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Effect of Succession on Fungi Functional Groups and Nutrient Levels in Soil

Abstract

Secondary succession plays a major role in species composition of fungi in forests and nutrient levels in soil between early and intermediate stages. This can be attributed to mutualistic relationships between plants and fungi. Plants receive greater access to nutrients from the fungi in exchange for Carbon that the fungi can use as an energy source for growth. In this study, we analyzed the 1936, 1954, and 1998 burn plots at the University of Michigan Biological Station in Pellston, MI to determine how succession affects the functional groups of fungi, specifically mycorrhizal and decomposing fungi, and percent Carbon and Nitrogen availability in soil. We determined the fungi functional group composition by surveying five 100m x 4m transects in the 1936 and 1954 plots and four 50m x 4m transects in the 1998 plot. We also analyzed soil samples for percent Nitrogen and percent Carbon in each of the plots. Our results showed that there was no significant difference is fungi diversity, or Carbon and Nitrogen levels between the three burn plots. However, there was a significant difference in fungi functional groups with a greater proportion of mycorrhizal fungi found in the 1998 burn plot. This could be attributed to limited amount of decaying wood, so decomposing fungi were not essential to the ecosystem productivity. All three burn plots are classified as an intermediate stage of succession; therefore we saw little variation in fungi diversity and nutrient levels in the soil. Our results can be applied to other symbiotic relationships and how they are affected by secondary succession. Also, the DNR could take into consideration the Carbon and Nitrogen levels and functional groups of fungi found when determining when to prescribe a controlled burn.

Introduction

Forest succession is characterized as a change in species composition and development over time (Barnes, 1980). In a secondary succession resulting from a burn, all of the above ground biomass is destroyed, but the contents of the soil remains intact. Forest secondary succession can be influenced by a number of factors including organisms that are interacting with the ecosystem such as animals or fungi. Fungi play an important role in a forest ecosystem by influencing the nutrient levels in soil and interacting with plants. Fungi do not have any chlorophyll, so they depend on the organic matter in the soil for their source of carbon and energy (Brady, 1974). Two functional groups of fungi are mycorrhizal and decomposers. Most of the mycorrhizal fungi in the temperate forests of Northern Michigan are ectomycorrhizae (ECM), which indicates that they do not penetrate the cell wall of the plant roots but they still have a mutualistic relationship. The interaction is mutualistic because both species benefit from the relationship. The plant gains increased access to the soil allowing for greater water and nutrient uptake, while the mycorrhizal fungi receive carbon from the plant to use for growth and other physiological functions (Hudson, 1986). The most common mycorrhizal fungi that we expected to find in Northern Michigan were Golden Chanterelle (*Cantharellus cibarius*), Aspen Bolete (*Leccinum aurantiacum*), Birch Bolete (*Leccinum scabrum*), and King Bolete (*Boletus edulis*) (Ostry, 2010).

The other main functional group of fungi found in forests is decomposers. Fungi are the main form of decomposers in forests because they have the enzymes needed to decompose lignin, which is a complex chemical substance found in wood (Hudson, 1986). After the decomposing fungi use enzymes to break down the decaying material in the forest, they absorb these nutrients and use them for growth and reproduction. Unlike mycorrhizal fungi,

decomposing fungi can potentially acquire Carbon, Nitrogen, and Phosphorous from one source by decomposing organic matter and absorbing the nutrients (Treseder, 2005). The most abundant decomposer fungi found in Northern Michigan are Oyster Mushrooms (*Pleurotus populinus*), Artist's Conk (*Ganoderma applanatum*), and Smokey Polypore (*Bjerkandera adusta*) (Ostry, 2010).

Nitrogen is one of the essential nutrients for plant growth, so the level of nitrogen in soil can be used to compare forest composition. Nitrogen can be a limiting nutrient for plant growth. When plants do not receive enough nitrogen their growth is stunted, which explains why plants use mycorrhizal fungi to increase their area of nutrient uptake (Dighton, 2005). Carbon is also a limiting nutrient for plant growth, so we are expected to see optimal plant growth when neither Carbon nor Nitrogen levels are limiting. Carbon to Nitrogen ratios can be useful in comparing nutrient availability in different stages of secondary succession.

This study investigated how the age of a forest affects the functional groups of fungi and the Nitrogen and Carbon levels of the soil. We predicted that the 1954 and 1936 burn plots would have a greater diversity of fungi since they had more time to develop. If plants depend on mycorrhizal fungi to increase their nutrient uptake for growth, we predicted to find more mycorrhizal fungi in the 1998 plot where plants are in earlier growth stages. The older two plots have more decaying wood, so we predicted to find more decomposers in the 1954 and 1936 plots than the 1998 plot. We also predicted that there would be higher Carbon and Nitrogen available in the 1954 and 1936 plots because they are actively growing and should have a greater nutrient turnover.

Methods

We surveyed the 1936, 1954, and 1998 burn plots at the University of Michigan Biological Station, located in Pellston, MI, in order to determine how the time since a disturbance affected which species and functional groups of fungi are present how this can affect soil nutrient content (Fig. 10). We chose these burn plots because they were all clear-cut, and experienced a controlled burn in their respective years.

We surveyed the fungi species in each burn plot using transects. Five 4m x 100m transects were conducted every 20m in the 1936 and 1954 burn plots, while the 1998 plot only had four 4m x 50m transects since it was smaller. We identified each fungi species that we found as Golden Chanterelle, Aspen Bolete, Birch Bolete, King Bolete, Oyster, Artist's Conk, Smokey Polyphore or "other" based on literature. Each fungi was further classified into a functional group of either mycorrhizal or decomposer. The functional group of the "other" fungi were determined based on where they were located and by appearance. We also collected soil samples at different increments along each transect. This allowed us to analyze Carbon and Nitrogen levels in each plot to see if it varied between the three different aged plots. We analyzed the soil by drying and grinding it, then we used a CosTech Elemental Combustion Analyzer to measure the Carbon and Nitrogen levels. We repeated this process three times.

After surveying, we calculated the Shannon Diversity Index for each plot and conducted an ANOVA to compare the fungal diversity between the three plots. We also conducted a chi-squared test to measure if the fungi functional group composition was the same between the three burn plots. This test showed us if fungi functional groups were statistically different in the older plots versus the newer ones. We conducted a series of ANOVA tests to compare if the soil nutrient levels were significantly different based on the age since disturbance. First we analyzed the soil Nitrogen levels in each plot by using an ANOVA to compare the average percent

Nitrogen of the three burn plots. We also used an ANOVA to compare the mean percent Carbon between the three plots. Finally we used an ANOVA to compare the soil C:N ratio between the three plots.

Results

A Shannon Diversity Index was calculated to compare fungi diversity between the three burn plots that we surveyed. The 1954 burn plot was the most diverse (H = 1.822), followed by the 1936 burn plot (H = 1.795). The 1998 burn plot was the least diverse (H = 1.265). An ANOVA comparing the fungal diversity between the three plots showed that there was no significant difference in fungal diversity ($F = 3.957$, $df = 2, 6$, $p = 0.08$) (Fig. 1).

The most abundant species of fungi found in the 1936 plot were Golden Chanterelle (16%), King Bolete (16%), Artist's Conk (13%) and Smokey Polyphore (13%) (Fig. 2). Mycorrhizal fungi (65%) were more abundant than decomposers (35%) (Fig 3). In the 1954 burn plot, Golden Chanterelle (20%), Smokey Polyphore (18%) and Aspen Bolete (13%) were the most abundant fungal species (Fig. 4). Similar to the 1936 plot, there were a greater percentage of mycorrhizal fungi (66%) than decomposing fungi (34%) (Fig 5). In the 1998 plot the most abundant species of fungi were Aspen Bolete (16%) and King Bolete (15%) (Fig. 6). The 1998 plot was almost entirely composed of mycorrhizal fungi (94%) and very few decomposer fungi (6%) (Fig. 7). Results of the chi-squared showed that there was a significant difference in the functional groups of fungi between the three plots ($X^2 = 30.66$, $df = 1$, $p < 0.05$) (Fig. 2 and 3).

Nutrient levels in the soil did not vary significantly between the three plots. The soil in 1936 plot had an average percent Nitrogen of 0.327, average percent Carbon of 8.592, and an average C:N ratio of 26.301. The soil in the 1954 plot on average consisted of 0.452% Nitrogen,

11.273% Carbon, and a C:N ratio of 24.941. The 1998 plot average 0.304% Nitrogen, 7.483% Carbon, and a C:N ratio of 24.648. There was no significant difference in percent Nitrogen content of the soil between the 1936, 1954, and 1998 burn plots ($F = 0.948$, $df = 2, 36$, $p = 0.397$) (Fig. 8). Carbon levels in the soil also did not significantly change between the three plots that we analyzed ($F = 0.839$, $df = 2. 36$, $p = .441$). The Carbon to Nitrogen ratio between the three plots was also found to be insignificant ($F = 0.772$, $df = 2, 36$, $p = 0.470$) (Fig. 9).

Discussion

Fungi play an important role in nutrient cycling of organic matter and depend on plants and animals for growth, so they can be useful indicators in studying succession (Suzuki, 2002). In order to analyze how secondary succession impacted fungal diversity, we used a Shannon Diversity Index. We predicted that there would be a greater diversity in the 1936 and 1954 plots compared to the 1998 plot. The Shannon Diversity Index that we calculated showed that there was a greatest fungal diversity in the 1954 plot; however, none of the burn plots were significantly different. Other studies have found that it only takes fifteen years for fungi to return to their pre-fire levels (Treseder, 2004). The youngest plot that we analyzed was burned sixteen years ago; therefore it is likely that all of the plots have reestablished their pre-fire fungal diversity. One source for error in our analysis is that we calculated the Shannon Diversity Index using only the seven species of fungi that we identified by name. Even though the other mycorrhizal and other decomposer groups contributed to the species diversity, we did not separate them by species so they could not be included in our calculation.

We found that there was a significant difference in the functional group of fungi between the three burn plots. This difference was seen in the 1998 plot, which consisted of 94%

mycorrhizal fungi while the 1954 and 1936 plots were composed of 66% and 65% mycorrhizal fungi respectively. However, it was not due to a greater abundance of mycorrhizal fungi found in the 1998 burn plot, but rather a lack of decomposing fungi. This can be attributed to the limited amount of decaying matter. The plot was burned sixteen years ago, so there were not as many dead trees found as compared to the other two plots, reducing the abundance of decomposers in the 1998 burn plot. It has also been found that mycorrhizal fungi have the capacity to decompose soil organic matter (Talbot, 2008). Most of the decaying matter in the 1998 plot is composed of dead leaves in the organic layer of the soil, so the mycorrhizal fungi that are already present use enzymes to decompose the leaves in exchange for Carbon. There is no need for decomposing fungi to grow when the already existing mycorrhizal fungi can perform the same function.

Nitrogen is an essential nutrient for plant growth, so the mutualistic relationship between plants and mycorrizal fungi is a strong driver of ecological processes (Read, 2002). Plants need mycorrhizal fungi to increase their nutrient uptake; in return the mycorrhizal fungi receive Carbon as a source of energy. Nitrogen is a limiting resource in plant communities; therefore it is a major factor in determining species composition and diversity in communities and successional dynamics (McLendon, 1991). We predicted that percent Nitrogen levels in the soil would be highest in the 1954 and 1936 plots since they are actively growing and should have the highest nutrient turnover. We found that the highest level of percent Nitrogen in the soil was in the 1954 plot, followed by the 1936 burn plot, however percent Nitrogen levels were not statistically different between the three plots. Past studies have found that there is the greatest nitrogen availability in the soil within ten years after a disturbance followed by a slight decline as succession proceeds (Vitousek, 1989). As a forest ages, nitrogen becomes a limiting resource, which restricts plant growth and abundance as a forest reaches climax. However, all of our plots

were considered to be an intermediate stage of succession even though their ages varied, so we did not see a significant change in the percent Nitrogen availability in soil.

Carbon is also a limiting nutrient to plant growth; therefore Carbon availability in soil can be measured to compare successional stages. We predicted that Carbon levels in the soil would be higher in the 1954 and 1936 burn plots, but our results showed that there was not a significant difference in percent Carbon between the three plots. Past studies have indicated that percent Carbon availability in soil can be correlated to percent Nitrogen availability (Knops, 2000). Our study supports this result since the C:N ratio was not significantly different between the three burn plots.

One limitation in our study was that all three of the burn plots were considered to be in an intermediate stage of succession. The soil is unharmed in secondary succession, therefore the forest regenerates fairly quickly and the early stage typically only lasts five to ten years (Wohleab, 1963). A forest reaches climax when it is composed of a stable, self-maintaining mature plant community and species diversity dramatically decreases (Whittaker, 1974). A forest does not usually reach climax until after a hundred years. Our plots all fell in an intermediate stage of succession, which explains why we did not see a lot of variation between fungal diversity and nutrient availability between the three plots.

Secondary succession impacted the functional groups of fungi. Fungi play an important role in nutrient cycling of organic matter, however, Nitrogen and Carbon levels are reestablished to their pre-disturbance levels after about ten years, so we did not see a great variation in nutrient availability. Fungal diversity also only takes about fifteen years to be reestablished, so we did not find a difference in the fungal diversity between the three plots. Further study should be done analyzing plots that have been disturbed about five years ago and over one hundred years ago in

order to represent an early stage of succession and a climax community. This data can be important in determining the impact of succession of fungal functional groups and nutrient availability in soil, since the three plots that we studied all represented an intermediate stage of succession. This study can be important when studying other symbiotic relationships and how they are affected by forest succession and nutrient levels. The results can also be applied to prescribed burnings by the DNR, and how it will impact nutrient levels and fungal communities.

Figures

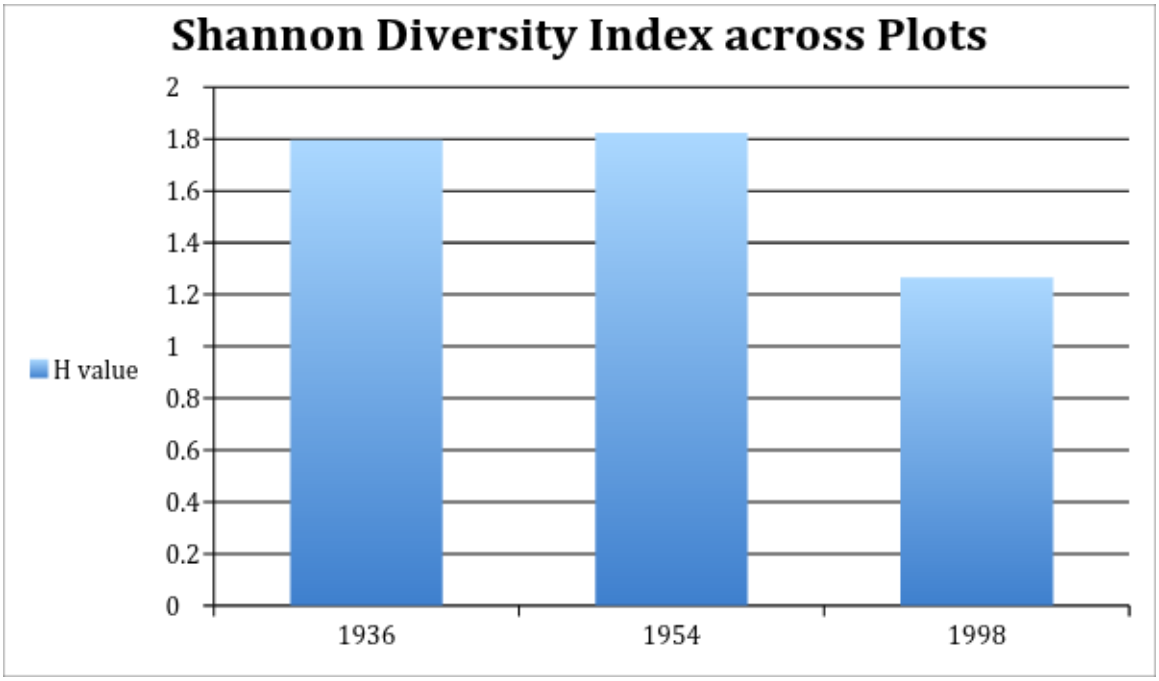

Figure 1: The figure shows the Shannon Diversity Index of the 1936, 1954, and 1998 burn plots. There was no significant difference in fungal diversity between the three plots.

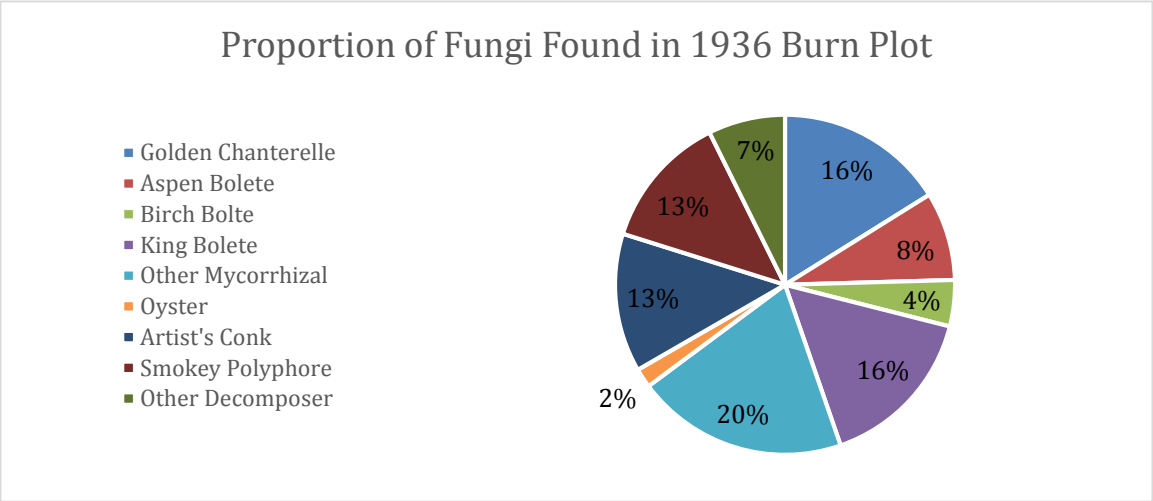

Figure 2: The proportion of fungi species found in the 1936 burn plot. The figure shows that the most abundant fungal species were Golden Chanterelle and King Bolete.

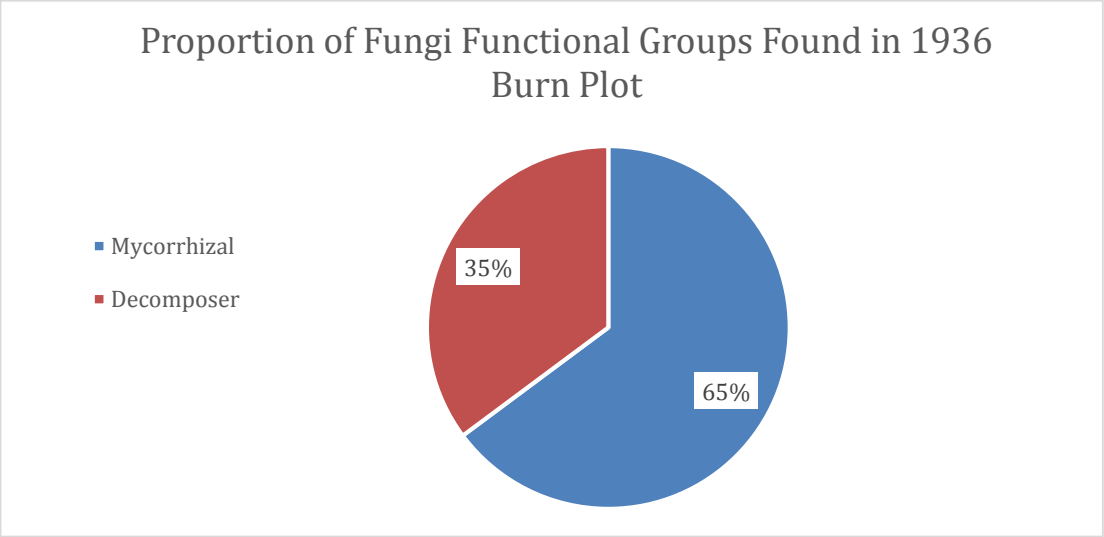

Figure 3: The proportion of fungi functional groups found in the 1936 burn plot. The figure shows that the majority of fungi surveyed were mycorrhizal fungi.

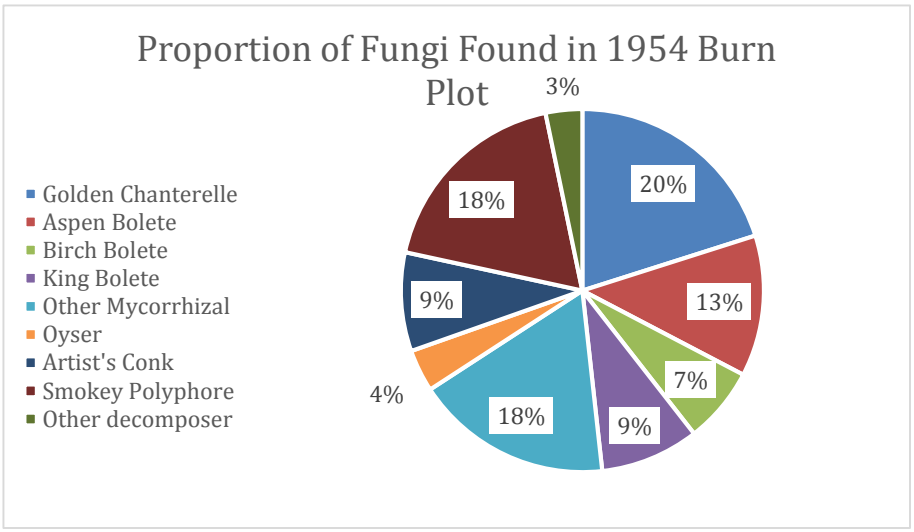

Figure 4: The proportion of fungi species found in the 1954 burn plot. The figure shows that the most abundant fungal species were Golden Chanterelle and Smokey Polyphore.

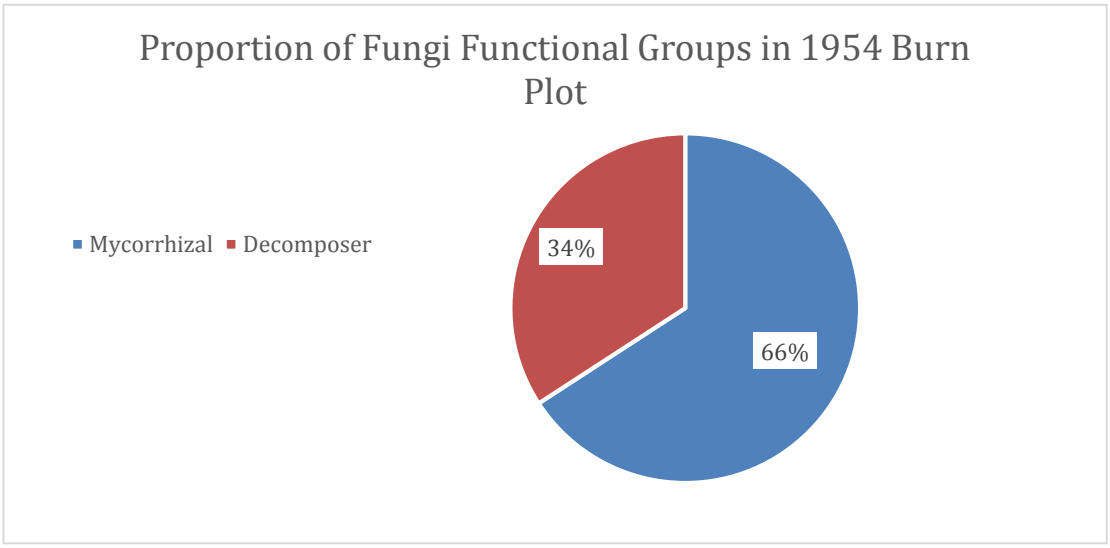

Figure 5: The proportion of fungi functional groups found in the 1954 burn plot. The figure shows that the majority of fungi surveyed were mycorrhizal fungi.

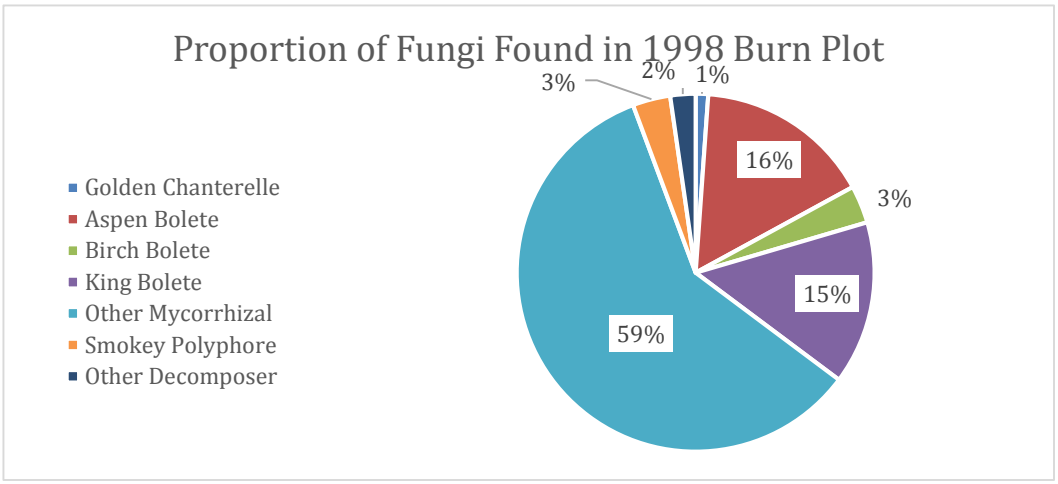

Figure 6: The proportion of fungi species found in the 1998 burn plot. The figure shows that the most abundant fungal species were Aspen Bolete and King Bolete.

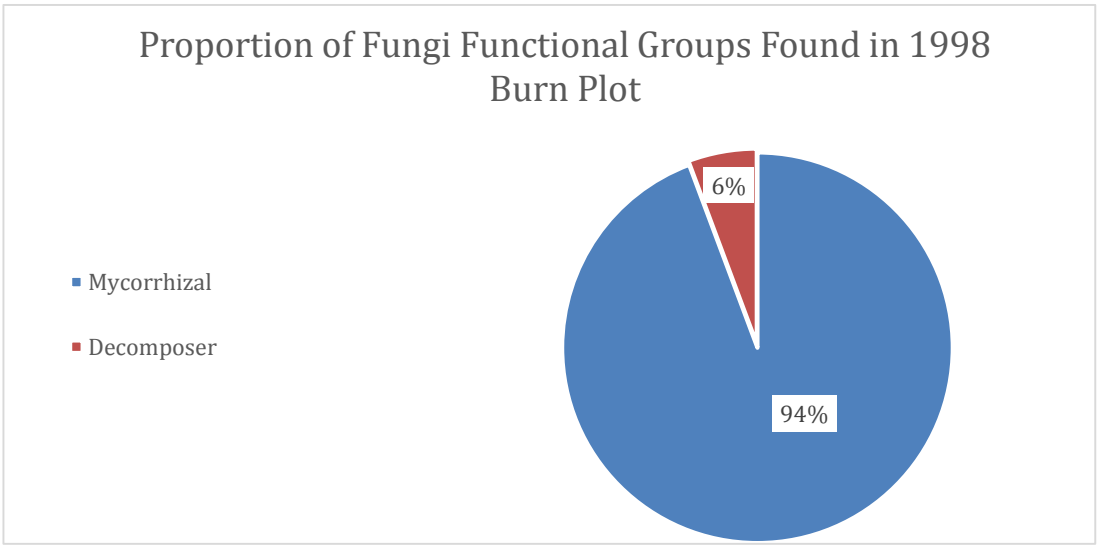

Figure 7: The proportion of fungi functional groups found in the 1998 burn plot. The figure shows that almost all of the fungi surveyed were mycorrhizal fungi.

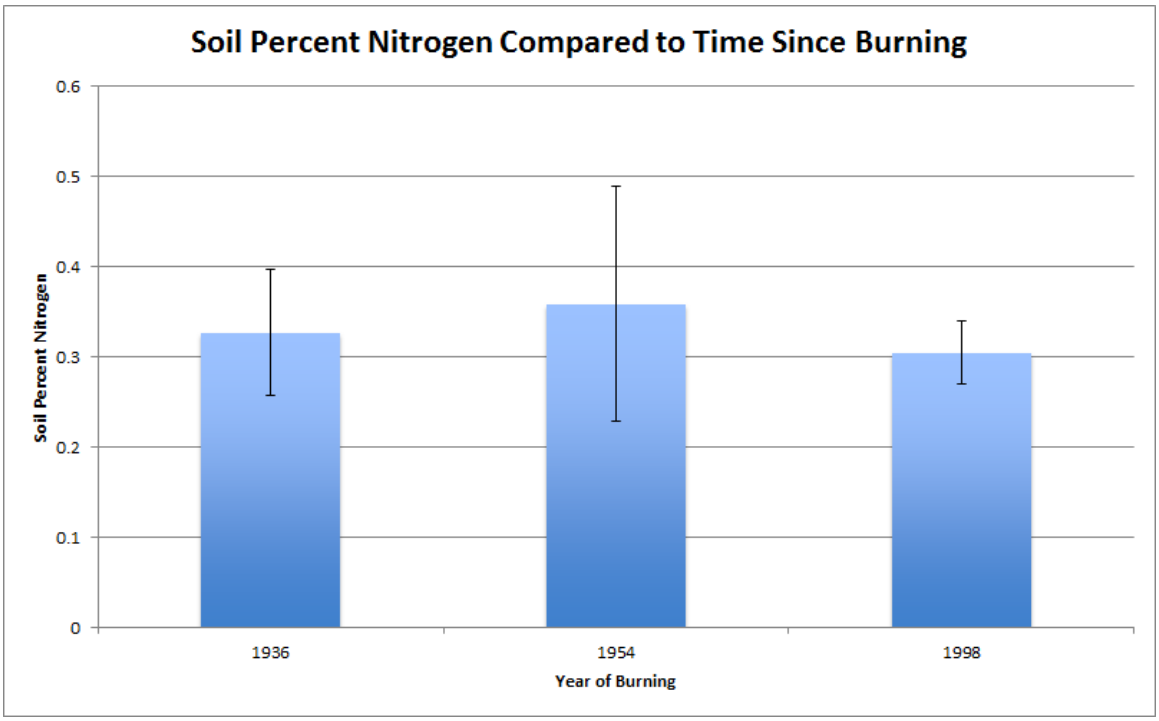

Figure 8: The average percent Nitrogen level in soil in the 1936, 1954, and 1998 burn plots. The figure shows that there is no significant difference in soil Nitrogen availability between the three plots.

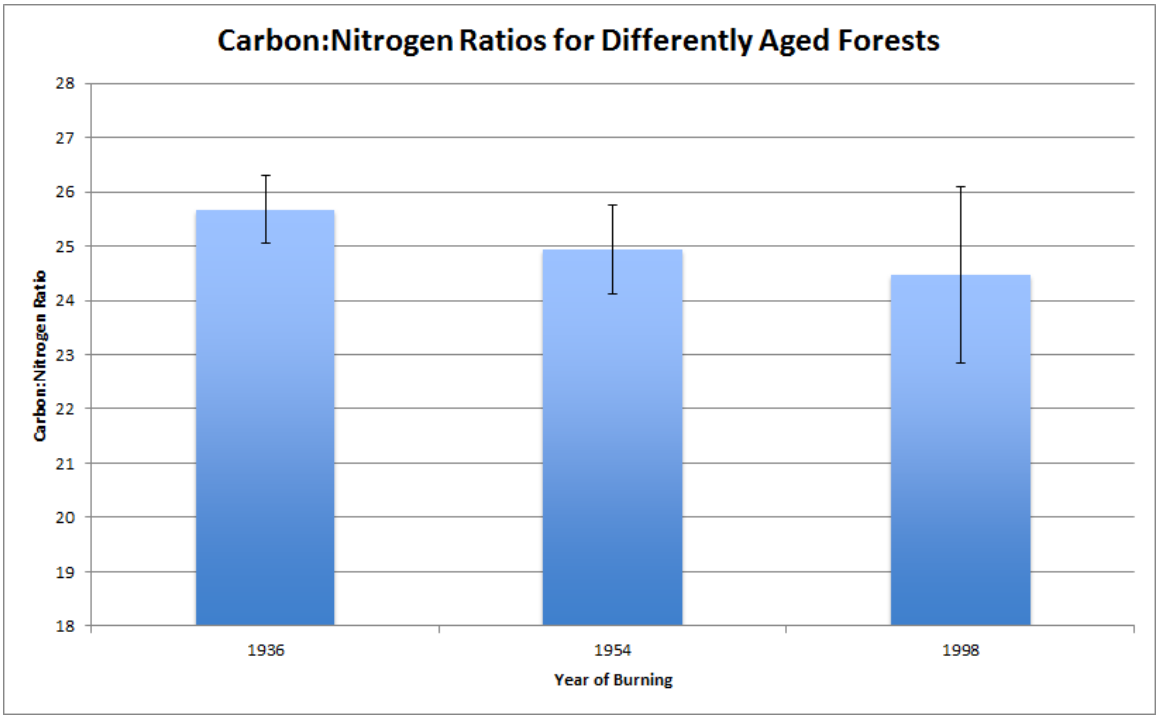

Figure 9: The average C:N ratio of soil in the 1936, 1954, and 1998 burn plots. The figure shows that there is no significant difference in the C:N ratio between the three plots.

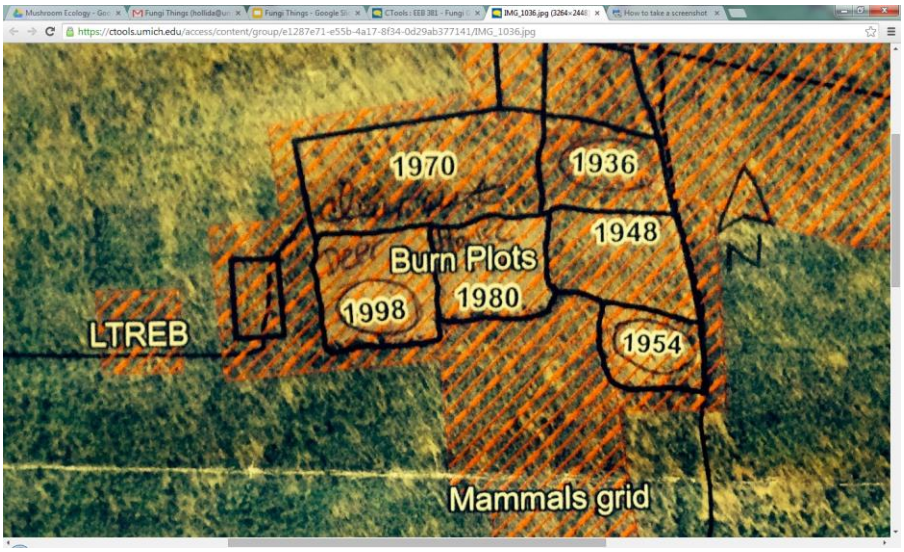

Figure 10: A map of the burn plots at the University of Michigan Biological Station. The plots we studied were 1936, 1954, and 1998.

Literature cited

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