Understory Vegetation in Sugar Maple Monoculture Forest Stands and Mixed Deciduous and Coniferous Forest Stands

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Abstract

One of the most important ecosystems services performed by forests is carbon sequestration. Forests also contribute to ecosystem productivity which is affected by biodiversity. Since the understory is home to a great volume and diversity of plants it is important to understand how the forest understory contributes to carbon sequestration and ecosystem productivity. In this study, I examined how much light reaches the understory and forest floor and how this differs between sugar maple and mixed forest stands. Twenty sites were used in this experiment: 10 sugar maple and 10 mixed. Mixed forest stands were found to have less dense canopies, denser understories, and greater total leaf cover than sugar maple stands. This greater amount of understory vegetation in mixed forest implies that they have greater carbon sequestration potential than sugar maple forest and possibly other monoculture forests.

Introduction

One of the most important ecosystems services performed by forests is carbon sequestration (carbon storage), which provides a sink for the carbon from both natural processes and human activity. Forests can generally be divided into two sections: the overstory (canopy) and the understory. Studies in the past have examined the impact of climate change on canopy tree species as well as their link to carbon sequestration, but few have looked at the impact of the understory (Jandl and Schindlbacher 2014). These two sections vary in biodiversity, their ability to store carbon, photosynthetic capacity and many other factors (Liu et al. 2017). Biodiversity in both the overstory and understory species is thought to be linked to ecosystem productivity (Paquette, A. and C. Mesier 2010). Thus, it is important to understand how canopy structure and light availability can affect biodiversity (Williams et al. 2017).

The forests around University of Notre Dame Environmental Research Center (UNDERC) are recovering from Michigan’s long history of logging, agriculture, and burning. When a forest stand is in a state of recovery, the composition and structure of the forest changes, and these changes can have implications for the climate through ecosystem services such as carbon sequestration (Kirby and Potvin 2007). This state of recovery makes the forests around

UNDERC a good candidate for understanding the long-term effects of human activity on temperate forest biomes. In this study, I examined how much light reaches the understory and forest floor and how this differs between sugar maple and mixed forest stands. I looked at mixed forest and sugar maple forest, since sugar maple is dominant in late-successional forests and sugar maple seems to be becoming the dominant species in many forests in the temperate forest biome (Clebsch and Busing 1989). Mixed forest on the other hand is a common type of early successional forest.

An existing canopy will also affect the type of understory vegetation growing underneath it, as different tree assemblages partition resources, such as soil nutrients and moisture, woody debris, and light availability, differently (Sercu et al. 2017, Chávez and Macdonald 2010). Sugar maples typically form dense canopies. However, in general, the crown architecture of monoculture canopies is patchier than in mixed stands, allowing for more light availability and heterogeneity at the forest floor and more understory vegetation growth (Brisson 2001, Sercu et al. 2017). Thus, I expect there to be a lower proportion of light reaching the forest floor and a greater proportion of light reaching the understory beneath sugar maple monoculture canopies than below mixed forest canopies. This is expected because more light is coming through the canopy of sugar maples, which leads to more understory vegetation and less light reaching the forest floor. I also expect, given that monocultures tend to exhibit greater heterogeneity of light from their more spread out, or patchier, canopies, that the standard deviation of light reaching the understory should be greater in sugar maple stands than in mixed stands.

The greater light availability in the understory and greater heterogeneity, or variability, in the canopy should be positively related to larger diversity indices (Shannon, Simpson's, and alpha, beta, and gamma diversity) in understory vegetation since a wider variety of shade tolerant and intolerant species have the potential to grow in a brighter understory.

Materials and Methods

Sites

This study was conducted at the University of Notre Dame Environmental Research Center (UNDERC) which sits on the border of Wisconsin and the Upper Peninsula of Michigan. The property contains a wide variety of habitats from lakes, marshes, and bogs to hardwood and coniferous forests. I used the ArcGIS UNDERC habitat map to find sugar maple and mixed forest stands that were 3,600 m^2 or more. In the field, I confirmed this information before setting a grid and collecting data. The grids used were 60m by 60m or 3,600 m^2 with grid points every 20m (9 points per grid) (Figure 1). Twenty sites were used in this experiment: 10 sugar maple and 10 mixed (Figure 2).

Species Data Collection

Species data were collected at half of the sites (10 total, 5 sugar maple, and 5 mixed). I used stratified random sampling so that there was a random sample plot in each of the nine grid sections. Within each grid section, a random number generator was used to determine the location of the $1m^2$ sample plot. For each $1m^2$ sample plot, every individual plant was counted. Separate species were differentiated using morphospecies. This data was used to calculate Shannon, Simpson's, alpha, beta, and gamma diversity.

Light Data Collection

Light data were collected using a sun system photosynthetically active radiation (PAR) meter (Sunlight Supply; Inc. product# 748205). At each site, I controlled for sky condition by taking a reading every minute for 10 minutes both before and after collecting data in the grid. At each of the nine 20m grid points, I took two readings, one above the understory and one at the forest floor. These readings were averaged to characterize light reaching the understory, light reaching the forest floor and the sky condition before and after for each stand.

Statistical Analysis

Shapiro-Wilk test was used to determine if response variables followed a normal distribution. Those that followed a normal distribution were analyzed using the parametric t-test to compare means between sugar maple and mixed stands. Data that did not follow a normal distribution and could not be transformed to follow a normal distribution was analyzed with the non-parametric Mann-Whitney U test. I used Mann-Whitney to compare the proportion of light reaching the understory and forest floor, the amount of light lost in the understory, and the standard deviations of light reaching the understory and forest floor of sugar maple and mixed forest stands. I used t-tests to compare the diversity indices of sugar maple and mixed forest stands. To find relationships between the diversity indices and the light data I used linear regressions. All statistical tests were done with R (R Core Team, 2016)

Results

All the diversity indices (Shannon, Simpson's, alpha diversity, beta diversity, and gamma diversity) were found to have normal distributions (Shapiro-Wilk: p-value = 0.219, p-value = 0.1151, p-value = 0.09361, p-value = 0.6067, and p-value = 0.177 respectively). The other variables (proportion of light reaching the understory (US), proportion reaching the forest floor(FF), average difference between US and FF, standard deviation (SD) of US, and SD of FF) were found to not follow a normal distribution and could not be transformed to do such (Shapiro-Wilk: p-value = 9.659e-05, p-value = 7.2e-08, p-value = 0.0002411, p-value = 3.19e-06, and p-value = 1.667e-07 respectively).

Sugar maple stands were found to have a significantly larger proportion of light reaching the FF by 5.7%, and larger SD of light at the FF by 11.7% (W=14, p-value=0.005196; W=21, p-value=0.02881) (Figure 3a and 3b). However, mixed stands had a significantly larger difference in the proportion of light reaching the US and FF by 7.9% (W=80, p-value=0.02323) (Figure 3c). While no significant difference was found in the proportion of light reaching the US and its SD, they were approaching significance and could have been significantly different with a larger sample size (W=69, p-value=0.1655; W=72, p-value=0.1051) (Figures 4). The mixed stand values were larger for these two variables, the percent difference was 2.2% and 2.7% respectively.

No significant difference was found among any of the diversity indices of between sugar maple and mixed forest stands. However, Shannon, Simpson's, and alpha diversity were all approaching significance and might have been significantly different with a larger sample size (t=1.6, df=7.22, p-value=0.1502; t=1.71, df=5.8, p-value=0.1392; t=1.57, df=5.62, p-value=0.1713). In all three of these instances, mixed forest stands showed larger values than those of sugar maple stands, the difference was 0.44, 0.12, and 1.4 respectively (Figure 5).

Alpha diversity was found to increase with the proportion of light reaching the US (Multiple R^2 =0.60, df = 8, p-value=0.008305) (Figure 6). Alpha diversity also increases with the standard deviation of the light reaching the understory (Multiple R^2 =0.42, df = 8, p-value=0.04232) (Figure 7).

Discussion

I found that sugar maple stands had a significantly greater proportion of light reaching the forest floor and, while not significant, mixed stands had a greater proportion of light reaching the understory. This implies that the combination of the overstory and understory in sugar maple stands is less dense than in mixed stands. With a larger sample size, it would likely be found that sugar maple stands tend to have denser canopies than those of mixed stands. With these findings, I reject my hypothesis that a lower proportion of light will reach the forest floor and a greater proportion of light will reach the understory beneath sugar maple monoculture canopies than below mixed forest canopies, as was found in Sercu et al.'s 2017 study. Sercu et al.'s study found that the canopies of English oak, Northern red oak, and European beech monocultures tend to be more spread out than mixed stands (2017). My findings show that sugar maple monocultures differ from these three species in canopy density and that it is difficult to generalize about monoculture forests without considering species differences.

Next, I hypothesized that sugar maple stands would exhibit a greater standard deviation of light reaching the understory, meaning the canopy would be patchier. No significant difference was found between sugar maple and mixed stands. However, the difference was approaching significance, with mixed stands having a little more variation in the amount of light reaching the understory than sugar maple stands. This means that mixed stands may have greater heterogeneity in their canopies than sugar maple stand. My findings agree with a 2010 study on forest canopy mosaics found that the mosaic of canopy patches in mixed stands (characterized by having greater canopy heterogeneity) promotes the coexistence of a wider variety of understory species (Chávez and Macdonald 2010).

Diversity indices were greater in mixed forest, although the difference was not significant. This result is expected since mixed stands exhibited more light coming through the canopy and this factor is positively related to alpha diversity, one of the diversity indices that tended to be greater in mixed stands. However, this result differs from previous studies that have found greater understory diversity in monoculture stands such as sugar maple (Barbier et al. 2008).

Finally, I found that, regardless of stand type, alpha diversity increases with both the proportion of light that reaches the understory and its standard deviation. This supports my hypothesis that a greater light availability and greater heterogeneity leads to greater diversity in understory vegetation. It is interesting that alpha diversity was the only significant diversity index, as it was applied to the plot (local) level. This indicates that while light is an important factor for diversity at very small scales, there are other important factors that affect it at the stand level. Other studies have found factors such as soil nutrients, moisture, and temperature and ground cover to be significant factors impacting diversity on a stand level and this could be the case here (Chávez and Macdonald 2010).

This study shows that mixed forests have more understory vegetation than sugar maple forests and may also have more diversity than sugar maple forests. This implies that the understory of mixed forests contributes a larger proportion of carbon to the forest's total carbon sequestration and that mixed forests have greater total carbon sequestration potential. The greater understory diversity implies that mixed forests have a greater ecosystem productivity as they have both diverse canopies and understories. This brings into question if late successional forests, such as sugar maple, are as important as earlier successional forests, such as mixed forest, as carbon sinks and productive ecosystems. Thus, mixed forest is an important forest type to consider when developing forest management strategies in the future. Further research on this topic could expand the number of canopy species to include other tree species that are common in the north temperate forest biome, such as *Franxinus, Quercus, Abies,* and *Tsuga*. This knowledge could help clarify how the greater understory vegetation found in mixed forests contributes to the carbon sink. Further analysis of the diversity indices in each forest type could also help contextualize the ecosystem productivity of different forest types.

Figures

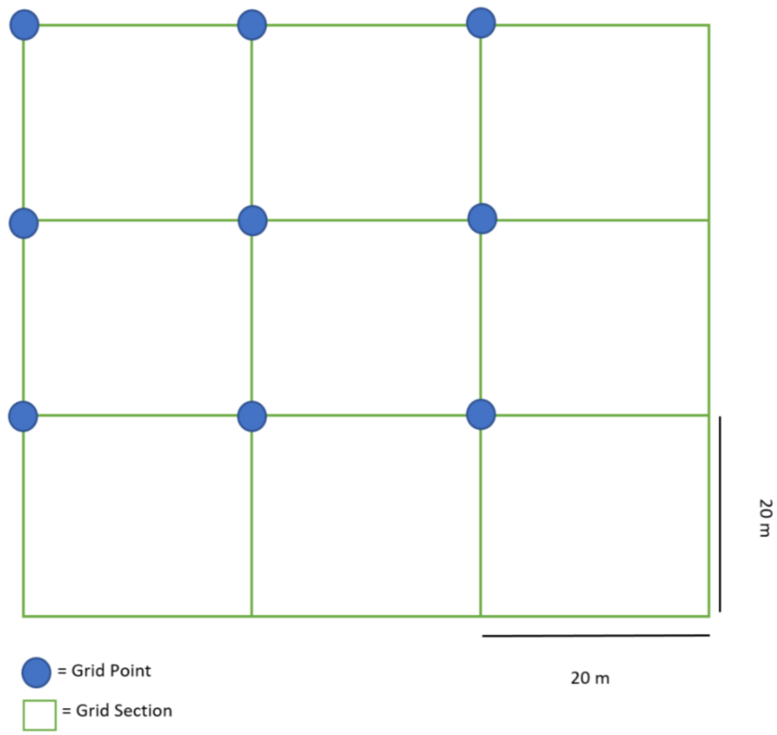

Figure 1. Grid layout. The blue dots represent the 9 grid points that were sampled for light readings. The squares represent each of the grid sections that were sampled for the species data.

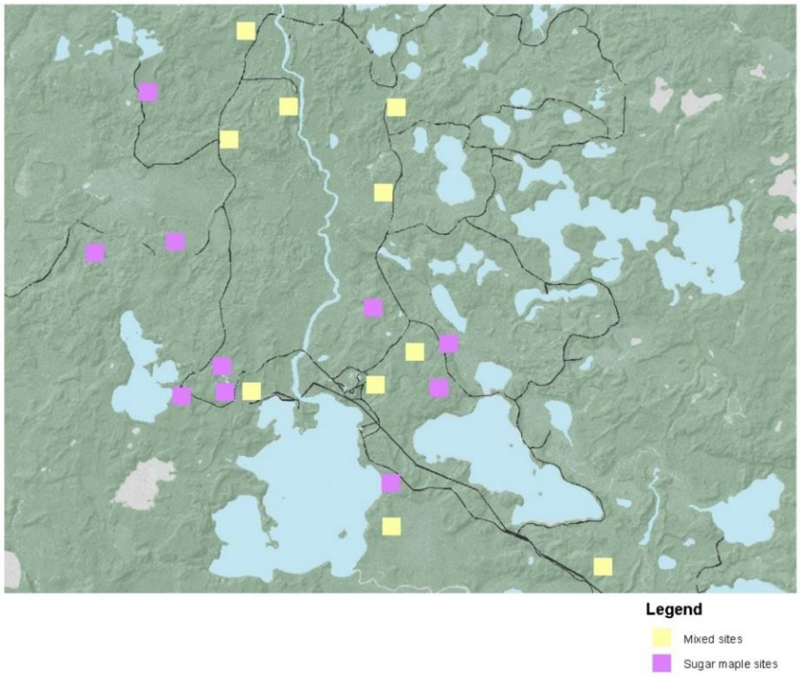

Figure 2. Map of sites. Shown above are the locations of the 20 sites that were used in this study. Lakes and roads are shown in blue and black respectively to provide a reference. Sugar maple sites are shown in pink and mixed sites are yellow.

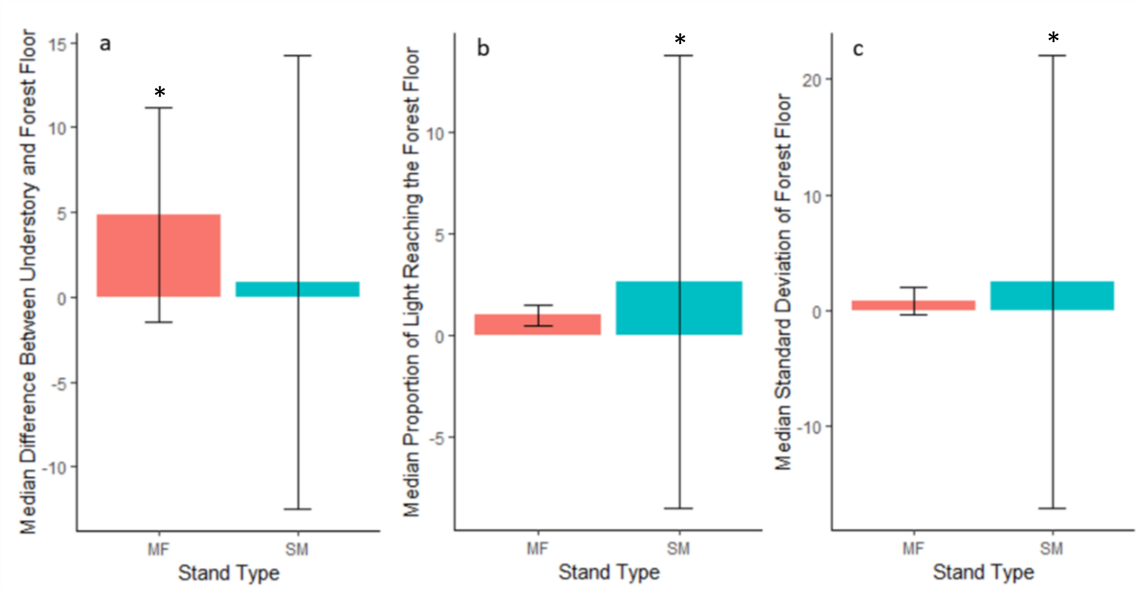

Figure 3. Median values for the difference between light on understory and forest floor, proportion of light reaching the forest floor, and standard deviation of light at the forest floor of mixed and sugar maple forest stands. The bars represent median values (instead of means) since the Mann-Whitney U test was used to compare the medians of the groups, the asterisk (*) denotes which forest type was significantly larger than the other, MF is mixed forest stands, SM is sugar maple forest stands, and the error bars represent standard deviation as a measure a variation in the data. (a) The median difference between the light reaching the understory and forest floor was significantly larger in mixed forest stands ($p = 0.02323$). (b) The median proportion of light reaching the forest floor was significantly greater in sugar maple forest stands ($p = 0.005916$). (c) The median standard deviation of light reaching the forest floor was significantly greater in sugar maple forest stands ($p = 0.02881$).

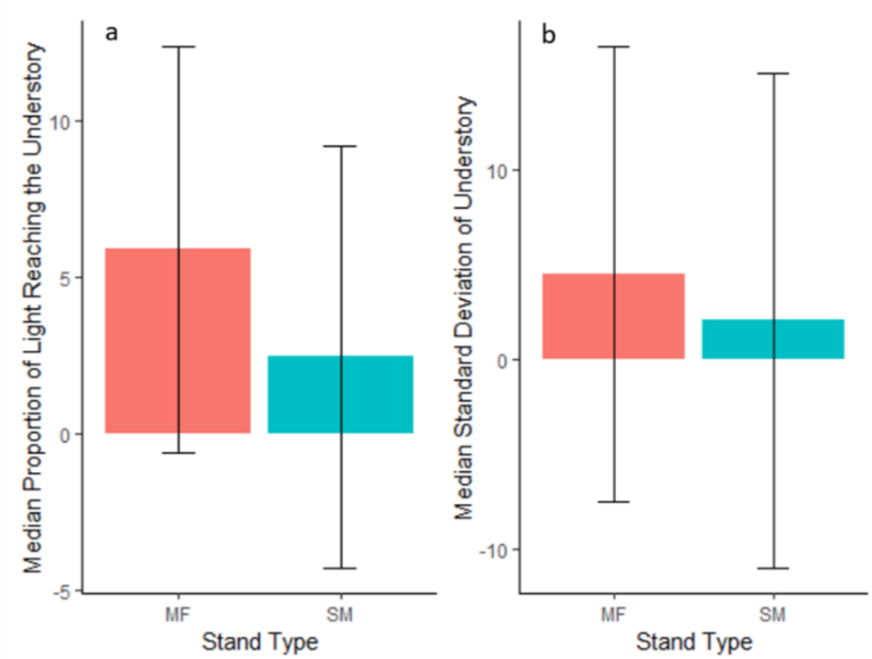

Figure 4. Median values for the proportion of light reaching the understory and standard deviation of light reaching the understory for mixed and sugar maple forest stands. The bars represent median values because the Mann-Whitney U test was used to compare the medians of the groups, MF is mixed forest stands, SM is sugar maple forest stands, and the error bars represent standard deviation as a measure a variation in the data. (a) The median proportion of light reaching the understory was larger in mixed forest stands, but not significantly so ($p = 0.1655$). (b) The median standard deviation of light reaching the understory was greater in mixed forest stands, but not significantly so ($p = 0.1051$).

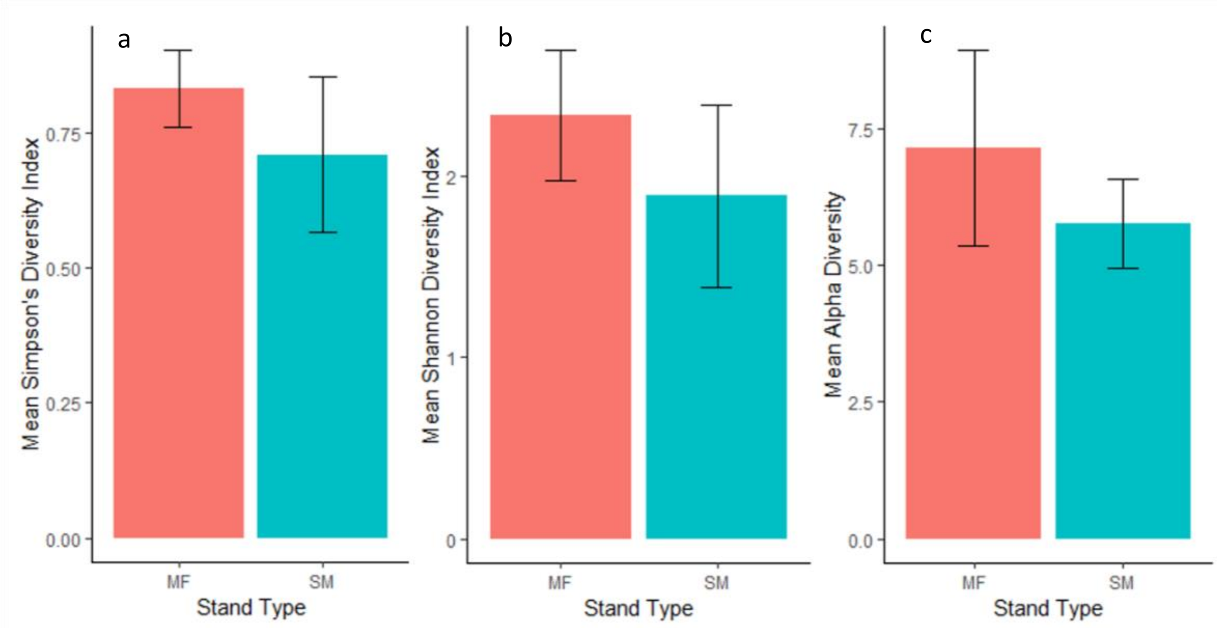

Figure 5. The mean diversity indices of mixed and sugar maple forest stands. The bars represent median values because the Mann-Whitney U test was used to compare the medians of the groups, MF is mixed forest stands, SM is sugar maple forest stands, and the error bars represent standard deviation as a measure a variation in the data. (a) The mean Simpson's diversity index was not significantly different between mixed and sugar maple stands, but appears slightly larger in mixed stands ($p = 0.1392$). (b) The mean Shannon diversity index was larger in mixed stands, but not significantly so ($p = 0.1502$). (c) The mean alpha diversity was not significantly different between the two stand types, but mixed stands appear to have slightly larger values.

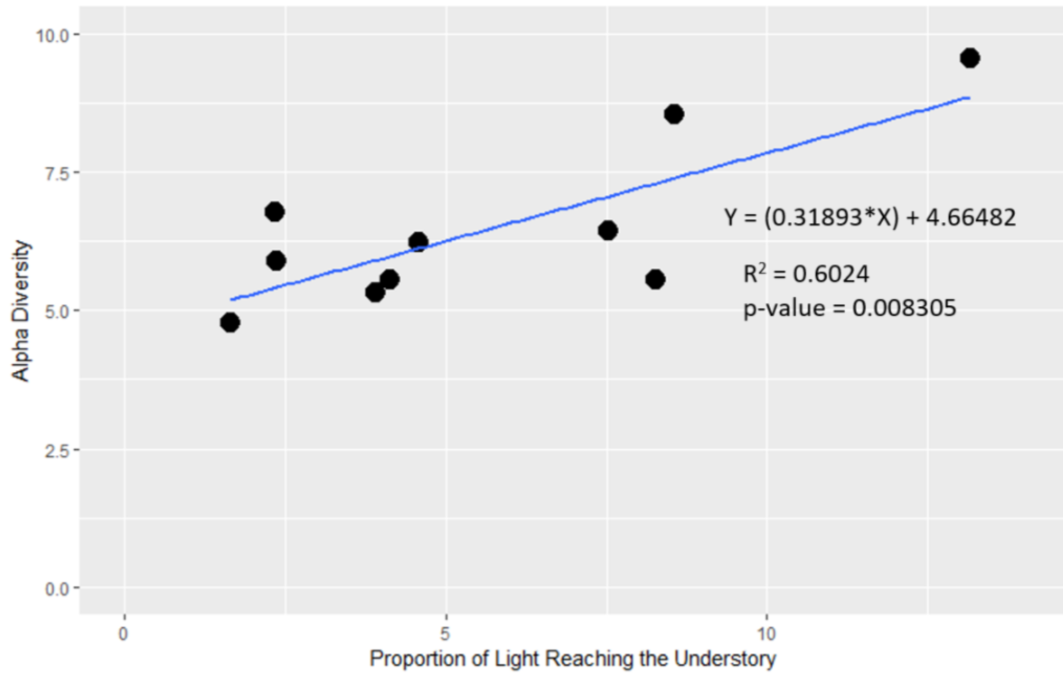

Figure 6. The proportion of light reaching the understory vs alpha diversity. Each dot represents one stand. The graph shows the positive relationship between alpha diversity and the proportion of light reaching the understory. The proportion of light reaching the understory explains 60% of the variance in alpha diversity and the slope and intercept are significantly different from zero ($p = 0.0083$, $p < 0.0001$).

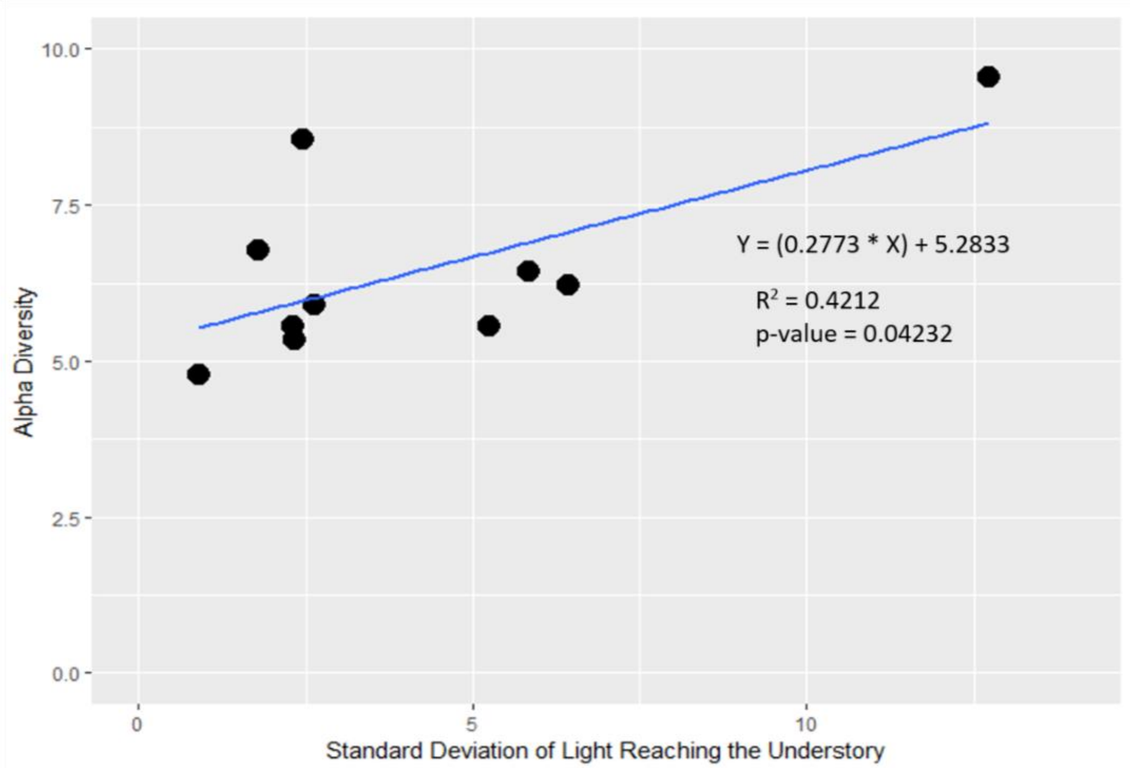

Figure 7. The standard deviation of light reaching the understory vs alpha diversity. Each dot represents one stand. The graph shows the positive relationship between alpha diversity and the standard deviation of light reaching the understory. The standard deviation of the light reaching the understory explains 42% of the variance in alpha diversity and the slope and intercept are significantly different from zero ($p = 0.0423$, $p < 0.0001$).

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