The Effect of Topography on Soil Characteristics, Diversity and Biomass in Interior Plots of SUNY Old Westbury Forest

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ABSTRACT

Certain topographical features e.g., percent slope can promote water runoff and an export of nutrients which impact soil properties, vegetation diversity, biomass, and carbon storage. Prior studies about the relationship between topography, edaphic attributes, and vegetation above-ground concern a few species of plants, roots measurements, or vegetation restoration efforts in areas that do not fall under the current temperate forest map. Thus, the effect of topography on characteristics of soil and vegetation is largely unknown in temperate forests such as our study site. Our study investigated the relationship between topographical variation among the three permanent, interior forest plots at SUNY Old Westbury forests and its impact on vegetation's diversity, biomass, carbon storage, and soil characteristics. Specific objectives included the comparison of topographic and physicochemical soil features (percent slope, elevation, aspect, soil texture, density, and pH), in relation to α and β-diversity of the plots, and productivity measured as biomass and carbon accumulation based on mean diameter at breast height. We also compared the dispersion pattern for each tree species and rank abundance curves in the plots. This study found that the interior plot with the lowest percent slope (5%) had the highest average biomass (18687.72 Kg. ha^{-1}), average carbon storage (8876.67 Kg. C. ha^{-1}), percent water content (40%), percent relative humidity (25%), and the most dominant/codominant trees with the highest mean diameter at breast height (41.87 cm). However, the relationship between the highest α-diversity in the plot with the highest percent slope needs to be explored further.

Introduction

Forests cover 30% of the earths land surface, accounting for 50% of the primary production (Keenan et al., 2015, Llado et al., 2018). Approximately 45% of the carbon on land is tied up in forests (Suzuki et al. 2004, Llado et al., 2018). They also provide a stratified habitat for many plants and animals, and many services of economic value to humans like timber and recreational facilities (Cardenas et al., 2015, Wood et al., 2017). Deciduous forests account for only 5.3 % of earth's land surface and their net primary productivity ranges from 600–1500 g m-2 yr-1(Vasseur, 2012; Forseth, 2010). Historically deciduous forests have been exploited for logging, clearing for agricultural uses and eventually urbanization (Vasseur, 2012). It is estimated in Central Europe only 1% of the original forests remain (Donoso, 1997). The permanent forest plots located at SUNY Old Westbury campus are part of a temperate forests situated approximately at 40.795506 °N, -73.0571704 °W. Our study site is in a 100-acre mixed hardwood forest patch located within the SUNY College at Old Westbury campus on Long Island's North Shore with a diverse topography ranging in altitudes between 100 ft to 400 ft (approximately 30 m to 122 m) (New York Water Science Center, 2017). The forest ecosystem is composed of both abiotic (for e.g., soil, temperature, and rainfall) and biotic (for e.g., flora and fauna of the forest) factors (Sher & Molles, 2022). Both factors affect the sustainable management of forests, and subsequently have immediate and long-term consequences on global health. It is understandable that there is interaction among land topography, the properties of soil, and the type of vegetation above it. The land topography includes study of factors associated with land such as land aspect, elevation and percent slope to name a few.

Topographical features of land affect the land's soil properties and vegetation. A recent study has elucidated that in topographic regions that are wetter, the fine root lifespans were longer and that the fine root lifespans were affected by soil's depth and series, season of birth and slope face orientation (Primka et al.,2021). Since roots are major parts of trees, their lifespan would have direct impact on the vegetation's growth, distribution, species and diversity. Another study noted that the slope and aspect had significant correlation with above-ground biomass and herb coverage, and additionally, the slope and aspect affected availability of nutrients such as nitrogen and phosphorus, soil water content, and soil's silt/sand/clay compositions (Wang et al., 2016). Since topographic factors influence the water and nutrient accumulation and run-off, it becomes crucial to study the impact of such topographic variation on diversity and biomass of vegetation. A better understanding of topography and its influence on forest biomes can help encourage practices for sustainable forest management in future.

This study of SUNY Old Westbury's permanent forest plots focused on the three interior plots and their topographical features such as aspect, elevation, and percent slope. Additionally, such topographic variation among the interior plots were used to compare the soil characteristics and vegetation's diversity, biomass, and carbon storage of the same plots.

Materials and Methods

Study site:

Our study site includes a 100-acre forest plot located within the SUNY College at Old Westbury campus on Long Island's North Shore. This land consists of mud, sand, gravel, and boulders eroded from Upstate New York and New England and deposited as part of the Harbor Hill Moraine and its outwash plain. Underlying bedrock is found at a depth of several hundred feet and is overlain by sediments of the Cretaceous period that were uplifted above sea level and eroded during the Tertiary period and later covered with glacial outwash and till which created the present-day landscape. The vegetation is that of a mesophytic hardwood forest that occurs on moist, well-drained sites in south-eastern New York.

Plot setup, tree identification and tree tagging:

In this study, there were three permanent forest plots assigned as interior plots: Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3. These interior plots were located ≤30 m from the forest edge. The geographical coordinates of the North-East corners for the interior plots were (40.79464°, -73.57104°), (40.794860°, -73.571440°), and (40.794540°, -73.571760°) respectively. The interior plots were located using a compass or an online Compass navigation app. The dimensions of the plots were determined and verified using a measuring tape. Each plot was 20 m x 20 m in size, and there were 5 m x 5 m grids (subplots) inside each plot. Therefore, there were 16 subplots inside each interior plot. The outmost corners of each interior plot and the subplots were demarcated with wire flags.

Every tree stem of at least 2.5 centimeters of diameter at breast height (DBH) was tagged with aluminum tags. If the trees have multiple stems arising from below the level of 1.37 m from the ground-above, each stem was tagged individually. All the trees were plotted in a plot map for each interior plot using the tag information. Utilizing the previous year's interior plot maps, trees within each interior plot were identified and verified with the help of tree tags.

Measurement of trees' diameter at breast height (DBH):

For every tree in the plot, the circumference of the stem at 1.37 m, ie. breast height, from the base of the tree was measured for each tree. Based on the circumference diameter at breast height was calculated using the formula,

$2r = \frac{C}{\pi}$ where r is the radius of the cross section of the stem, C is the circumference of the cross section of the stem, and π is the constant (π=3.1417). It was ensured that the measuring tape had to surround the stem and it had to be parallel to the ground for accurate measurement of the circumference.

Tree soundness:

For the stem soundness, the lower 5 m of the stem was assessed for solidity of wood, any damage or hollow cavity. The stem soundness was ranked from 1 to 3. If the stem appeared 95 to 100% solid in the lower 5 m of the stem, the tree was ranked a 1 indicating that there was no obvious cavity into the lower 5 m section of the stem. Any small cracks were not considered if the stem was otherwise solid. A tree was ranked 2 if the stem appeared 50 to 94% solid in the lower 5 m of the stem. In these trees, the stem had an opening that is >5% of its circumference, or a hollow core that comprised between 5 and 50% of the stem volume for most of the lower 5 m of the stem. Finally, if a stem appeared <50% solid in the lower 5 m of the stem, it was ranked a 3. In these trees, the stem had an opening that is >5% of its circumference, or a hollow core that comprised over 50% of the stem volume for most of the lower 5 m of the stem.

Tree crown class:

The forest stratification was classified based on the diameter at breast height (DBH). The trees that had the diameter at breast height >18 cm were classified a Dominant/Co-Dominant tree. These would be the highest trees and would make the top canopy of the interior forest plots. The trees that conformed to the parameter 8cm ≤DBH ≤18 cm were categorized as Intermediate canopy/trees. Finally, the trees with the diameter of breast height less than 8 cm were Overtopped canopy/trees.

Tree species identification:

The Trees Species Identification Guide and PlantNet app were used to identify all the trees that were tagged in each of the interior plot. The 6- or 7-character abbreviation for the scientific names of living trees were recorded. In the scientific names, the first three characters represented the first three letters of the Genus, and the last three characters represented the first three letters of the species. In scientific names that had seven characters, the seventh character was added to differentiate between the trees that would give same scientific names if only six characters were used. All the trees that were dead were recorded as SNAG. If the standing dead trees are leaning by less than 45°, they were inventoried; however, if they were leaning by more than 45°, they were included as downed trees.

Measurement of elevation, slope %, and aspect:

For the measurement of elevation, a study team member stood at the North-East corner or the highest point of each plot, and recorded the elevation using an online Compass navigation app. Then, for aspect measurement, an online compass was used. The compass was pointed towards the direction the slope of the plot was facing. The aspect was read in degrees and recorded between 0° to 360° as measured. Finally, for the measurement of slope %, a clinometer was used. Two study team members of the same height walked to the opposite uphill/downhill sides of the plot. One of the team members looked through the clinometer aiming at the height of the second team member that is equal to his/her eye level. The slope from the left side of the scale visible in the view finder was recorded (PFPP Protocol and Database).

Various webtools were utilized to obtain plot data such as Bailey's Ecoregion, mean annual air temperature, average annual precipitation, total precipitation preceding 12 months, and length of growing days. Other data was collected from the field (Accuracy Project, https://www.accuracyproject.org/w-FreezeFrost.html; Forest Service U.S. Department of Agriculture, www.fs.usda.gov; Weather Underground, https://www.wunderground.com/history/; USGS, https://www.usgs.gov; Planta Greenhouses, www.plantagreenhouses.com; Long Island Sound Study, https://longislandsoundstudy.net/; Current Results, https://www.currentresults.com/).

Soil studies (gravimetric study): %relative humidity, pH, %water content, bulk density, and particle density (Gravimetric Soil Moisture Protocol, Lab Guide)

Soil sample collection

Four samples of soil were collected from four separate subplots of each interior plot. For collection of soil samples, litter on the ground was removed to gain access to the soil. Then, a soil core borer (which had a diameter of 2 cm) was planted into the ground in the subplot of interest. The soil core borer was pressed down until at least half the length of the soil core borer was inside the ground. If the soil core borer hits something hard at shallower depth, a different location was used for soil sample collection. Then, the soil core borer was removed from the ground ensuring that the soil it collected did not fall off. Further, a ruler was used to measure the height (h) of the core for the soil sample collected. The soil samples were then immediately stored in individual Ziplock bags to prevent the soil from drying out. Utilizing the radius of the soil core borer and height of the soil core, volume of the soil sample was calculated for each soil sample using the formula: Volume $(V) = \pi \cdot r^2 \cdot h$.

% Relative humidity and pH

In the field, a pH and % relative humidity meter was used at each soil sample location to measure pH and % relative humidity of each soil sample. This cone-shaped meter had two scales: the top scale read pH and the bottom scale read %relative humidity. At each soil sample location, the meter was planted onto the ground. First, pH of the soil was recorded. Then, the button was held to measure the % relative humidity. It was ensured not to place hands on the metal portion of the meter such that any oil from hands can be avoided. Additionally, the meter was cleaned up in between two soil sample collections.

% Water content

As soon as the soil samples were brought to the lab, their wet mass was measured. For each soil sample, a piece of aluminum foil was placed on the weighing scale and the scale was tared. Then, soil sample was poured onto the aluminum foil ensuring that soil sample was not lost outside of the aluminum foil. The wet mass was recorded for each soil sample. Once the wet mass for soil samples were collected, they were stored in an oven at 100° C (approximately) for a week. Further, the % water content of the soil samples was calculated utilizing the Soil Study Protocol provided. For this measurement, the soil samples stored in an oven were taken out, and their dry mass was measured immediately. % Water content was calculated using the formula:

$$\%Water\ content = \frac{wet\ soil\ mass(g) - dry\ soil\ mass(g)}{dry\ soil\ mass(g)}.\ 100\%$$

Bulk density

For bulk density, a sieve with pores of 2 mm was cleaned first and it was weighed. Then, the soil samples were sieved individually to separate any particles (such as rocks) with more than 2mm in diameter. Soil samples were pressed down onto the sieve without bending the sieve. Additionally, a 100 ml cylinder was used to measure the volume of water. The rocks separated in the sieve were placed into the cylinder. The soil samples' dry mass, once the rocks were separated from the soil, was measured. Applying the Archimedes' Principle, the difference is the water volume from before placement of rocks and after the placement of rocks was the volume of rocks. Bulk density for each soil sample was calculated using the following formula:

$$Bulk\ density = \frac{\cdot\ dry\ soil\ mass\ (g)}{\cdot\ soil\ volume\ (cc\ or\ ml)}$$

where *soil volume is the difference between soil core volume (as calculated above) and rocks' volume (as calculated above), and *dry soil mass is the mass of soil after rocks were separated. Once the dry soil mass was measured, all the soil samples (without particles > 2mm such as rocks) were placed back into the oven at 100°C (approximately) for about a week.

Particle density

The soil samples (without particles > 2mm such as rocks) that had been in an oven were taken out of the oven, and 25 g of each soil sample was measured. For this, a piece of aluminum foil was placed on the weighing scale and the weighing scale was tared. Then, the soil sample was slowly placed onto the aluminum foil using a spatula until the soil sample weighed 25g. Each soil sample was placed into a 100 ml volumetric flask individually. Then, 50 ml of water was poured into each volumetric flask. Then, the mixture was boiled over a hot plate gently for 10 minutes (approximately). During the boiling process, the mixture was stirred for 10 sec every minute. After 10 minutes of boiling, the volumetric flask was removed from the hot plate and allowed to cool. Once the volumetric flask was cooled down thoroughly, the flask was capped, and the sample was stored for use the following week.

The following week, the cap of the volumetric flask was removed, and the flask was filled with water such that the bottom of the meniscus was at the 100 ml mark. The soil/water mixture in the flask was measured on a weighing scale without the cap, and its mass was recorded. The thermometer's bulb was placed into the mixture for about 2 to 3 minutes until the temperature measurement stabilized and the temperature was recorded. Finally, each volumetric flask was cleaned and dried out properly, and their individual mass (without cap) was measured in a weighing scale. The known value of density of water at that temperature measured, and mass of empty flask (without cap) were used to calculate particle density of the soil samples using the formula:

$$Particle\ density = \frac{Mass\ of\ soil\ (g)}{Volume\ of\ soil(ml)}$$

where mass of soil was 25 g (from above), and volume of soil was equal to the difference of 100ml (since water was filled up to 100 ml mark in the flask) and volume of water in the flask.

Biomass and carbon storage

To convert the diameter at breast height (DBH) into biomass and carbon storage, the following Biomass equation was used: $bm = Exp(\beta_0 + \beta_1 ln\ dbh)$ where bm is the total aboveground biomass (kg) for trees 2.5 cm and larger in dbh, dbh is the diameter at breast height (cm), Exp is exponential function, and ln is natural log base "e" (2.718282)

For all species group that are considered hardwood, parameters such as β_0 and β_1 were used for mixed hardwood (β_0=-2.4800 and β_1=2.4835). For White Spruce/ *Picea glauca* that was in Interior_Plot_3, species specific β_0 and β_1 (β_0 = 2.0773 and β_1= 2.3323) was used (Jenkins et al., 2004). For carbon storage calculation, it was assumed that 47.5% of a tree's biomass is made up of carbon. Each interior plot had a size of 20m x 20 m (which is equal to 0.04 ha).

Species richness, species evenness and β-diversity indices:

For calculating α-diversity for each interior plot,

$$Shannon - Wiener\ \alpha\ diversity\ index, H' = -\sum_{i=1}^{n} P_i \times \log_{10} P_i$$

where $P_i = \frac{number\ of\ individual\ species}{total\ number\ of\ individuals\ of\ all\ species}$

To understand species evenness,

$$Shannon's\ evenness\ index, J = \frac{H'}{H'_{max}}$$

where H' is Shannon-Wiener diversity index and H'_{max} is ln s in which s is the number of species per plot (Birhanu, 2021). Finally, β-diversity indices were calculated using $Bray\ Curtis, B - C = 1 - \frac{2C_{ij}}{S_i+S_i}$ where C_{ij} is the sum of the lesser values for only the species in common between both sites and $S_i + S_j$ is the total number of individuals of all species at both sites of comparison.

Non-metric Dimensional Scaling Analysis (NMDS):

Finally, to understand the relationship among multiple variables, such as tree species and soil characteristics, obtained from the three interior plots, NMDS ordination analysis was done using vegan package in the R Statistical Software (v4.2.2; R Core Team 2022 & v2.6.4; Oksanen et al. 2022).

Results

The topographic features noted in Table 1 include the elevation, aspect, slope, and landscape shape. The Interior_Plot_2 had the highest elevation at 78.94 m whereas the Interior_Plot_1 had the lowest elevation at 25 m. Even though the direction of aspect measurement were not provided for Interior_Plot_1 and Interior_Plot_3, the Interior_Plot_2 had aspect of 181°S. Furthermore, the %slope for Interior_Plot_1 was the highest at 13% and that of Interior_Plot_3 was the lowest at 5%. Finally, landscape shape for all the interior plots were reported at planar.

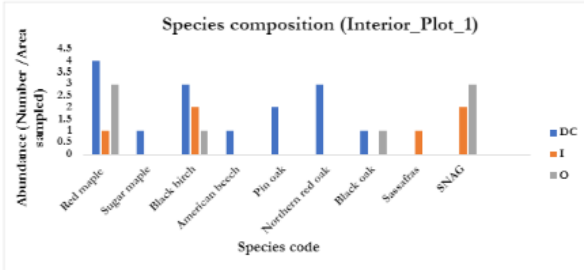
Interior plot 1 had 24 different trees, including 8 different species. As shown in Figure 2 below, Interior_Plot_1, had the greatest number of red maple (*Acer rubrum)* at 4 for dominant/codominant (DC) crown class. The numbers of Northern red oak *(Quercus rubra*), Black birch (*Betula lenta*), and Pin oak (*Quercus palustris*) followed at 3, 3, and 2 respectively for the same crown class. The intermediate (I) crown class was composed of red maple (*Acer rubrum*), Black birch (*Betula lenta*) and Sassafras *(Sassafras albidun*); The overtopped (O) crown class consisted of Red maple (*Acer rubrum)*, Black birch (*Betula lenta*) and Black oak (*Quercus velutina*). Interior plot 2 had 26 different treeswith only 4 species. As for interior plot 1, the most abundant tree species in the dominant/co-dominant crown class was red maple (*A.rubrum)* with 9 individuals. The intermediate crown class was composed of red maple (*A. rubrum)* and black birch (*B. lenta*); the overtopped crown class consisted also of red maple and American beech (*Fagus grandifolia)*. Finally, Interior_Plot_3 had a total of 22 trees. The plot had the highest number of Black birch (*B. lenta*) at 8 for dominant/codominant crown class. The intermediate crown class was composed of red maple (*A. rubrum)*, Black birch (*B. lenta*), and white spruce (*Picea glauca*); the overtopped crown class consisted of red maple (*A. rubrum)*, Black birch (*Betula lenta*) and Black ash (*Fraximus nigra*).

Therefore, Interior_Plot_1 had the highest number of species and Interior_Plot_2 had the lowest number of species even though Interior_Plot_2 had the highest number of trees.

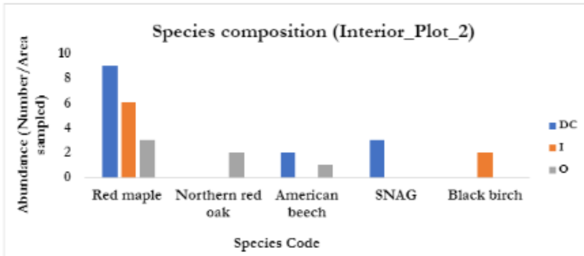
Table 1: Features of the three interior plots reported in Permanent Forest Plot data entry tool.

	Interior_Plot_1	**Interior_Plot_2**	**Interior_Plot_3**
Elevation	25 m	78.94 m	76.2 m
Aspect	263°	181°S	182°
Slope	13%	11%	5%
Landscape shape	planar	planar	planar
Longitude (of the NE corner of the plot)	-73.5704°	-73.57144°	-73.57176°
Latitude (of the NE corner of the plot)	40.7964°	40.79486°	40.79454°
Dominant groundcover	Forest floor: Leaf/woody litter cover 25-49% of the plot (FF)	Forest floor: Leaf/woody litter cover 25-49% of the plot (FF)	Forest floor: Leaf/woody litter cover 25-49% of the plot (FF)
Secondary ground-cover	Forest floor (FF)	Forest floor (FF)	Forest floor (FF)
Invasive species	No	No	Spruce tree
Vegetation typical	Yes	Yes	Yes
Wetland status	No	No	No
Disturbance history	Observed ants in general area and some disease in the form of fungus on fallen leaves	None	None
Urban status	Yes	Yes	Yes
Bailey's Ecoregion	Domain: Humid temperate Division: Hot continental Province: Eastern broadleaf forest	Domain: Humid temperate Division: Hot continental Province: Eastern broadleaf forest	Domain: Humid temperate Division: Hot continental Province: Eastern broadleaf forest
Mean Annual Air Temp (°C)	12.59 °	12.59 °	12.59 °
Average Annual Precipitation (mm)	1057.66 mm	1057.66 mm	1057.66 mm
Total precipitation preceding 12 months (mm)	892.05 mm	892.05 mm	892.05 mm
Length of growing days	165 days	165 days	165 days

(1a)



(1b)



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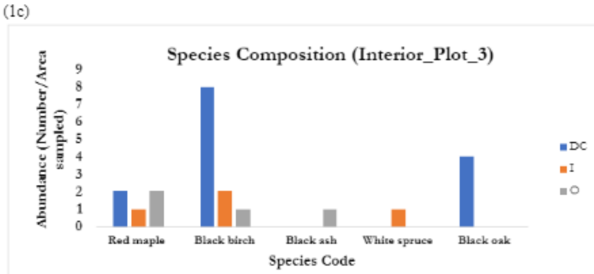

Figure 1: Species Composition. Species composition by crown class for Interior_ Plot_1, Interior_Plot_2, and Interior_Plot_3 was represented in Figure 1a, Figure 1b and Figure 1c respectively. DC=Dominant/Codominant crown class. I=Intermediate crown class. O=Overtopped crown class. The abbreviation SNAG represented “dead tree”. There were 4 trees in Interior_Plot_3 that were marked “X” for dead trees.

Additionally, Figure 2 shows the mean diameter at breast height (DBH) of trees for each crown class for the three interior plots. For dominant/codominant (DC) crown class in Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3, the mean diameter at breast height was 37.36 cm ±0.61. 28.19 cm ±3.12 and 41.87 cm ±4.59 respectively. For intermediate(I) crown class in Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3, the mean diameter at breast height were 16.44 cm±0.88, 13.39 cm ±0.83 and 12.96 cm ±1.46 respectively. Also, for overtopped (O) crown class in Interior_Plot_1, Interior_Plot_2, and Interior_Plot_3, the mean diameter at breast height were 4.91 cm ±0.74, 3.68 cm±0.74 and 4.7 cm ±0.62 respectively. Therefore, Interior_Plot_3 had the highest mean diameter at breast height (at 41.87 cm) for dominant/codominant crown class, and the lowest mean diameter at breast height (at 4.7 cm) for overtopped crown class among all the interior plots.

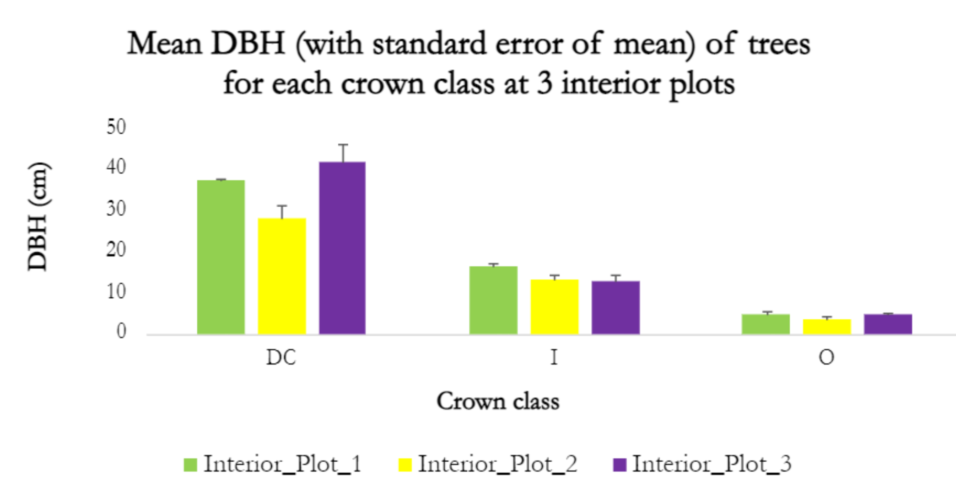

Figure 2: Mean diameter at breast height (with standard error of mean) for each crown class. For Interior_Plot_1, all dead trees had DBH measurement reported, and so they were included in this figure. For Interior_Plot_2, the two dead trees were standing, and their DBH measurements were reported and included here. For Interior_Plot_3, four dead trees did not have DBH measurement reported, and so they were excluded here. Additionally, for Interior_Plot_3, one Red maple (*Acer rubrum)* did not have DBH measurement reported, and therefore, it was excluded in this data.

Table 2 displays various soil characteristics assessed from soil samples obtained from the three permanent, interior plots. Additionally, Figure 3 shows the soil features for the three plots including mean bulk density, mean particle density, mean % relative humidity, % water content, and mean pH for four soil samples that were collected from each interior plot. Mean bulk density for Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3 was 0.54 g/ml ±0.07, 0.79 g/ml ±0.06 and 0.61 g/ml ±0.05 respectively. Mean particle density for Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3 was 2.21 g/ml ±0.63, 2.24 g/ml ±0.26 and 2.09 g/ml ±0.03 respectively. Similarly, mean % relative humidity for Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3 was 23.75% ±2.23, 22.5% ±4.33 and 25% ±2.89 respectively. Mean % water content for Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3 was 26.27% ±3.79, 17% ±1.99 and 40% ±12.09. Lastly, mean pH for Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3 was 6.25±0.06, 6.15±0.13 and 6.2±0.10 respectively. Therefore, Interior_Plot_3 had the highest mean bulk density (at 0.61 g/ml); Interior_Plot_2 had the highest mean particle density (at 2.24 g/ml); Interior_Plot_1 had the highest mean pH (at 6.25). Most notable was that the Interior_Plot_3 had the highest mean % relative humidity (at 23.75%) and % water content (at 40%).

Table 2: Soil characteristics from the three interior plots.

Soil samples	Bulk Density(g/ml)	Particle Density(g/ml)	%Relative Humidity	%Water Content	pH
Interior_ Plot_ 1	0.543	2.208	23.75	26.277	6.25
Interior_ Plot_ 2	0.791	2.237	22.5	17	6.15
Interior_ Plot_ 3	0.609	2.097	25	40	6.225

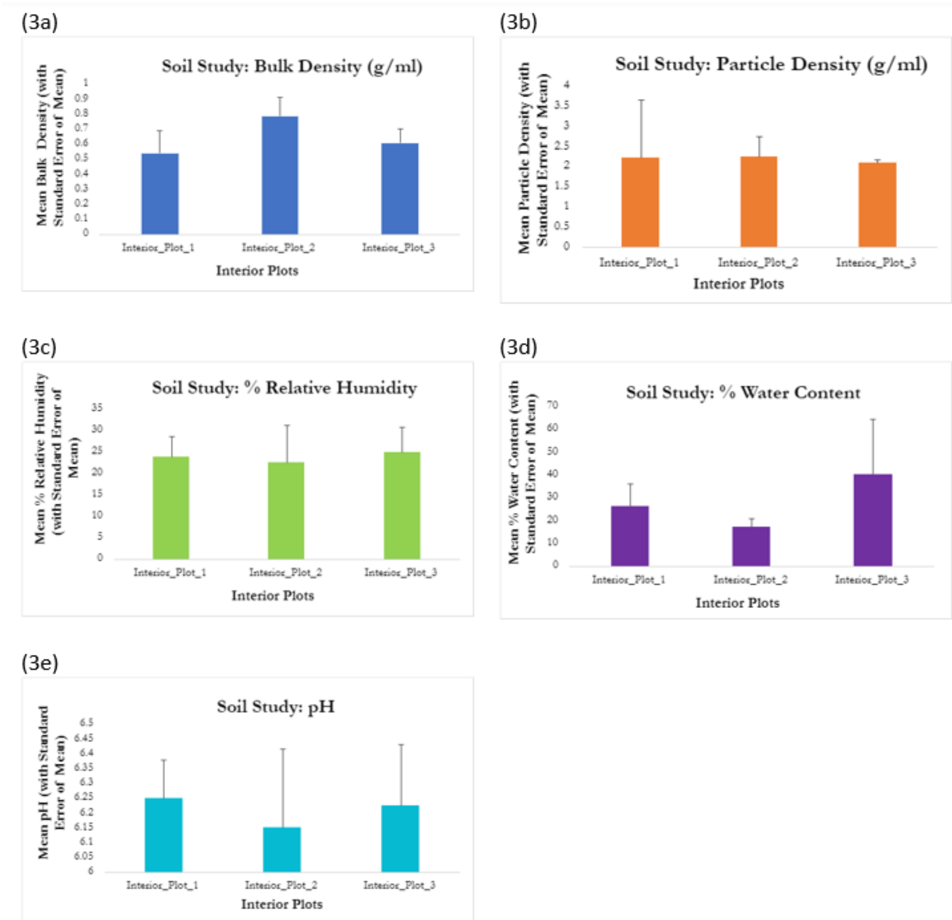

Figure 3: Soil Study-Bulk density, particle density, percent relative humidity, percent water content, and pH. All data were reported with standard error of mean. Figure 3a shows mean bulk density for 4 samples of soil collected per interior plot. Figure 3b presents data for mean particle density for 4 soil samples collected per interior plot. Figure 3c demonstrated mean percent relative humidity for 4 soil samples collected per interior plot. Figure 3d showed mean percent water content for 4 samples of soil per interior plot. Figure 3e presents data for mean pH for 4 soil samples per interior plot.

In Table 3, Shannon-Wiener diversity index (α diversity) and Shannon's evenness index for the three interior plots are given. Interior_Plot_1 had the highest α diversity at 0.683 and Interior_Plot_2 had the lowest α diversity value at 0.419. Further, the Shannon-Wiener diversity index for Interior_Plot_3 was the greatest at 0.341 and the value was the smallest for Interior_Plot_2 at 0.302. Similarly, Table 4 shows β diversity for three comparisons among the three plots. The β diversity value between Interior_Plot_2 and Interior_Plot_3 was the highest at 0.67 and between Interior_Plot_1 and Interior_Plot_3 was the lowest at 0.40. α diversity of each interior plot was calculated since each interior plot was the sampling unit 20 m x 20 m for sampling our forest.

Table 3: Shannon-Wiener diversity index (α diversity) and Shannon's evenness index.

	Shannon-Wiener diversity index (α diversity)	Shannon's evenness index
Interior_Plot_1	0.683	0.328
Interior_Plot_2	0.419	0.302
Interior_Plot_3	0.549	0.341

Table 4: β diversity.

	β diversity
Between Interior_Plot_1 and Interior_Plot_2	0.44
Between Interior_Plot_1 and Interior_Plot_3	0.40
Between Interior_Plot_2 and Interior_Plot_3	0.67

β diversity was calculated to make comparison between Interior_Plot_1 and Interior_Plot_2, Interior_Plot_1 and Interior_Plot_3, and Interior_Plot_2 and Interior_Plot_3.

We also analyzed the rank abundance for each of the plots. Figure 4 shows the rank abundance curves for the three plots individually. The number of species ranked in Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3 was 8, 4 and 5 respectively. This indicated that Interior_Plot_1 had the highest species richness among the three plots. Furthermore, in Figure 4a, the slope between the species ranks between 1 and 4 was the steepest. In fact, this slope was the steepest among the slopes of the three rank abundance curves in Figure 4. These results correlate with the Shannon's evenness indices from Table 2; Interior_Plot_3 had the highest species evenness than Interior_Plot_1 and Interior_Plot_3 since the value of Shannon's evenness index for Interior_Plot_3 was the closest to 1 among the values for the three plots.

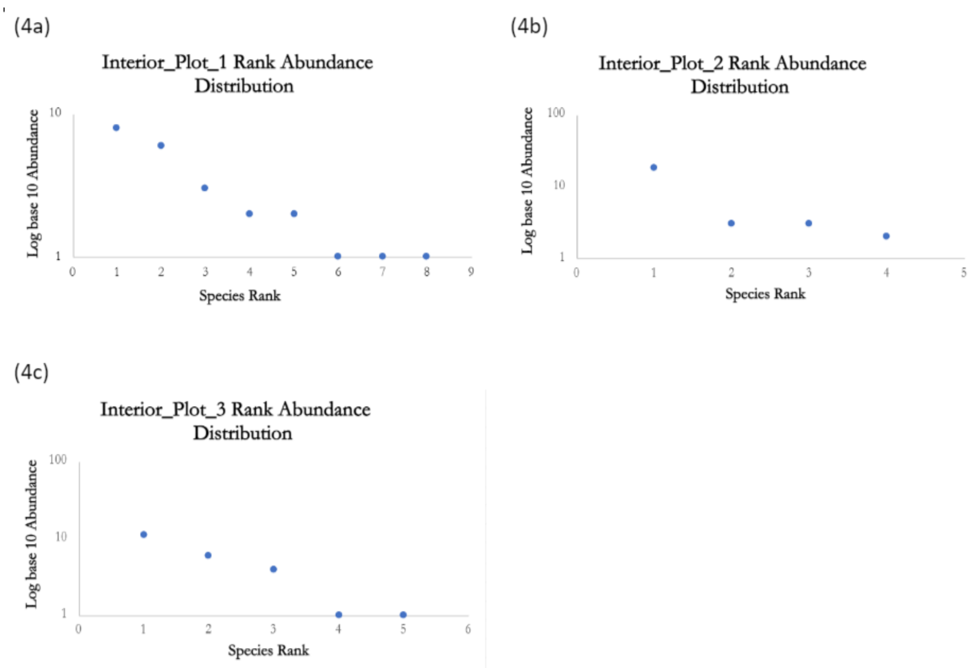

Figure 4: Rank abundance curve. Figure 4a showed rank abundance distribution for Interior_Plot_1; Figure 4b demonstrated rank abundance curve for Interior_Plot_2; Figure 4c showed rank abundance curve for Interior_Plot_3.

In Table 5, all the species from the three interior plots were listed, and their mean frequency in the plots and variance were calculated. Based on the calculated index of dispersion, the predicted dispersion pattern was clumped for five species (Red maple/ *Acer rubrum*, black birch/ *Betula lenta*, American beech/ *Fagus grandifolia*, Northern red oak/ *Quercus rubra* and Pin Oak / *Quercus palustris*), random for four species (Black oak/ *Quercus palustris*, Sassafras/*Sassafras albidun*, Black ash/ *Fraximus nigra* and White spruce/*Picea glauca*) and uniform for one species (Sugar maple/*Acer saccharum*). Furthermore, given the null hypothesis that the dispersion pattern for all tree species was random, the null hypothesis was rejected for Red maple/ *Acer rubrum* according to the Chi-Square test (df=18; α value=0.05).

Table 5: Index of dispersion.

Species	Mean	Variance	Index of dispersion	Dispersion Pattern (predicted)	Chi square value	Degrees of freedom (df)	α value	Critical value (from the probability table for Chi square distribution)	Reject null hypothesis (that dispersion pattern is random)?
Red maple/ *Acer rubrum*	10.67	41.33	3.87	Clumped	36.07	18	0.05	28.87	Yes
Black birch/ *Betula lenta,*	6.33	20.33	3.21	Clumped	19.720	18	0.05	28.87	No
American beech/ *Fagus grandifolia*	1.33	2.33	1.8	Clumped	3.124	18	0.05	28.87	No
Northern red oak/ *Quercus rubra*	2	3	1.5	Clumped	4.389	18	0.05	28.87	No
Sugar maple/ *Acer saccharum*	0.33	0.22	0.67	Uniform	0.258	18	0.05	28.87	No
Pin oak/ *Quercus palustris*	0.67	1.33	2	Clumped	5.176	18	0.05	28.87	No
Black oak/ *Quercus velutina*	2	2	1	Random	6.329	18	0.05	28.87	No
Sassafras/ *Sassafras albidun*	0.33	0.33	1	Random	2.259	18	0.05	28.87	No
Black ash/ *Fraximus nigra*	0.33	0.33	1	Random	2.259	18	0.05	28.87	No
White spruce/ *Picea glauca*	0.33	0.33	1	Random	2.259	18	0.05	28.87	No

Based on the calculated index of dispersion, dispersion patterns for each tree species were predicted. Then, Chi square values were calculated. These Chi square values were compared against the critical value for degrees of freedom=18 and alpha value=0.05 to indicate whether the null hypothesis (H_0), that the dispersion pattern was random, was rejected or not.

In Figure 5, average biomass and carbon storage were reported for all the three interior plots. Interior_Plot_3 had the highest average carbon storage and average biomass at 8876.67 Kg. C. ha^{-1} and 18687.72 Kg. ha^{-1} respectively. Furthermore, Interior_Plot_2 had the lowest average carbon storage and average biomass at 2826.11Kg. C. ha^{-1} and 5949.71Kg. ha^{-1}.

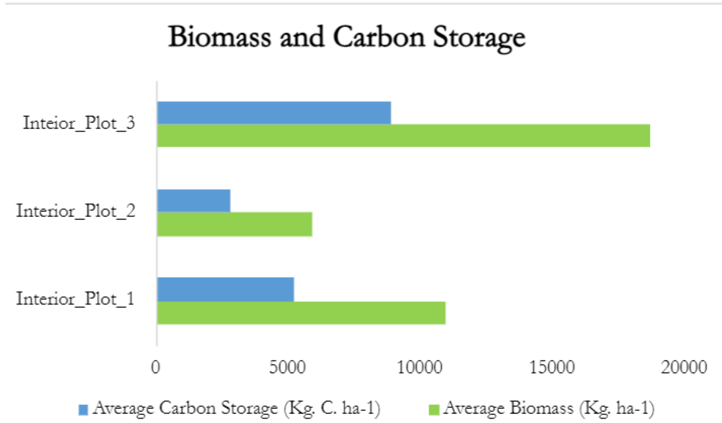

Figure 5: Average Biomass and Carbon Storage for three interior plots. For biomass calculation, β1 and β2 values for mixed hardwood were used for all hardwood trees. For White Spruce/ *Picea glauca*, specific β1 and β2 values for individual species were used. For carbon storage calculation, it was assumed that 47.5% of a tree's biomass is made up of carbon. Each interior plot had a size of 20m x 20 m (which is equal to 0.04 ha).

Finally, in Figure 6, the NMDS ordination analysis using NMDS demonstrated presence or abundance of clusters of Northern Red Oak /*Quercus rubra* (QUERUB), Red maple/ *Acer rubrum* (ACERUB), and American Beech/ *Fagus grandifolia* (FAGGRA) in Interior_Plot_2. Similarly, in Interior_Plot_3, there was presence or abundance of clusters of Black birch/ *Betula lenta* (BETLEN), Black oak/ *Quercus velutina* /QUEVEL and White spruce/ *Picea Glauca*/ PICGLA. The clusters of tree species for Interior_Plot_1 overlapped on the graph. Furthermore, Figure 6 indicated that the pH value of soil was the major factor that contributed to the clustering pattern of tree species noted in Interior_Plot_1; the particle density and bulk density of the soil played important role in tree species distribution in Interior_Plot_2; the % relative humidity and % water content were vital in Interior_Plot_3's tree species clustering pattern.

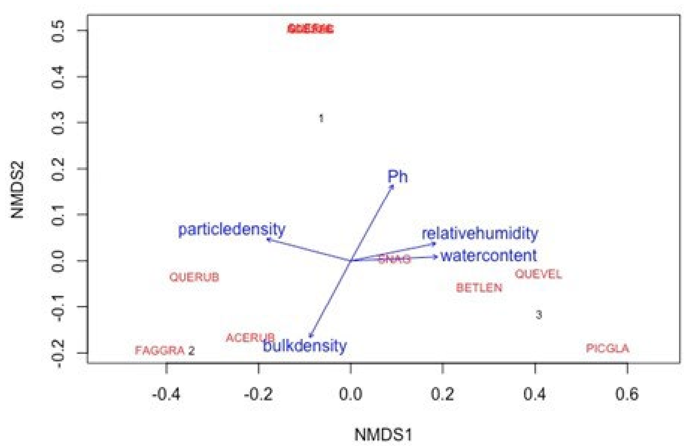

Figure 6: Non-metric dimensional multidimensional scaling. Interior_Plot_1, Interior_Plot_2 and Interior_Plot_3 are labeled as 1, 2 and 3 respectively. ACERUB=*Acer rubrum*/Red maple, BETLEN=*Betula lenta/*Black birch, FAGGRA=*Fagus grandifolia/* American beech, QUERUB=*Quercus rubra*/Northern Red Oak, ACESAC=*Acer saccharum*/Sugar maple, QUEPAL=*Quercus palustris*/Pin oak, QUEVEL=*Quercus velutina*/Black oak, SASALB=*Sassafras albidun*/Sassafras, FRANIG=*Fraximus nigra*/Black ash, and PICGLA=*Picea glauca* /White spruce. The units of particle density and bulk density are g/ml. The relative humidity and water content are given in percentages. The abbreviation SNAG represented "dead tree".

Discussion

In addition to the oceans, northern and tropical forests play vital role in carbon cycle as carbon sinks (Sher & Molles, 2022). In this study, as perhaps expected, the Interior_Plot_3 which had the lowest percent slope (5%) had the highest % relative humidity and %water content. Additionally, this plot was also the one with the highest biomass and carbon storage. This plot also had the most dominant/codominant trees with the highest mean diameter at breast height. It is quite possible that the lowest percent slope allowed for lesser runoff of water and nutrients in this plot and therefore, it contributed to the highest biomass, carbon storage, and mean diameter at breast height. Moreover, the data pointed out that the Interior_Plot_1, which had the highest percent slope (13%), had the highest number of tree species (8) and therefore, highest α diversity (0.683) even though species evenness for Interior_Plot_3 was the highest (0.341). Realized niche refers to the environmental factors that allow for growth and reproduction in the presence of biotic interaction such as competition (Sher & Molles, 2022). Therefore, any association between highest percent slope and highest α diversity needs to be further assessed in terms of whether the tree species identified in this plot found their realized niche in the plot or not, and what type of environmental factors contribute towards this realize niche. Furthermore, among the three β- diversity calculated, the β-diversity was the highest between Interior_Plot_2 and Interior _ Plot_3 (0.67) indicating that these two plots were the most dissimilar among the three interior plots. Even though there were only four tree species noted in Interior_Plot_2 and five tree species reported in Interior_Plot_3, only two species (Red maple/ *Acer rubrum* and Black birch/ *Betula lenta*) were common between these two plots and the numbers of the trees varied significantly making Red maple/ *Acer rubrum* the most abundant tree in Interior_Plot_2 and Black birch/ *Betula lenta* the most abundant tree in Interior_Plot_3. This could justify the highest β-diversity calculated between these two plots. As for the results of ordination analysis, there were only three samples (only one from each type of plot); therefore, the number of variables used in the multivariate study was most likely less than optimal. Even though the stress values generated during the ordination analysis were nearly zero, this value needs to be interpreted cautiously since the low number of samples might have caused the lower stress value. The three sites cluster separately along the two main NMDS axes based on tree species composition. However, the environmental variables such as % relative humidity, %water content and particle density spread out along the NMDS1 axis while bulk density and pH spread out along the NMDS2 axis.

Organic matter, which is a decomposed version of organic material, has several benefits in terms of nutrient supply, erosion prevention, soil structure aggregation and water-holding capacity of the soil (Funderburg, E., 2001). Further, pH of soil impacts the activity of roots, water content in leaf, and nutrient (for example, nitrogen and phosphorus) content in soil (Kaiwen et al., 2020). Therefore, to gain a comprehensive knowledge of factors that impact vegetation diversity, biomass, and carbon storage on vegetation above a particular forest ground, other factors such as percent organic matter, pH, bulk density and particle density of soil, microbiome, lower vegetation, and allelopathic nature of any vegetation in the plots should not be excluded. Nevertheless, this study elucidates a correlation among land topography, edaphic features and vegetation above-ground in temperate forests which was largely unexplored before and informs proper management and preservation of forests.

Conclusion

In conclusion, the interior plot with the lowest percent slope had the highest values of soil parameters (% relative humidity& % water content), the number of trees in dominant/codominant crown class, mean diameter at breast height by crown class, average biomass, and carbon storage. However, the reason as to why the plot with the highest percent slope had the highest number of tree species should be explored further. Finally, the roles of bulk density, particle density and pH of soil can be studied further to gain a more comprehensive knowledge on the effects of topographic features on vegetation diversity.

Limitations

It is also possible that the data collection was erroneous. Several different study team members, who were divided into groups by plot, were involved in data collection, and eventually, the collected data was shared among groups to answer the research questions each group had. Additionally, one tree (Red maple/ *Acer rubrum*) in Interior_Plot_3 was removed from mean diameter at breast height calculation since its diameter at breast height was not reported. Further, the predicted dispersion pattern for different tree species found in the interior plots were calculated to be either random, uniform or clumped. Based on the Chi-square test, the null hypothesis-that the dispersion pattern for all tree species was random-was rejected in the case of Red maple/ *Acer rubrum* only. Red maple/ *Acer rubrum*' s predicted pattern was clumped. In general, trees in forests have uniform dispersion patterns. The result obtained could be because the number of samples was too small given that this study looked at tree species only in the three interior plots. Similarly, the number of samples could be increased to strengthen the results noted in the Non-Metric Multidimensional Scaling (NMDS) ordination analysis as well.

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