperature variation in the loess was greater than that in coarser soils. Alternatively, Yakuwa (1946) found that daily temperature ranges decreased from coarse to fine soils in a study done in Hokkaido, Japan. Still, studies on Trinidad soils found that thermal conductivity decreases with decreasing soil grain size as a result of increased pore space. Evidently, soil texture alone does not control thermal properties, but instead other properties, such as the mineral composition of soil, also influence pore space and thermal properties of soils (Neill, personal communication).

CONCLUSIONS

Our analysis shows that scrub oak growth significantly corresponds with spring sapping valleys composed of coarse grained soils. We have confirmed that these valleys experience extreme microclimate fluctuations, and that these fluctuations are most heavily driven by low canopy and cold-air drainage. Thus, the correspondence of coarse soil texture and scrub oak appears simply to be a byproduct of valley formation, as soil alone does not influence the microclimate. These results suggest that, with the initial influence of cold air drainage, scrub oak can better compete with tree species susceptible to late spring frosts and establish a low canopy that maintains an extreme microclimate and self-perpetuates future success. This self-perpetuation of scrub oak thickets in spring sapping valleys lessens the need for tree-oak removal and makes spring sapping valleys economical regions for future management projects.

ACKNOWLEDGEMENTS

Thank you, Chris Neill, for encouraging me to pursue this project and for guiding me enthusiastically to its completion. Thanks, Rich McHorney, for introducing me to the concept of spring-sapping valley formation, and for guiding me through all of the geological endeavors of the project. Thanks to Paliza Shrestha, Vania, Amy Markstein, and Jessica Kunke for accompanying and assisting me in the field. I greatly appreciate the resources and guidance provided by Larry Poppe and Kate McMullen at the USGS in processing my soils for textural analysis. My ArcGIS work would not have been possible without the extensive assistance from Melanie Hayne. Thanks to all of the PIs involved with SES, Jen Peterson, Amanda Keledjian, and all of my classmates who have all been unceasingly supportive and great to work with for the semester.

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FIGURES

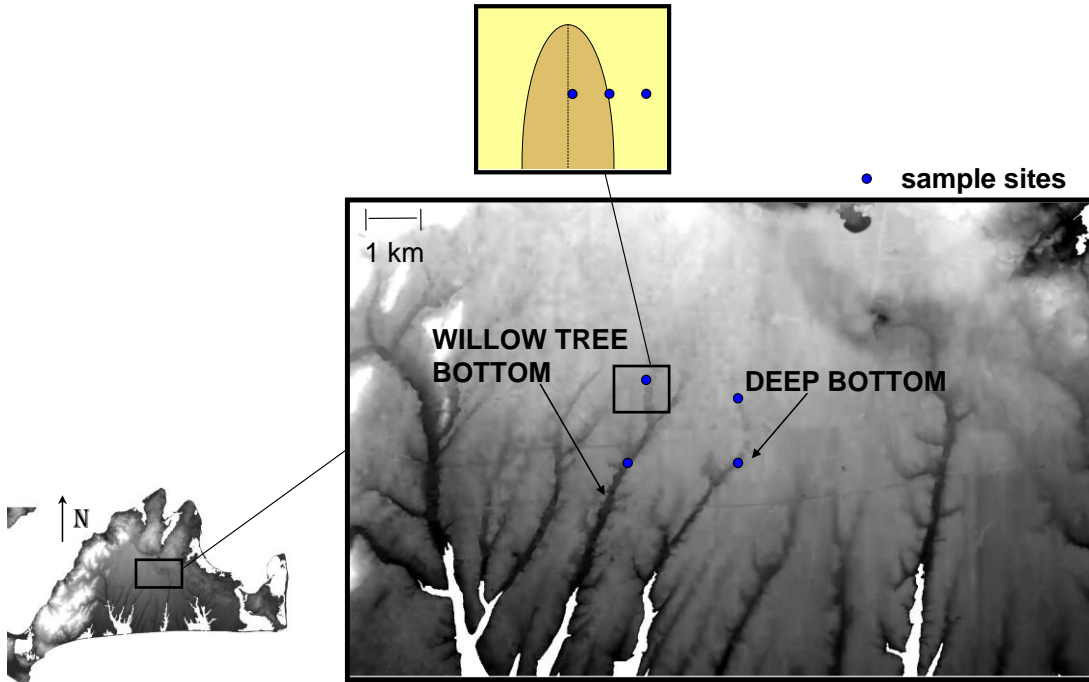


Figure 1- Map of study sites on Martha's Vineyard. Top diagram shows the relative location of each of the three sub-plots sampled at each site.

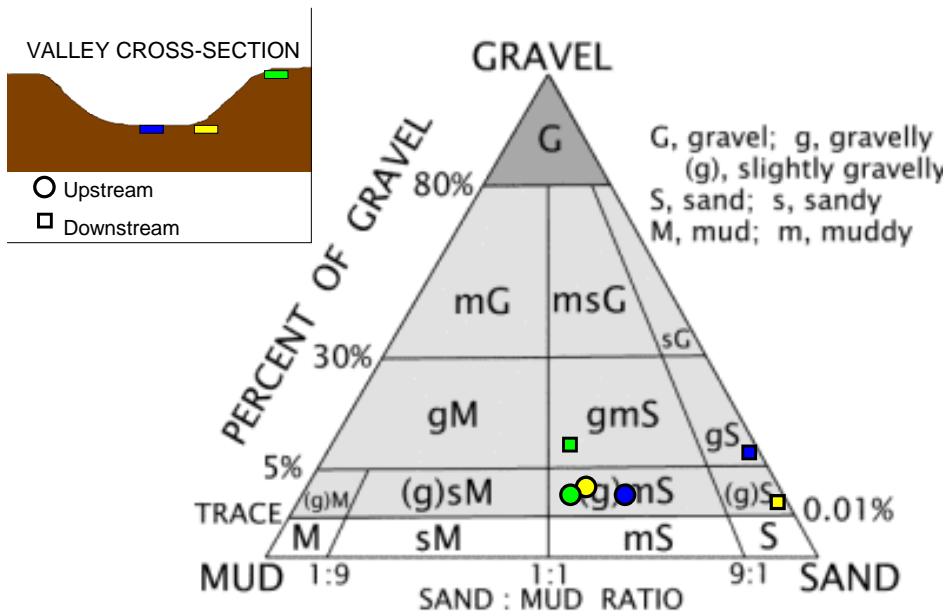


Figure 2- Soil samples collected from 0-10cm plotted on Folk's texture classification pyramid

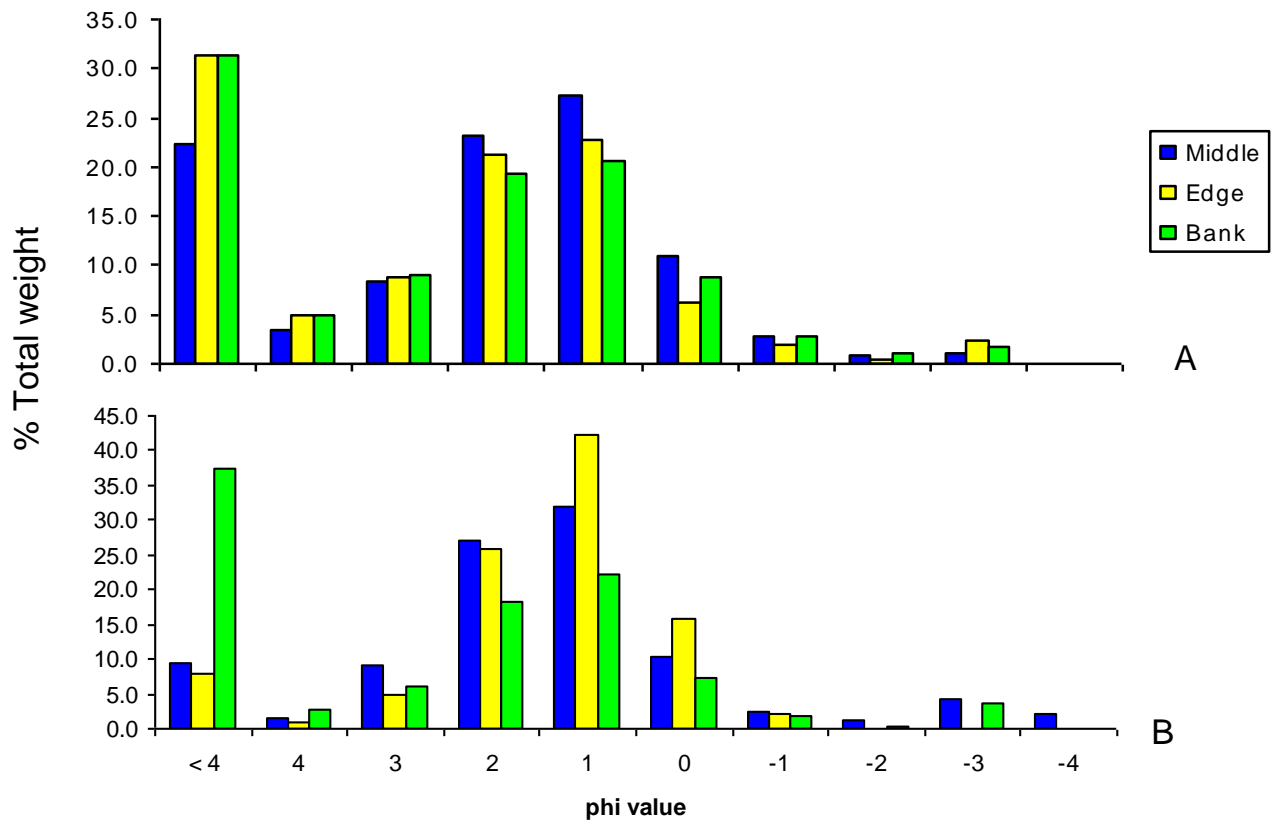


Figure 3- Sediment texture distribution across a valley upstream (A) and downstream (B) at a depth of 0-10 cm.

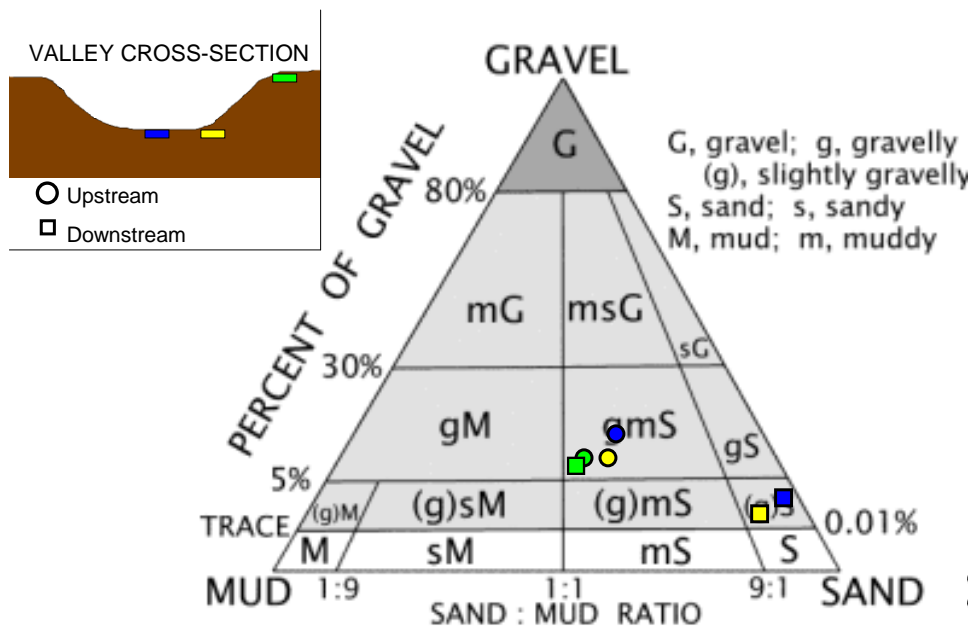


Figure 4- Soil samples collected from 20-30cm plotted on Folk's texture classification pyramid

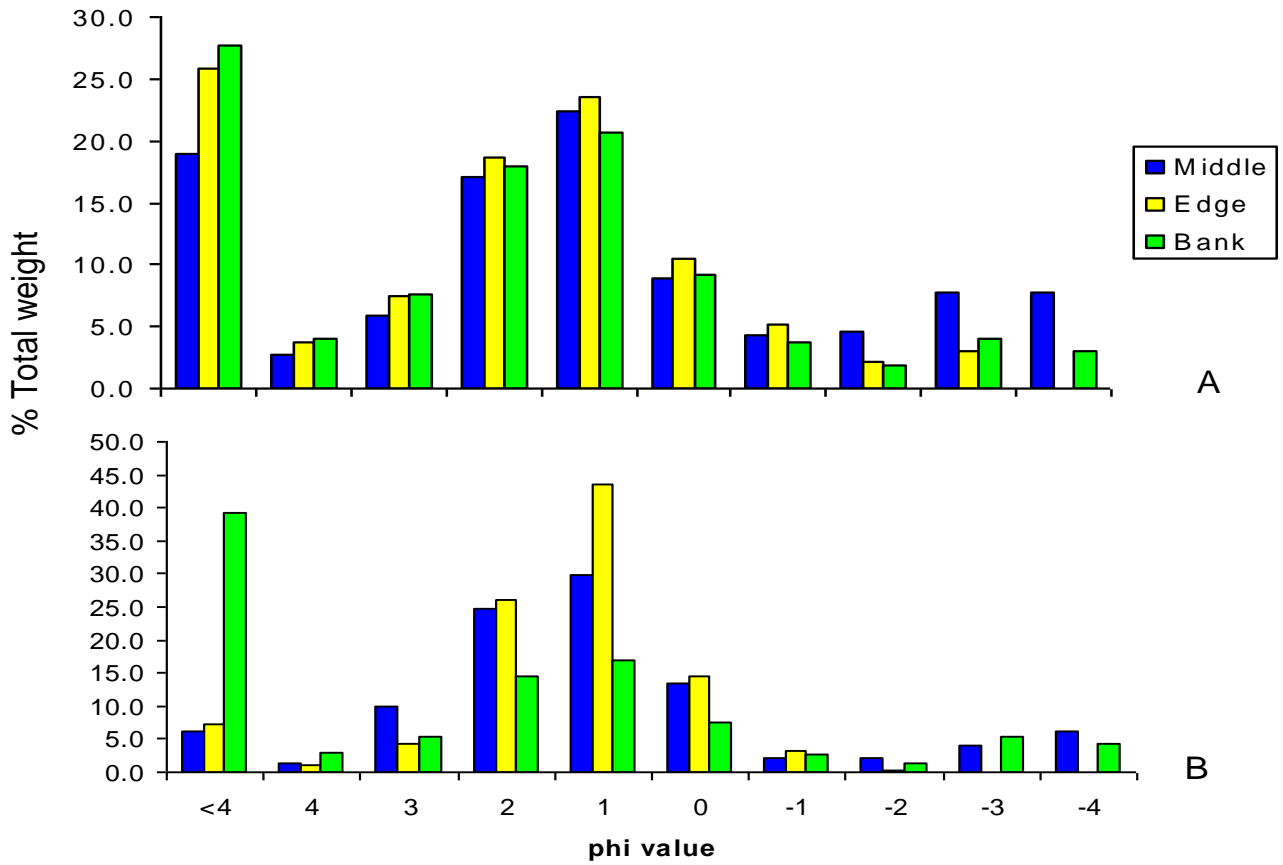


Figure 5- Sediment texture distribution across a valley upstream (A) and downstream (B) at a depth of 0-10cm.

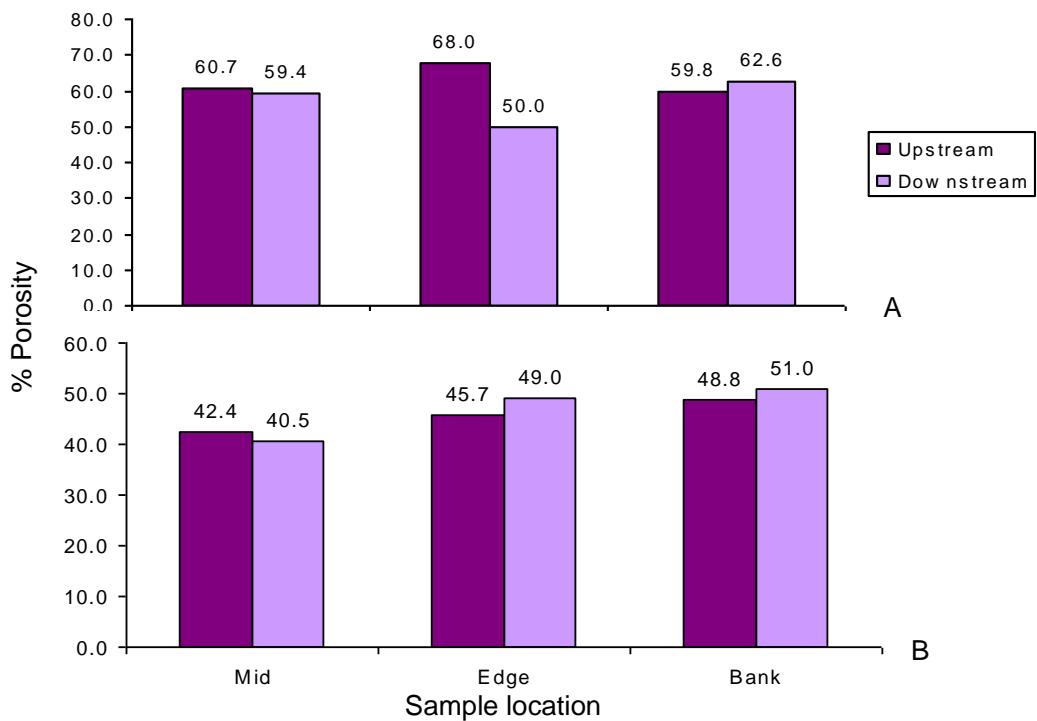


Figure 6- Porosity (%) across a valley at depths of 0-10cm (A) and 20-30cm (B).

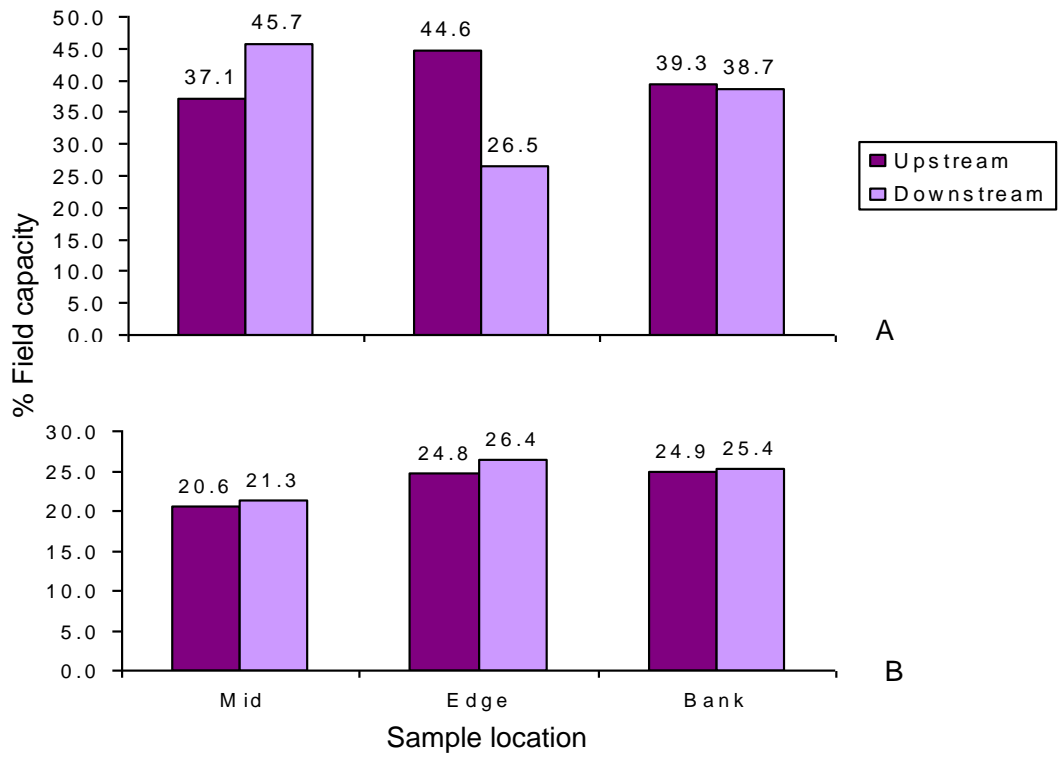
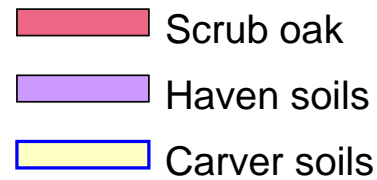
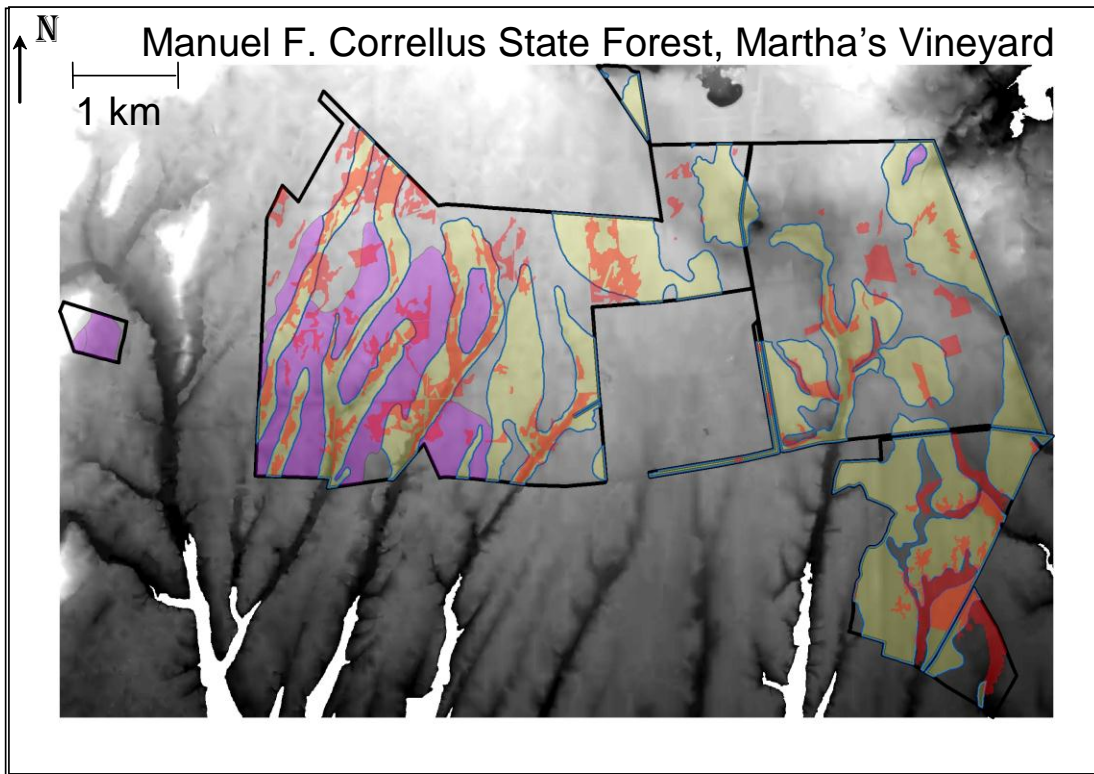
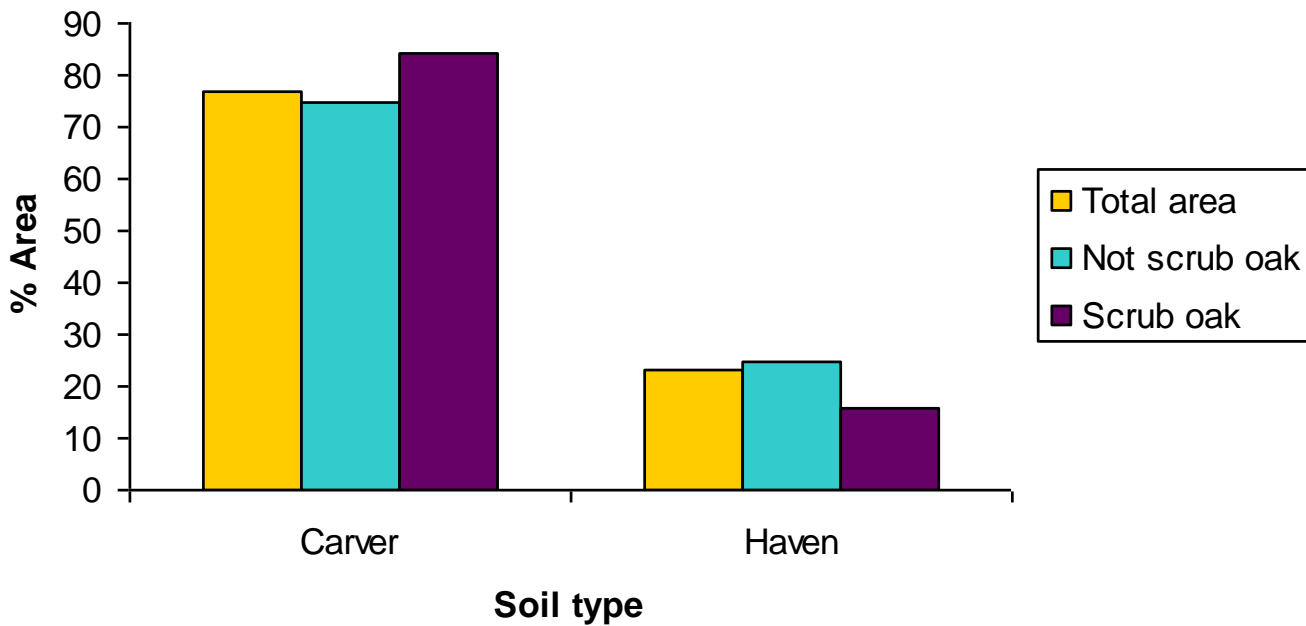


Figure 7- Field capacity across a valley at depths of 0-10cm (A) and 20-30cm (B).



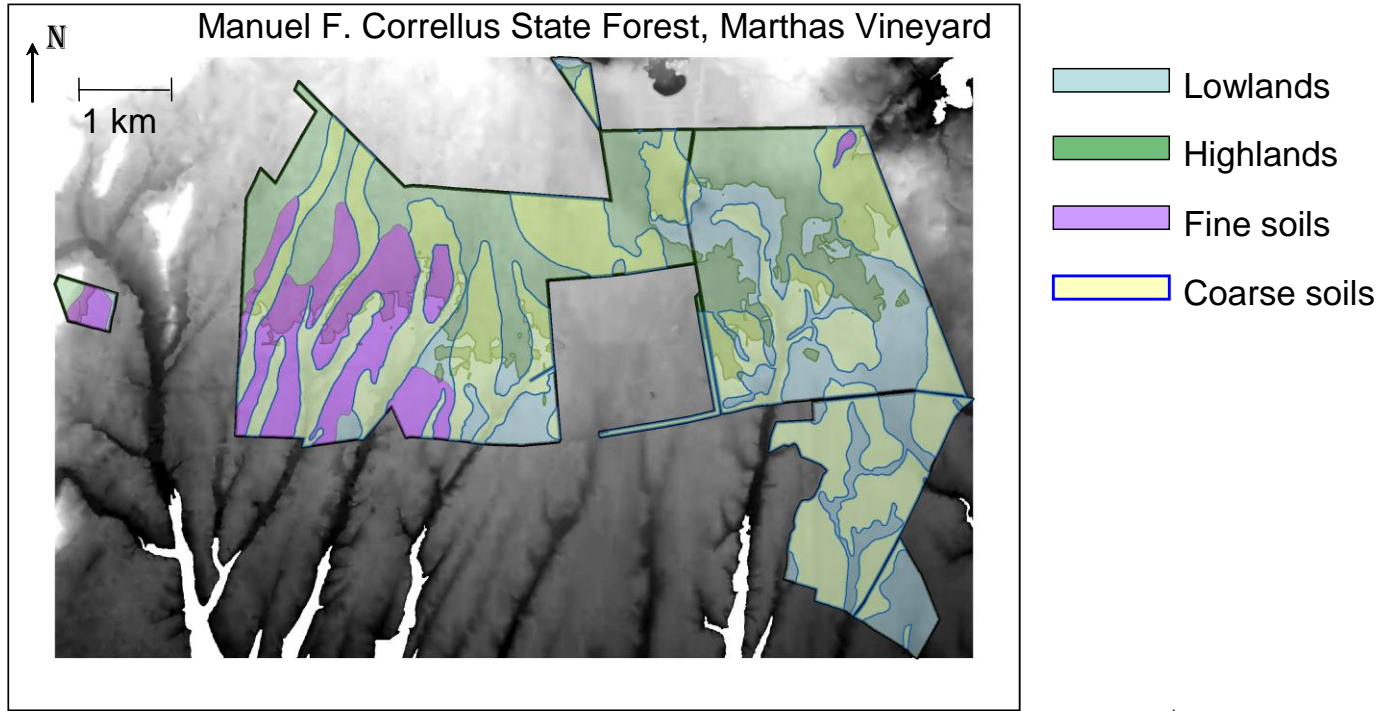
Chi-square $p < 0.001$

A



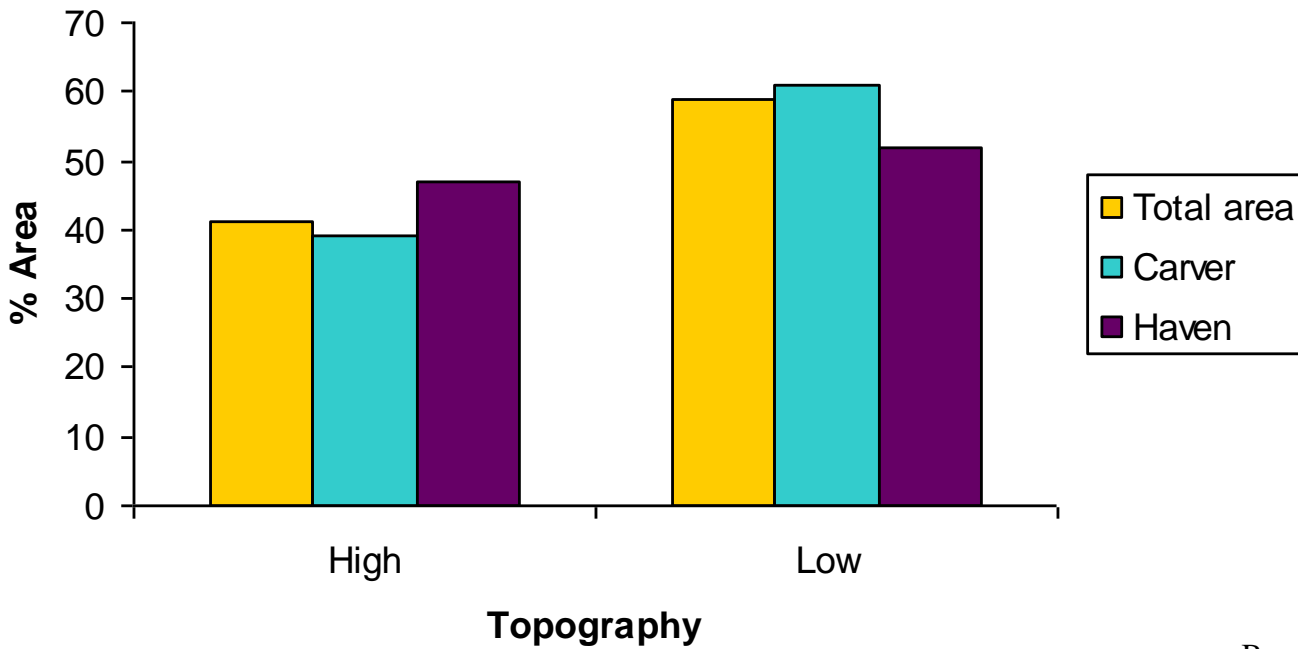
B

Figure 8- Occurrence of scrub oak on coarse (Carver) and fine (Haven) soil types within the State Forest (A). Distribution of scrub oak and all other vegetation on coarse and fine soils relative to the total area of each soil type (B). Values represent the overlap of layers from (A).



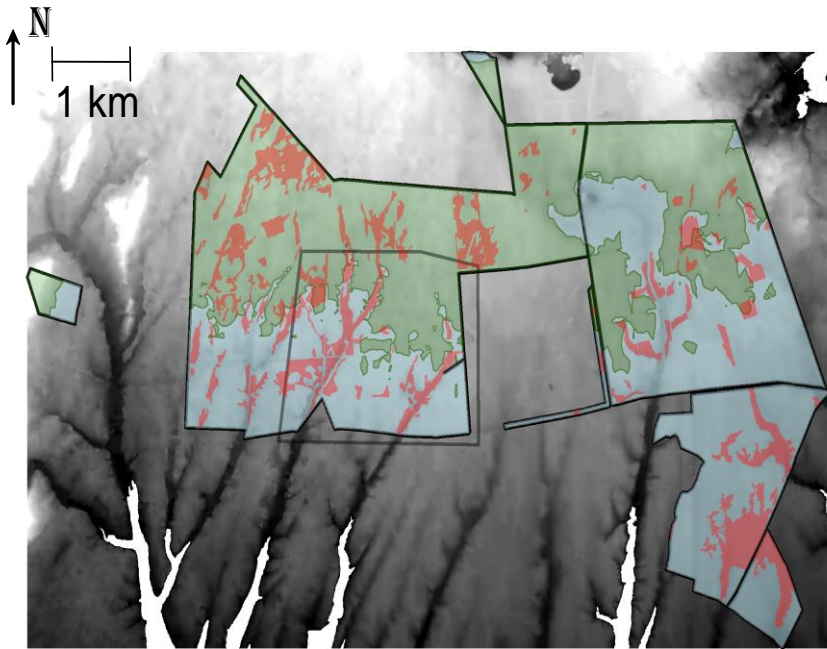
Chi-Square test $p < 0.001$

A



B

Figure 9- Occurrence of Carver and Haven soils on highlands and lowlands (A). Distribution of Carver and Haven soils on highlands and lowlands relative to the total area of each topographic category (B). Values represent the overlap of layers from (A).



Manuel F. Correllus State Forest, Martha's Vineyard

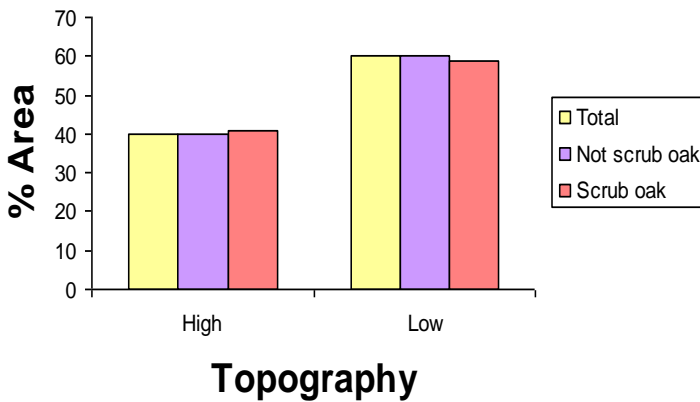
Lowlands

Highlands

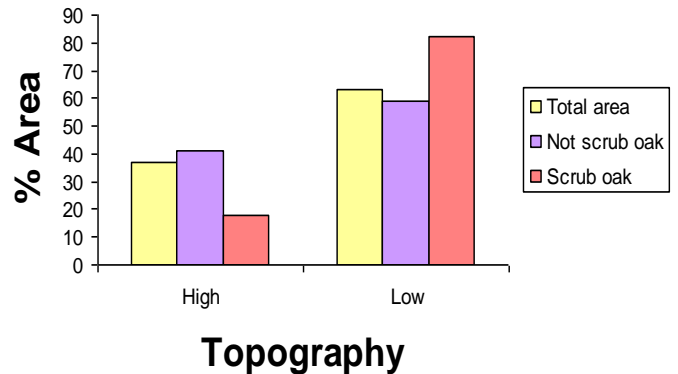
Scrub oak

Chi-Square test $p > 0.05$ throughout State Forest,
 <0.001 within study area

A

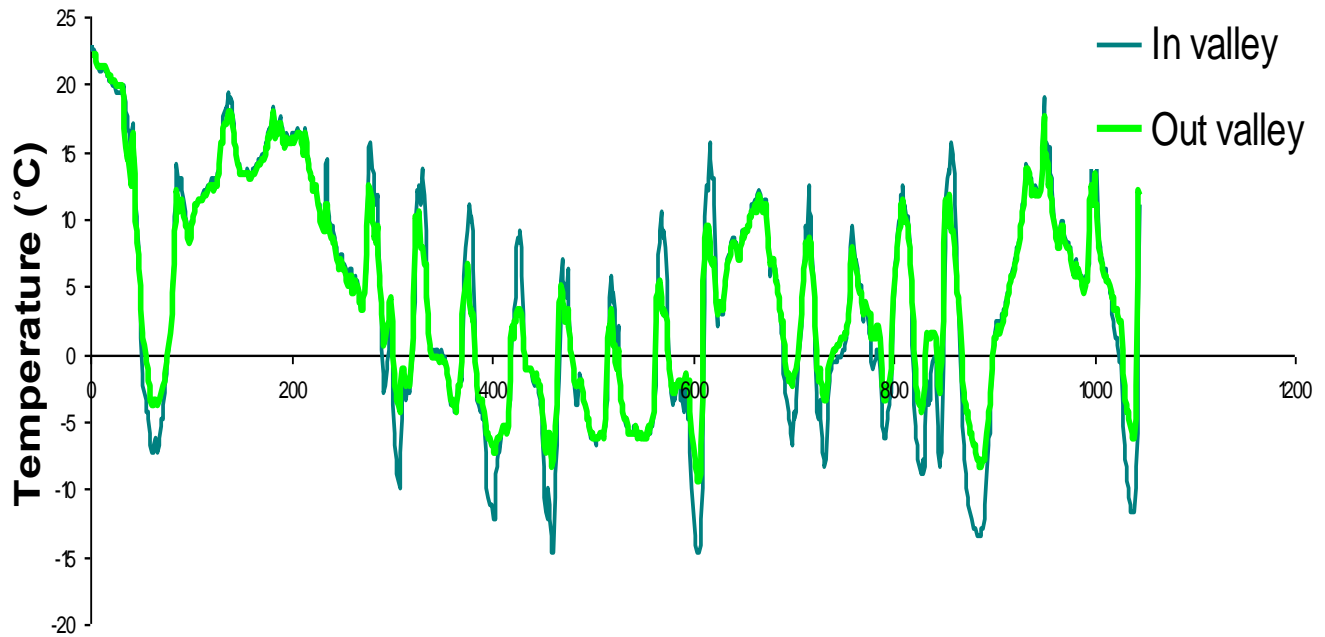


B



C

Figure 10- Occurrence of scrub oak on highlands and lowlands within the State Forest, and within a smaller study site demarked in gray (A). Distribution of scrub oak and all other vegetation on lowlands and highlands relative to the total area of each topographic category within the State Forest (B) and confined to the smaller study area (C).



1/2 Hours after logger deployment

A

VARIABLE		AVG. DAILY MIN. (°C)	AVG. DAILY RANGE (°C)
Canopy height	<i>Low (scrub oak)</i>	-4.0	17.0
Canopy height	<i>High (tree oak)</i>	-2.3	12.7
Soil texture	<i>Coarse</i>	-1.9	13.8
Soil texture	<i>Fine</i>	-1.9	13.0
Topography	<i>Low</i>	-4.8	18.4
Topography	<i>High</i>	-4.7	17.2

B

Figure 11- Daily temperature data within and outside Deep Bottom (A) and from sites in which each microclimate-controlling factor was addressed independently of one-another (B) over a course of twenty days.