Assessing the Effects of Environmental Variables and Landscape Change on Tree Stands at The Ridges Land Lab

Tanner Hammond[1*]

[1] Department of Geography, College of Arts & Sciences, Ohio University, Athens, Ohio

Corresponding Author: * th873721@ohio.edu

Finalized December 5, 2023

Abstract

This study explored the impacts of landscape variables on the tree stands of the Ridges Land Lab located in Athens, Ohio as assessed consequences of climate change on forest species composition. Understanding tree species composition within forest environments is crucial for effective forest management. Tree stands provide insights to disturbance regimes and are indicative of overall forest health. Forest stands have changed greatly due to human influences including climate change and are critical resources for understanding environmental change. I delineated ten standard plots and measured all contained trees to assess diversity, density, composition. I used a Digital Elevation Model (DEM) to record landscape variables. I assessed the effects of slope, aspect, and elevation on tree diversity and density and determined if landscape variables influenced tree stand composition. I also examined associations between shade tolerance, diameter at breast height (DBH), and species. No significant relationships were found between landscape variables and diversity or density. Significant relationships were found between shade tolerance and DBH and between DBH and species. Dominant species (white oak and sugar maple) abundances reflected their successional classes, revealing a lack of expected seedling white oaks. The observed species composition indicated features associated with landscape-scale mesophication, characterized by increased maples and declining oak populations due to the absence of fire regimes and climate change influences. This research contributes insights into the role of landscape variables and climate to forest succession.

Introduction

Forests play a crucial role in maintaining ecological balance and biodiversity, making it imperative to understand the factors influencing their composition and dynamics. Forests perform vital roles in the global earth system such as water filtration and carbon sequestration. Understanding the intricate dynamics shaping forest composition is essential for effective conservation and sustainable land management. Forest ecosystems are subject to various disturbance regimes that shape their structure and composition. Landscape dynamics of forests have historically been used to understand the role of disturbance upon landscapes, with particular interest in recent years lying on fire, or more commonly the lack of it. Disturbance regimes such as fire act as crucial regulation mechanisms within ecosystems (Babl-Plauche et al., 2022).

The Ridges Land Lab is a 163 acre property located in southeastern Ohio and administered by Ohio University. This study aims to assess the effects of environmental landscape variables (slope, aspect, and elevation) in relation to basic population metrics: diversity and density. The relations between tree size, species, and shade tolerance were also assessed. I conducted a survey of the trees present within ten plots at the Ridges Land Lab and assessed tree size and species composition. My hypothesis testing focused on associations between landscape variables (slope, aspect, and elevation), diversity, and density. No correlations were found between habitat variables and population metrics, but size class analysis of dominant species revealed evidence of mesophication in the stand (Palus et al., 2018).

Previous studies have found limited evidence of the role of slopes in landscape differences outside of extreme examples, although there is some association with specific species and slopes along with water infiltration (Abrams, 2003; Olivero & Hix, 1998). Aspect is highly correlated with plant diversity and density as a result of solar radiation exposure and water retention in soils (Fekedulegn et al., 2001; Olivero & Hix, 1998) Elevation typically has incredibly weak associations to diversity and density, especially at small ranges (Torres et al., 2019). Mesophication and climate change have more strongly related to changes in diversity among all organismal groups, including trees. Recent changes to the climate and disturbance regimes are attributed to great amounts of ecosystem change within forests of the eastern United States (Pederson et al., 2014).

Methods

Study Site

The Ridges Land Lab (“Ridges”; 39°19’0”N, 82°7’9”W) is a roughly 163 acre property owned by Ohio University located in Athens, Ohio. The property is the site of long-term research related to woodland and grassland ecology. The forests of the Ridges have been partially disturbed for the previous 200 years with the development of the Athens Lunatic Asylum which required removal of portions of the surrounding forest, which was compounded with agricultural activity by and surrounding the Asylum. Currently, the site houses a mix of primary and secondary growth forests—while the site is highly disturbed, a large portion of forest remains from before the area was developed, but invasive species such as honeysuckles and landscape change continue to intrude the area, especially surrounding developed areas (Ohio University, 2015).

Protocol

I utilized plot sampling for data collection. I delineated 15 m^2 plots using a measuring tape and survey flags along terrain gradients. Species and circumference of every tree taller than breast height (4.5 feet) within each plot was recorded. Circumferences were converted to diameter at breast height (DBH) and basal area for analysis. I used GPS locations of plots with digital elevation models in ArcGIS Pro to determine slope, aspect (as facing direction), and elevation values for each plot.

Statistical Methods

I tested whether slope, aspect, and elevation of plots affected shannon diversity and absolute basal area density ($\frac{Basal\ Area}{Plot\ Area}$) in the tree stands of the Ridges using R (R Core Team, 2023). I also tested the relationships between shade tolerance, size (as DBH), and species with R. I calculated Shannon diversity using the function diversity in the package vegan (Oksanen et al., 2021). I compared Shannon diversity and density with slope, aspect, elevation, and size using linear models and generalized linear models using poisson distributions.

Results

I recorded a total of 243 individual trees across ten plots. A total species richness of 11 was found across all plots. The most abundant species were sugar maple (n = 171) and white oak (n = 35). Abundance, density, and diversity varied heavily between plots (Table 1). I found no significant relationship between Shannon diversity and density (0.15; $F_{1,8} = 0.74$, $P = 0.22$, $R^2_{adj} = -0.08$). I found no significant relationship between slope and Shannon diversity (< -0.01; $F_{1,8} = 0.29$, $P = 0.87$; $R^2_{adj} = -0.12$) or slope and density (-0.03; $F_{1,8} = 0.29$, $P = 0.61$; $R^2_{adj} = -0.09$; Figure 2). I found no significant relationship between aspect and Shannon Diversity (E: 0.83 ± 0.22 (mean ± SE); N: 0.48 ± 0.45 ; $F_{2,7} = 4.68$, $P = 0.051$) or aspect and density (E: 2.22 ± 1.12; N: 1.08 ± 0.33; $F_{2,7} = 1.06$, $P = 0.39$; Figure 3). I found no significant relationship between elevation and Shannon diversity (< 0.01; $F_{1,8} = 0.33$, $P = 0.58$; $R^2_{adj} = -0.08$) or elevation and density (-0.03; $F_{1,8} = 1.35$, $P = 0.28$; $R^2_{adj} = 0.04$; Figure 4). I found a significant relationship between DBH and species (White Oak: z = 7.54, $P = 4.61e^{-14}$; Sugar Maple: z = 2.69, $P = 0.007$; Figure 5) and between DBH and shade tolerance (Intolerant: 44.41 ± 2.75; Intermediate: 22.30 ±

5.93; Tolerant: 19.20 ± 3.72; Very Tolerant: 11.07 ± 0.66; $F_{11,231}$ = 96.85, P = < 2.16e^{-16}; R^2_{adj} = 0.69; Figure 6).

Discussion

I found that landscape variables had little effect on diversity and density of trees at the Ridges. I did not find a significant association between slope and diversity or density. I found that Shannon diversity and density decreased at rates of 0.01 and 0.03 respectively per degree increase of slope. Trees generally do not grow on steep slopes due to low water infiltration and root stability. Slopes have heightened erosion rates, further decreasing stability (Olivero & Hix, 1998). Sugar maple typically is more prevalent on slopes than white oak (Abrams, 2003). Instability on low degree slopes is typically low (Olivero & Hix, 1998). In this study, maximum slope values reached were 25 degrees.

I did not find a significant association between elevation and diversity or density. I found that Shannon diversity and density increased at a rate of <0.01 and decreased at a rate of 0.03 respectively per meter increase of elevation. White oaks have a high tolerance for alpine environments, while sugar maples have a low tolerance for alpine environments (Abrams, 2003). The elevations surveyed only spanned 40 meters, which is a relatively low difference. Therefore, it is unlikely that effects of elevation difference would be shown at this scale. Similar studies have found variations in tree diversity and density along elevational gradients, but these are typically much larger scale than that of this study (Torres et al., 2019).

I did not find a significant association between aspect and diversity or density. Aspect has been shown to have a significant influence on the growth rates of oaks and maples. Tree stands on south facing slopes tend to decrease in growth rates and diversity due to the decreased water availability as a result of increased solar radiation (Fekedulegn et al., 2001; Olivero & Hix, 1998). At the Ridges, I found that north-facing slopes had lower average diversity and densities. Due to the composition of tree stands at the Ridges being composed of majority white oak and sugar maple, the decreased density is likely a result of north-facing slopes being more mesic, which supports more shade tolerant sugar maples (Burns & Honkala, 1990). I expected density at north-facing sites to be lower due to the small combined basal area of sugar maples compared to the large combined basal area of white oaks. Shannon diversity was likely also lower on north-facing slopes due to increased sugar maple abundance. Shannon diversity is highly affected by abundances of individual species due to its use of evenness in calculations—the high number of sugar maple present at north-facing sites leads to a decrease in overall diversity assuming a similar richness is observed (Barrantes & Sandoval, 2009).

I found a significant association between tree size, shade tolerance, and species. I also found differences between expected and actual distributions of tree size based on successional classes. Sugar maples are consistent with expected distributions, but sugar maples show a distinct lack of seedling and sapling individuals. The dominant species present in forest stands (white oak and sugar maple) as well as their size distributions indicate that the Ridges is currently undergoing mesophication, a process where forests become dominated by shade tolerance (mesic) species. The low number of seedling and sapling white oaks present at the Ridges are indicative of issues with establishment and regeneration. Mesophication has been an ongoing process in the eastern United States, and has resulted due to landscape factors and climate change (Palus et al., 2018). Historic fire suppression has been the main factor attributed with mesophication, as fire acts as a regular controller of shade-tolerant (and also typically fire-intolerant) species. Canopy closure has increased due to a lack of fire stress on shade-tolerant species, which have begun to reach larger sizes resulting in fewer canopy gaps.

This reinforces the impact of shading of the forest floor and an increase in water availability, which inhibits fire. Decreased leaf litter buildup due to the higher decomposition rates of non-oak species also negates fire from re-entering the ecosystem at similar extent (Babl-Plauche et al., 2022). Recent changes in the world's climate have also impacted forest stands. While increased temperatures have increased the frequency of fire across the United States in general, moisture availability has been increasing co-currently in the northeastern United States, resulting in increased fire suppression (Pederson et al., 2014).

This study examined the composition of tree stands at the Ridges Land Lab, emphasizing the influence of specific landscape variables. Forest species assemblages are extraordinarily complex and affected by a variety of environmental factors. While the impacts of climate on forest stands have not been fully assessed due to its complex impacts, historical context shows impacts of both climate and altered fire regimes by humans (Pederson et al., 2014). Future studies may benefit from sampling at wider scales to encompass larger landscape gradients and include assessments of the proposed effects of climate. The presence of mesophication within forests in the eastern United States has been a cause of concern since its realization. The staggering decline of oaks within eastern United States forests requires additional research to address, but is an immediate problem for the future of these stands.

Literature Cited

Abrams, M.D. (2003). Where Has All the White Oak Gone? *BioScience* 53(10): 927–939. https://doi.org/10.1641/0006-3568(2003)053[0927:WHATWO]2.0.CO;2.

Babl-Plauche, E.K., Alexander, H.D., Siegert, C.M., Willis, J.L., Berry, A.I. (2022). Mesophication of upland oak forests: Implications of species-specific differences in leaf litter decomposition rates and fuelbed composition. *Forest Ecology and Management*. 512: 120141. https://doi.org/10.1016/j.foreco.2022.120141

Barrantes, G. & Sandoval, L. (2009). Conceptual and statistical problems associated with the use of diversity indices in ecology. *Revista de Biología Tropical*, 57(3), 451–460. http://www.scielo.sa.cr/scielo.php?script=sci_arttext&pid=S0034-77442009000300001&lng=en&tlng=en.

Burns, R.M. & Honkala, B.H. (1990). Silvics of North America, Volume 2. USFS.

Fekedulegn, D., Hicks, R.R., Colbert, J.J. (2001). Influence of topographic aspect, precipitation and drought on radial growth of four major tree species in an Appalachian watershed. *Forest Ecology and Management* 177: 409-425.

Ohio University. (2015). The Ridges Framework Plan, Volume 1. Ohio University. https://www.ohio.edu/university-planning/planning/master-plans/ridges-framework-plan

Oksanen J, Simpson G, Blanchet F, Kindt R, Legendre P, Minchin P, O'Hara R, Solymos P, Stevens M, Szoecs E, Wagner H, Barbour M, Bedward M, Bolker B, Borcard D, Carvalho G, Chirico M, De Caceres M, Durand S, Evangelista H, FitzJohn R, Friendly M, Furneaux B, Hannigan G, Hill M, Lahti L, McGlinn D, Ouellette M, Ribeiro Cunha E, Smith T, Stier A, Ter Braak C, Weedon J (2022). _vegan: Community Ecology Package_. R package version 2.6-4, <https://CRAN.R-project.org/package=vegan>.

Olivero, A.M., Hix, D.M. (1998). Influence of aspect and stand age on ground flora of southeastern Ohio forest ecosystems. *Plant Ecology* 139, 177–187. https://doi.org/10.1023/A:1009758501201

Palus, J.D., Goebel, P.C., Hix, D.M., Matthews, S.N. (2018). Structural and compositional shifts in forests undergoing mesophication in the Wayne National Forest, southeastern Ohio. *Forest Ecology and Management*. 430: 413–420. https://doi.org/10.1016/j.foreco.2018.08.030

Pederson, N., D'Amato, A.W., Dyer, J.M., Foster, D.R., Goldblum, D., Hart, J.L., Hessl, A.E., Iverson, L.R., Jackson, S.T., Martin-Benito, D., McCarthy, B.C., McEwan, R.W., Mladenoff, D.J., Parker, A.J., Shuman, B. and Williams, J.W. (2015). Climate remains an important driver of post-European vegetation change in the eastern United States. *Glob Change Biol* 21: 2105–2110. https://doi.org/10.1111/gcb.12779

R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Torres, B., Vasseur, L., López, R., Lozano, P., García, Y., Arteaga, Y., Bravo, C., Barba, C., García, A. (2019). Structure and above ground biomass along an elevation small-scale gradient: case study in an Evergreen Andean Amazon forest, Ecuador. *Agroforestry Systems* 94: 1235–1245

Tables & Figures

Table 1. Calculated metrics for assessing tree stands for each plot. Values have been rounded to two decimal places.

Plot Number	Abundance	Absolute Density	Shannon Diversity
1	26	0.77%	1.10
2	25	2.44%	1.24
3	24	2.72%	1.25
4	20	1.32%	0.80
5	28	1.06%	0.71
6	29	2.84%	1.15
7	26	3.47%	0.69
8	25	0.84%	0.17
9	21	2.59%	0.90
10	19	1.53%	0.78

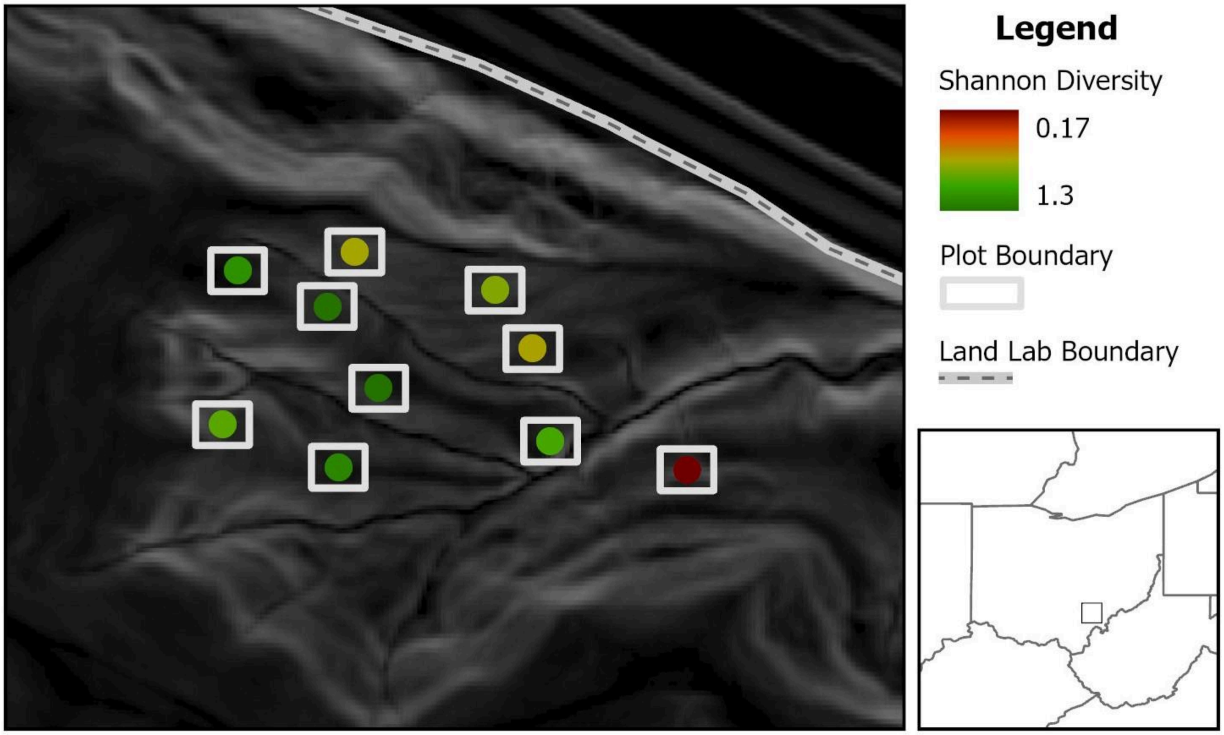

Figure 1. Locations of all plots within the Ridges Land Lab. Point color represents Shannon diversity values. Boundaries around plot points represent 15 m^2 areas. Plots overlaid on a digital elevation model depicting slope in degrees. Locator map depicts the Ridges Land Lab's location in southeastern Ohio.

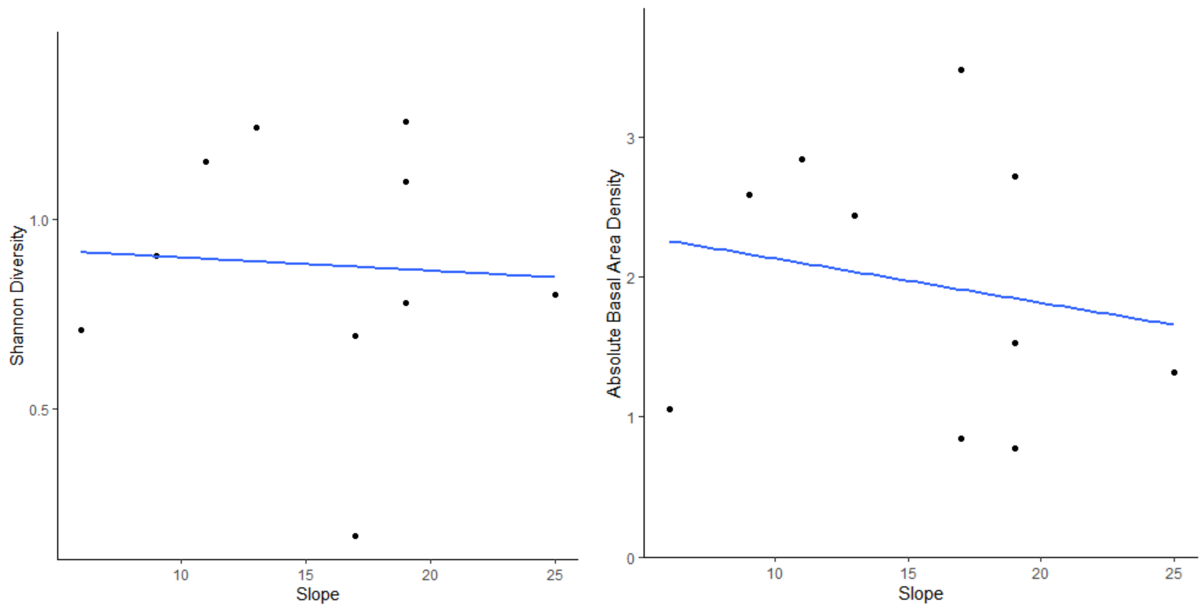

Figure 2. Slope compared to Shannon diversity and absolute basal area density. Trend line depicts the fitted linear regression between slope and Shannon diversity and slope and absolute basal area density.

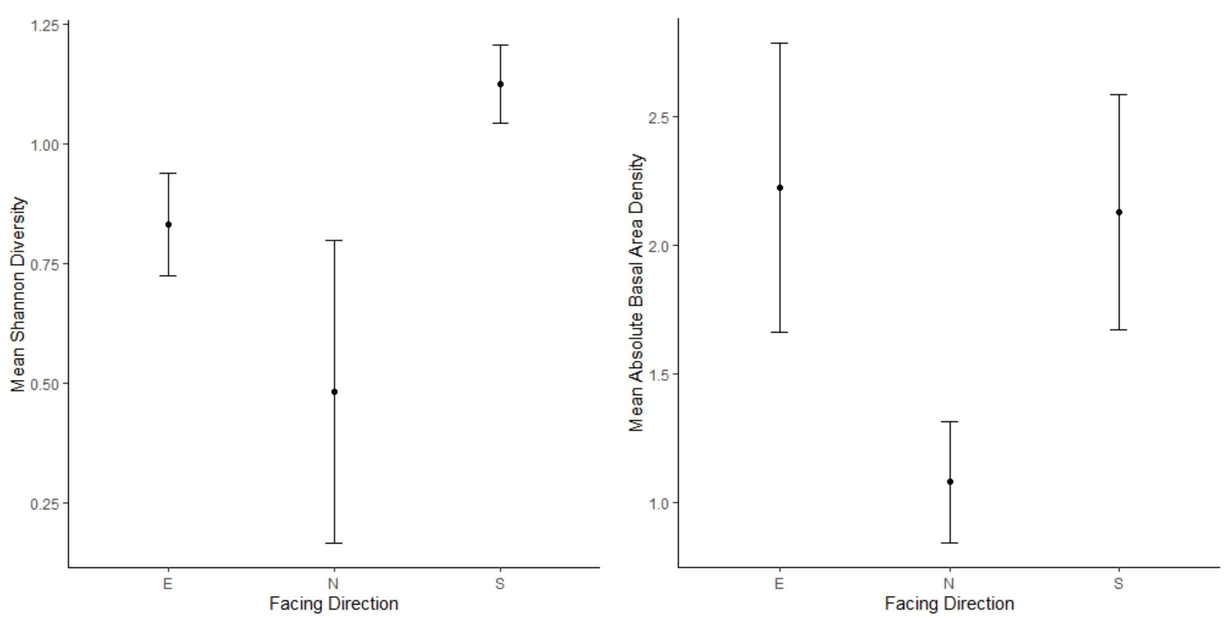

Figure 3. Aspect compared to Shannon diversity and absolute basal area density. Points represent mean. Error bars represent percent error.

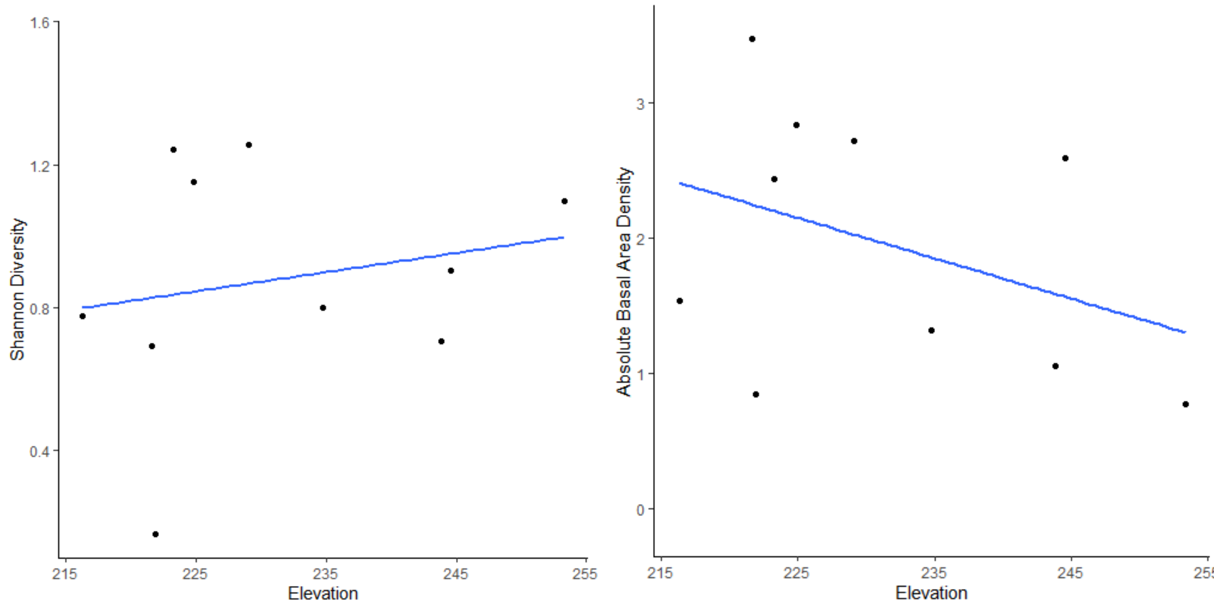

Figure 4. Elevation compared to Shannon diversity and absolute basal area density. Trend line depicts the fitted linear regression between elevation and Shannon diversity and elevation and absolute basal area density.

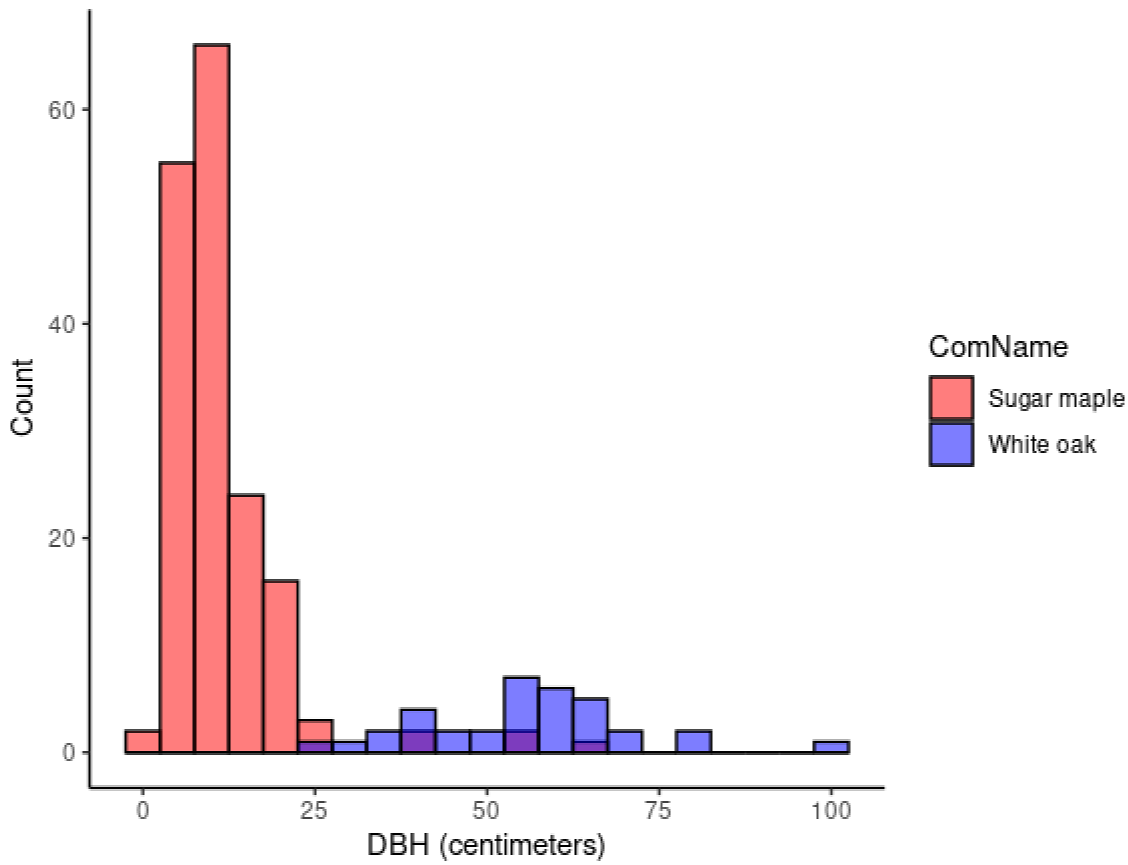

Figure 5. Histogram depicting the number of individuals of the two most common species at the Ridges land Lab (sugar maple and white oak) per size class. Sugar maple largely consists of smaller individuals, while white oak consists of larger individuals. Bin Width = 5 cm.

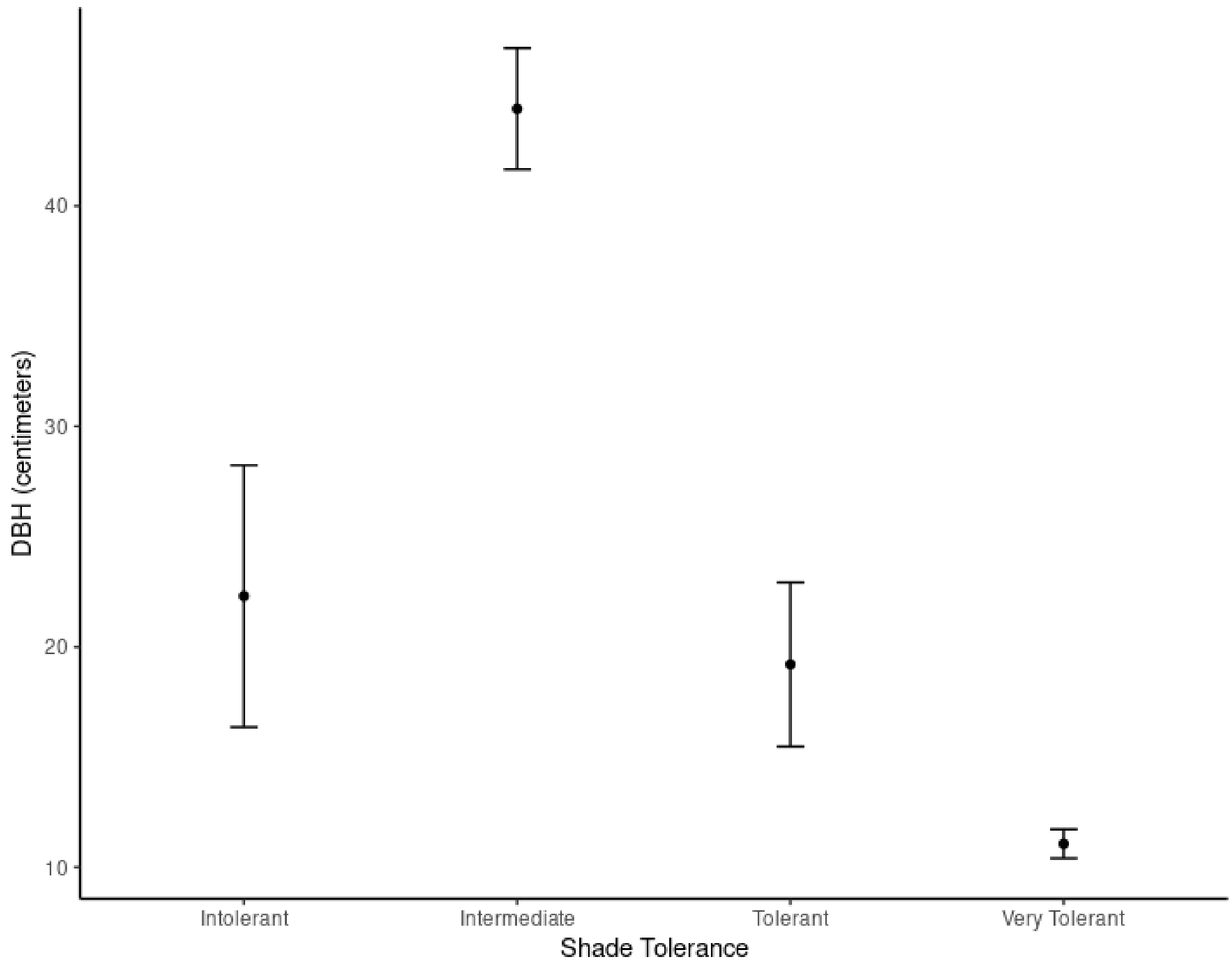

Figure 6. Shade tolerance compared to DBH and absolute basal area density. Points represent mean. Error bars represent percent error.