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Prescribed fire effects on groundcover vegetation over time

Introduction

The forests of northern Lower Michigan have always been prone to wildfires. In fact, many northern forests are considered to be dependent on the periodic cycle of natural fires for continued growth (Van Wagner, 1978). In 1911, a large fire destroyed most of the forest of the Pellston area, particularly around the University of Michigan Biological Station (UMBS). Starting in the 1930s after fire control measures were developed (See Figure 1), UMBS researchers began to experiment with prescribed burning in small plots around the station property. The burn experiments have been completed approximately every twenty years to study the long-term effects of fire on succession, starting in 1936. The most recent burn plot was finished in 1998 (Walsh and Randall, 1998).

Typically, the study of succession in any ecosystem is a long-term process. Changes in a habitat from one type of community to another are gradual progressions that must be observed over time (Chander et. al., 1983). The purpose of UMBS's prescribed burning experiments was to be able to observe a natural process on a quicker timeline, as most natural fires in northern forests occur in intervals of 50 to 150 years. In order to understand the placement of the vegetation in a habitat, one must understand its history and the patterns of post-fire succession (Johnstone et. al., 2003).

Fire, when it is severe enough, has the ability to completely destroy the principal species of a community. When an ecosystem is disturbed to such a great degree, succession will regress from its previous trajectory to allow a new sequence of communities to appear (Chandler et. al., 1983). Plants have evolved many adaptations to fire exposure to ensure that the plants survive throughout their life cycle, particularly protection of buds, seeds, and ground storage of seeds and roots to allow for quick regeneration after fire (Chandler et. al., 1983). Some flora in particular, such as aspens, require bare mineral soil with no other competitors, in order to germinate successfully. Burning of the habitat can create such a situation (Kay, 1993). Aspen and other plants that come into an area right after a fire often have clonal or asexual methods of establishment, allowing them to spread quickly after only one or two colonizers have begun growth (Hellman, 1991).

Fires have a profound effect on soil quality and composition. They destroy the organic horizon of protective soil cover, leaving the soil exposed to the air. Removing the organic horizon removes a source of easily used nutrients, temperature regulation, and defense from erosion (Neary et. al., 1999). It can take up to six years for the moisture in soil to build up to its previous levels after even a small fire (Robichaud, 2000). Soil is also the platform on which basic hydrologic and biogeochemical cycles run, and hold a nutrient reservoir critical to survival of flora and fauna. In many ways, soil composition determines the structure of the community aboveground (Neary et. al., 1999). Nitrogen especially, as one of the most limiting nutrients in the environment, is essential in post-fire recovery of an ecosystem, notably for its role in retrieving previous productivity (Wan et. al., 2001).

The groundcover composition that occurs after a fire is directly influenced by the effects of the fire on its habitat. Seedlings of either trees or herbs that are produced after a fire have a greatly increased chance of survival in comparison to an unburned area because of increased light (from the removal of the tree canopy) and increased nutrients from soil exposure (Ashton, 1981). The contrast between burned and unburned areas can also be seen from the type of growth that occurs. Perennials with shallow root systems are common in unburned sites, while annuals or other plants that come with deep root and storage systems can be found to colonize after a fire (Ahlgren, 1960). White birch and aspen are able to form clonal structures, allowing them to colonize rapidly (Chandler et. al., 1983). Fires have always been an important catalyst to forest communities.

In our study, the groundcover of several burn plots at UMBS were surveyed and compared for species composition and diversity over decades' worth of prescribed burning, as well as to the oldest forest available, from the 1911 natural fire. We hypothesized that the most recent experimental plots exposed to fire would contain significantly different groundcover communities than the oldest. We also hypothesized, based on the Intermediate Disturbance Theory, that the burn plots with a relatively moderate amount of time to recover would contain the most diversity.

Methods

To compare the ground cover of four burned plots and a non-prescribed burn area, we collected data on twelve square meter sections in the middle of each plot. Samples were taken within the 1936, 1954, 1980, and 1998 burn plots, as well as from a control plot within the natural 1911 forest. Each transect cut across the length of the plot and each section was spaced 10 meters apart. By not collecting data on anything within 15 meters of the perimeter of the plot, we avoided edge effect. The number of plant species and the percent coverage of the section by each species were recorded.

To analyze the data, a Braun-Blanquet coverage-abundance scale was used. Five categories named 1 to 5 were used where 1 = less than 5% coverage, 2 = 5-25% coverage, 3 =

25-50% coverage, 4= 50-75% coverage and 5 = greater than 75% coverage. An additional category of 0.5 was also used when species were only present, or equal to less than one percent coverage of the section sampled.

Correspondence analysis (CA) was used to analyze the multi-variant data collected. . Species data was condensed by removing any species in the data that was recorded less than three times. Rarer species were down-weighted so that outliers would not unnecessarily affect result patterns.

Kruskal-Wallis tests were run to detect differences in species densities between plots for four species commonly found throughout the different experimental plots: Bracken fern, blueberries, wintergreen and moss. Mann-Whitney tests were also conducted to determine which plots were statistically different ($p < 0.05$) from other plots in pair-wise tests of different years.

Data was also collected on the average percent canopy cover, amount of light reaching the understory, and the thickness of the organic layer (O Horizon). Organic matter was recorded in metric units using a meter stick. Canopy cover was measured via a Spherical Densiometer, Model-C. Standard densiometer procedure was followed to calculate the percentage amount of cover. Light reaching the understory was measured via a digital handheld light sensor, the Li-Cor model LI-189 quantum photometer, at a height of 1 meter above the ground. For both light and organic layer thickness, three measurements were taken at random within each plot.

Results

Correspondence analysis of the data revealed that the most recently burned plots contained the most variation in species composition, with plots becoming more similar to the 1911 forest as they aged (Figure 2). Diversity among plot (beta-diversity) decreases with increasing age, reducing down to the levels of the 1911 plot. Species optimums illustrated where a species was found most commonly (Figure 2). Species optimums located closely to one another on the chart are found together more commonly, and optimums located far away from each other were much less likely to be found in the same plot.

Of the four species chosen to compare for statistical significance, only bracken fern and wintergreen were significantly different across years (Figure 3). Differences in bracken fern and wintergreen densities were found typically between younger and older plots, rather than between plots close in age (Figure 4).

Average light readings showed that light reaching the understory decreased with increasing time since the last burn (Figure 5). Average canopy cover was less conclusive, but showed that the most recent burn had significantly less canopy cover than all other plots (Figure 6). Organic layer exhibited increasing thickness with increasing age of the plot (Figure 7).

All of the plots sampled contained large amounts of bracken fern, but the youngest in particular were dominated by the species. The older plots on average (1911 to 1954) had groundcover make-ups dominated by blueberries and wintergreen, young tree saplings, and organic matter. Blueberries and wintergreen tended to be found in larger densities together. The younger plots (1980 to 1998) were much more likely to have bare soil, moss, and lichen.

Discussion

The results of the correspondence analysis revealed that the original hypothesis was correct, but only in part. The most recent burn plots were indeed significantly different from those that were exposed to fire longer ago, but not in the pattern that was expected. According to the Intermediate Disturbance Hypothesis, the plot with an intermediate amount of time to recover from fire should have had the most biodiversity, rather than the oldest or youngest sites. Therefore, it was expected that the 1954 plot would have the most diverse community composition. Instead, the correspondence analysis showed that the more recent experimental plots contained the most biodiversity, in particular the 1998 burn plot (Figure 2). Diversity narrowed from a wide range at the young experimental sites towards a minimum in the oldest forested areas, which suggests several interesting questions.

The first of these questions is to ask how quickly a forest can recover from fire disturbance to a point where the habitat could be considered similar to nearby climax community. Although the area near the burn plot should likely not be considered a climax community, since it has only had 100 years to recover from natural fire that destroyed the entire Pellston area, it has had the most time to recover and at this point represents peak forest growth. The fact that the 1954 plot contained a very similar community to the 1911 one may mean that post-fire recovery in northern forests is an exponential process, rather than a linear one. Studies have suggested that diversity is more dependent on the rates of colonization of different species, and that as woody plant biomass increases, there is much more competition for resources and herbaceous plant richness will decrease (Guo and Rundel 1997; Keeley 2005). Therefore the reduction in groundcover diversity in the older plots may be directly linked to the fact that these habitats are more tree-dominated, in contrast with the very open, aspen sapling habitat of the 1998 and 1980 plots.

Another question raised by this study's results is whether the Intermediate Disturbance Hypothesis still applies to the data, but not in the way originally applied. The original hypothesis used the definition of intermediate disturbance as a factor of the time occurring since the disturbance took place. However, the Intermediate Disturbance Hypothesis also can be measured in how intense or severe a disturbance is to a habitat. In this interpretation, it may make more sense that the older plots exposed to fire have less diversity, because the older plots are likely to have been exposed to much more severe fires. The 1911 fire is supposed to have been particularly harsh, as it completely destroyed the Pellston area forests. It is also quite possible that the first few experimental burns were more severe than the most recent due to more primitive fire control and suppression techniques. An intermediate level of severity also may have been achieved in the experimental burn sites because the plots were clear-cut before they were set aflame, which would reduce the severity in comparison with the 1911 fire. The reduction of forest fuel buildup on the ground has been demonstrated to diminish both the severity and frequency of fires (van Leeuwen 2008).

The speed with which the burn plots recovered and the great biodiversity found within the youngest burns is relatable to the studies done on the Kingston Plains in the Upper Peninsula. This site demonstrates how post-fire recovery may depend much more on severity of disturbance than on time since disturbance occurred. The Kingston Plains were logged heavily for white pine in the 1890s, with much slash and detritus left behind. This gave way to a raging inferno in 1900, which destroyed the soil so completely that today the site is still a barrens, dominated by lichen and bracken fern (Lytle 2005). Even though it has had approximately the same time to recover from the fire as has the Pellston area from the 1911 fire, it most closely resembles the 1998 burn plot. Lytle estimates that the Kingston Plains will need at least another 200 to 300 years to recover back to a traditional forest ecosystem, if the climate remains somewhat stable. Compared to the Kingston Plains, the prescribed burn sites at UMBS can be considered intermediate, and explains their much greater diversity.

The second set of statistical tests that were performed involved comparing the distribution and percent cover of four species found commonly throughout all of the plots sampled. Although blueberries, moss, bracken fern and wintergreen were all tested, only the latter two had any statistically significant differences (Figure 3). We found that bracken fern and wintergreen, when compared across different plot years, had significant differences in general between the oldest and youngest plots, rather than those closer together in age, which is what we would expect in this situation, since our hypothesis is based in part on succession (Figure 4).

The characteristics of these two species and their preferred habitats allow for predictions to be made as to where they would be found within the experimental plots. Bracken fern is a ubiquitous plant, meaning that it can be found in nearly any kind of habitat. It does well in both sun and shade, and is not repelled by either dry or acidic soils (Reznicek 2011). They are also clonal, spreading mainly by rhizomes despite being capable of sexual reproduction (Parks 1993). Clonal organisms, such as aspen, are often found in environments that have been recently exposed to fire, so this explains bracken fern's overwhelming presence in the 1998 plot. It is likely the fern spread to the most recent plots through their rhizomes from the older growth. Bracken fern is also present in all other plots, though in different, much less vast numbers. This is also to be expected since they do well in shade, and can handle acidity from coniferous needle mast in older plots.

Wintergreen also has defining characteristics that allow predictions to be made as to their location within the plots sampled. It is considered to be a species that does well after fire exposure, explaining its significant presence in the most recent burn site (Reznicek 2011). However, it was also found in the older plots, which can be anticipated since wintergreen can grow in both dry and moist soils, and is commonly found with hardwoods such as oak, pine, red maple and aspen, all components of the older sites' tree composition. If one knows where species like to live, it is easy to find them. It is no surprise that some species had statistically different distributions among plots, because the different qualities of the plots leads to a different composition in the groundcover.

The measurements of light intensity, canopy cover percentage and organic layer thickness did not include enough data points to test them for statistical significance, but they did have some interesting patterns that could be further measured in a future study. Light intensity reaching the understory decreased with increasing age of the plot, which is common sense when one thinks of how many more large trees are present in the older plots to block light from reaching the ground (Figure 5). Canopy cover data revealed a more surprising pattern, where all of the plots except for the youngest had near full canopy cover (Figure 6). This is unexpected, particularly because it was thought that canopy cover would be directly correlated with how much light reached the understory. Organic layer thickness patterns matched again what was expected, with the O horizon increasing with age of the plot (Figure 7). This is another "common sense" pattern, because plots that have had more time to accumulate fallen leaves and other mast will have more organic matter left on the ground, while recently burned areas will have bare patches of soil because the previous organic layer was burned away and has not been completely rebuilt.

Past studies of the species composition and diversity of the burn plots have been conducted frequently over the years. One student in 1996 found data that supports the original hypothesis of this paper, with his intermediately aged plot containing the most diversity (Mahler 1996). At the time this student research was conducted, the last experimental plot had not yet been burned, and all of the forests had fifteen years less recovery time. This may explain the difference in pattern found between the experiment and our own. It would be interesting to conduct an analysis to determine if results of diversity are dependent on the time they are conducted in comparison with how long the individual experimental plots have had to recover from disturbance. Another student study found that taking samples from variously aged sites at a single time gave the same patterns of plant diversity and composition as those studies that were conducted over long periods of time at a single site (Garrison 1981). This is a gratifying result, because it means that multiple-plot sampling studies such as this one can give accurate representations of the succession occurring in plant diversity of the experimental plots.

Overall, this study was conducted easily and yielded satisfying results, which could be expanded on in the future. Nonetheless, it is important to note things that need improvement and other problems that occurred. Light readings and canopy cover readings were taken with older-style instruments, which may have affected their accuracy. Also, for light, canopy cover, and organic layer readings there must be much more data collection if a statistical analysis was to be performed to determine significant differences. One further problem involved the different treatment of data collection in the 1998 plot. A deer enclosure was placed after the burn, along with a control enclosure in the 1911 forest, as part of the experimental design. The enclosure encumbered movement while sampling within the most recent plot, as it surrounds all but the edge vegetation. The lack of deer foraging on groundcover in the 1998 plot is a variable that was not considered in this study that may have had a significant impact upon results.

Were there more time, a much more thorough study could be conducted. Firstly, facets of the study could be included to correct the problems discussed above, with many more light, canopy cover, and organic layer readings taken, as well as testing for deer foraging as a variable effecting groundcover in comparison to recency of fire. Secondly, more time would allow for questions to be asked that would take long-term sampling to be answered. One question in particular that would be intriguing to look at is if the different plots have different growing seasons for certain species, or whether different seasons cause statistically significant differences in the compositions of the various plots. Soil composition could be looked at and compared to see if it correlates with biodiversity or species composition. Long-term study would also allow for more complete sampling of entire plots.

Conclusion

The study of succession at University of Michigan Biological Station has been a long one. This research project is one of many that have attempted to see a change in communities in response to the disturbance of fire. Based on the Intermediate Disturbance Hypothesis, we believed that we would find most biodiversity and varied composition in the intermediate aged plots, but this happened not to be true. Instead, a pattern of increased biodiversity in the youngest plots was found, with diversity narrowing to a minimum in the oldest forest. The theory of Intermediate Disturbance may still apply to the experimental burn plots, but this fact will not be for us to discover. Some future researcher will one day have to endeavor to find whether severity, in the case of UMBS's forest, is more important than length of recovery in creating maximum biodiversity. Perhaps in the end, nature is just much more resilient than we think.

Acknowledgments

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<u>Literature Cited</u>

Ahlgren, C.E. 1960. Some Effects of Fire on Reproduction and Growth of Vegetation in Northeastern Minnesota. *Ecology* **41**,3:431-45. Accessed 22 July 2011. <http://www.jstor.org/stable/1933318>.

Ashton, D.H. 1981. Fire in tall open forest (wet sclerophyll forests) In A.M. Gill, R.H. Groves, and I.R. Noble, Eds., *Fire and Australian Biota*, Aust. Acad. Sci., Canberra, pp. 339-366.

Chandler C., P. Cheney, P. Thomas, L. Trabaud and D. Williams. 1983. *Fire in Forestry, Volume 1: Forest Fire Behavior and Effects*. Wiley and Sons: New York.

Garrison, W. 1981. The role of fire in succession on experimentally burned sites. Unpublished manuscript, University of Michigan Biological Station (UMBS). UMBS archives.

Guo, Q. & Rundel, P.W. (1997) Measuring dominance and diversity in ecological communities: choosing the right variables. *Journal of Vegetation Science*, **8**, 405–408. Accessed 13 August 2011. <http://onlinelibrary.wiley.com.proxy.lib. umich.edu/doi/10.2307/3237331/pdf>.

Hellman, K. 1991. Successional trends of bigtooth aspen (Populus grandidentata), red maple (Acer rubrum) and red oak (Quercus rubra) in the 1980 burn plot at UMBS. Unpublished manuscript, University of Michigan Biological Station. Accessed 22 July 2011. < http://deepblue.lib.umich.edu/handle/2027.42/54276>.

Johnstone, J.F., F.S. Chapin III, J. Foote, S. Kemmett, K. Price, and L. Viereck. 2003. Decadal observations of tree regeneration following fire in boreal forests. *Can. J. For. Res*. **34**: 267–273. Accessed 22 July 2011. <http://www.nrcresearchpress. com/ doi/pdf/10.1139/x03-183>.

Kay, C.E. 1993. Aspen seedlings in recent burned areas of Grand Teton and Yellowstone National Parks. *Northwest Science*. **67**, 2: 94-105. Accessed 22 July 2011. < http://www.idahoforwildlife.com/Charles%20Kay/14%20Aspen%20 Seedling%20in%20Recently%20Burned%20Areas%20of%20Grand%20Teton%20and%20Yellowstone%20National%20Parks.pdf>.

Keeley, J. E., Fotheringham, C. J. and Baer-Keeley, M. (2005), Factors affecting plant diversity during post-fire recovery and succession of mediterranean-climate shrublands in California, USA. *Diversity and Distributions*, **11**: 525–537. doi: 10.1111/j.1366-9516.2005.00200.x Accessed 13 August 2011.

Lytle, D.E. 2005. Palaeoecological evidence of state shifts between forests and barrens on a Michigan sand plain, USA. *The Holocene*, **15**: 821-836.

Mahler, M. 1996. Secondary succession: A survey of plant species composition, species richness, and species diversity at the University of Michigan Biological Station burn plots. Unpublished manuscript, University of Michigan Biological Station (UMBS). UMBS archives.

MICHIGAN FLORA ONLINE. A. A. Reznicek, E. G. Voss, & B. S. Walters. February 2011. University of Michigan. Web. August 15, 2011. http://michiganflora.net/ species.aspx?id=1168.

MICHIGAN FLORA ONLINE. A. A. Reznicek, E. G. Voss, & B. S. Walters. February 2011. University of Michigan. Web. August 15, 2011. http://michiganflora.net/ species.aspx?id=1216.

Neary, D.G., C.C. Klopatek, L.F. DeBano, and P.F. Efolliott. 1999. Fire effects on belowground sustainability: a review and synthesis. *Forest Ecology and Management*. **122**:51-71.

Parks, J.C. and Werth, C.R. 1993. A Study of Spatial Features of Clones in a Population of Bracken Fern, Pteridium aquilinum (Dennstaedtiaceae). *American Journal of Botany,* Vol. **80**, No. 5, pp. 537-544

Robichaud, P.R. 2000. Fire effects on infiltration rates after prescribed fire in Northern Rocky Mountain forests, USA. *Journal of Hydrology*. **231-232**:220-229.

van Leeuwen, W.J.D. 2008. Monitoring the effects of forest restoration treatments on post-fire vegetation recovery with MODIS multitemporal data. *Sensors*, **8**: 2017-2042. Accessed 13 August 2011. < http://www.mdpi.com/1424-8220/8/3/2017/pdf>.

Van Wagner, C.E. 1978. Age-class distribution and the forest fire cycle. *Can. J. For. Res*. **8**:220-227. Accessed 22 July 2011. <www.nrcresearchpress.com>.

Walsh, M. and S. Randall. 1998. Effects of clear-cutting and fire on the succession of tree species in northern lower Michigan. Unpublished manuscript, University of Michigan Biological Station. Accessed 22 July 2011. < http://deepblue.lib.umich.edu/handle/2027.42/54817>.

Wan, S., D. Hui, and Y. Luo. 2001. Fire effects on nitrogen pools and dynamics in terrestrial ecosystems: a meta-analysis. *Ecological Society of America*. **11.5**:1349-65. Accessed 22 July 2011. <http://www.jstor.org/stable/3060922>.

Figure 1. Map of Clear-Cut and Burn Experimental Plots at UMBS

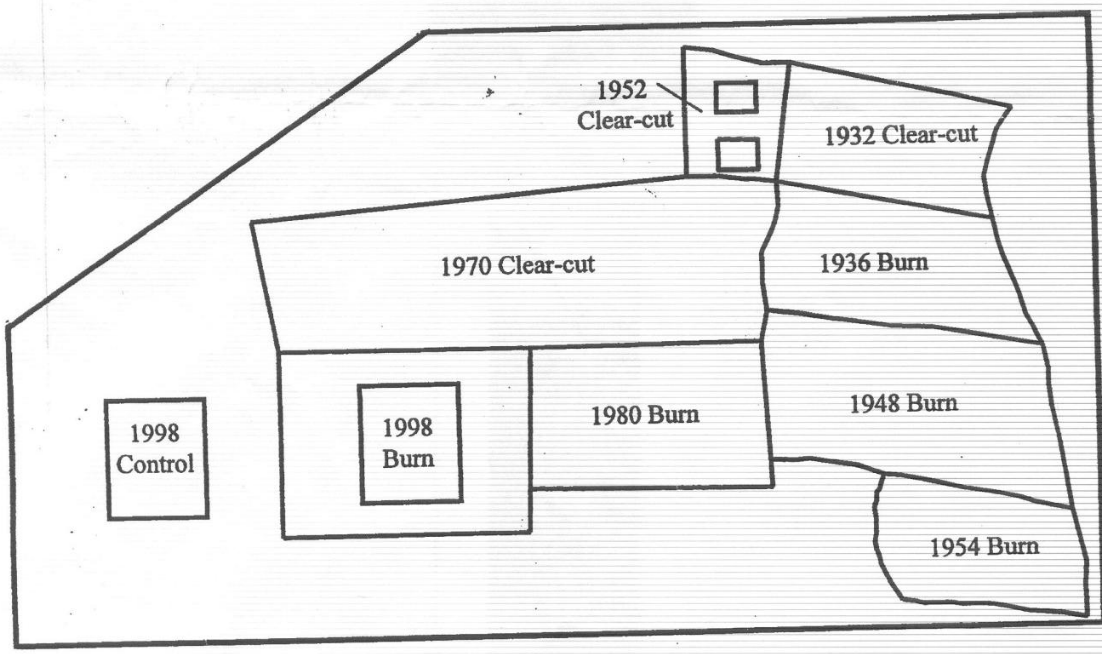


Diagram illustrating the layout of the clearcut and burn chronosequence, Section 32, Township 37 North, Range 3 West, University of Michigan Biological Station, Cheboygan Co., northern Lower Michigan.

Figure 2. Correspondence analysis of the burn plots compared with the 1911 forest, with species optimums included. The first two axes explain 37% of the variance within the data. Blue = blueberries, Winter = wintergreen, Wpine = white pine, Smaple = sugar maple, Rmaple = red maple, FuzUn1 = fuzzy unknown species 1. Bracken fern is located within the large cluster of points at the bottom left.

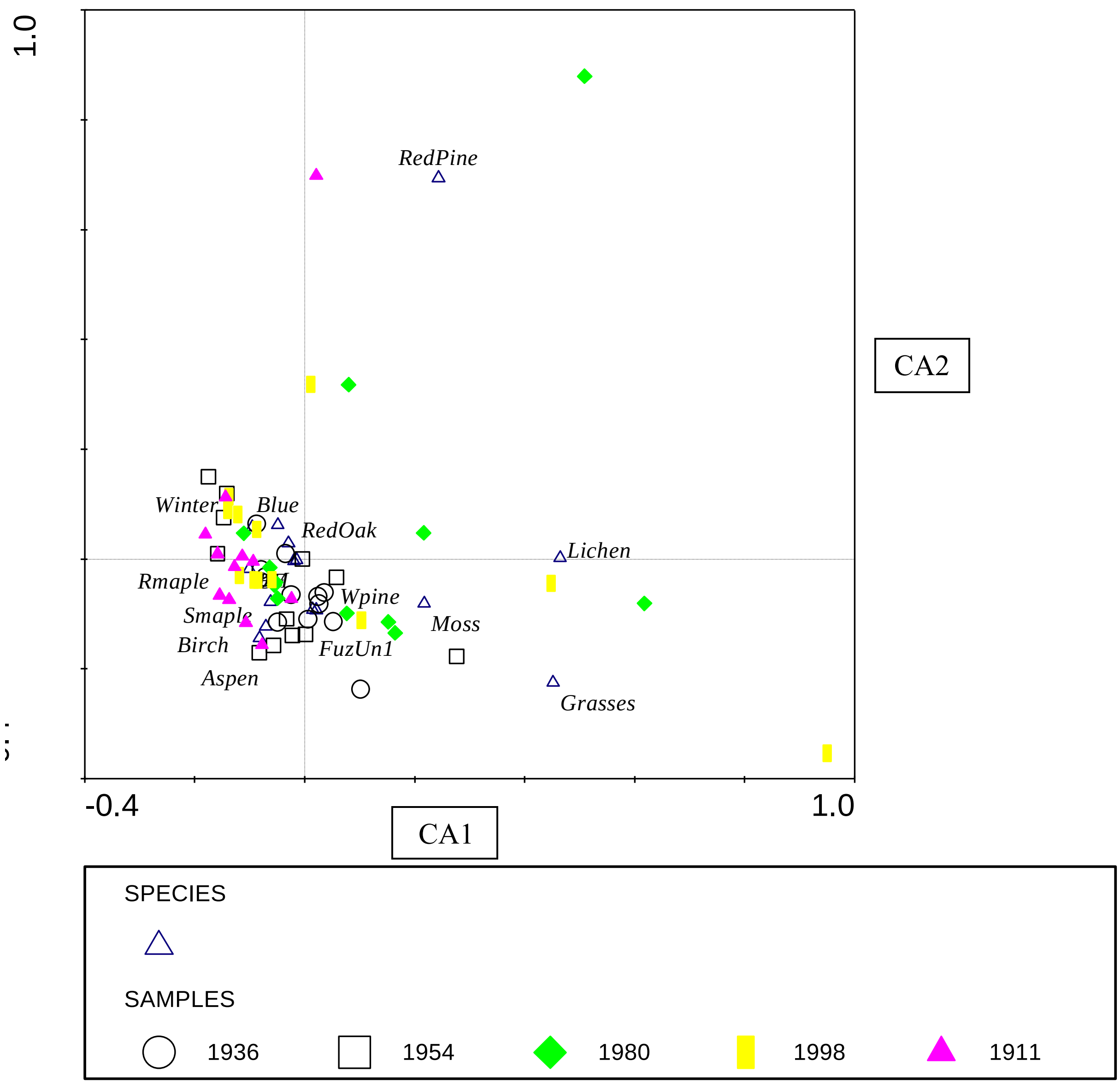


Figure 3. Summary of Kruskal-Wallis tests to compare distributions and medians. Only bracken fern and wintergreen are statistically significant across different plot years ($p < 0.05$).

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of BF are the same across categories of Plot Year.	Independent-Samples Median Test	.004	Reject the null hypothesis.
2	The distribution of BF is the same across categories of Plot Year.	Independent-Samples Kruskal-Wallis Test	.004	Reject the null hypothesis.
3	The medians of Blue are the same across categories of Plot Year.	Independent-Samples Median Test	.441	Retain the null hypothesis.
4	The distribution of Blue is the same across categories of Plot Year.	Independent-Samples Kruskal-Wallis Test	.308	Retain the null hypothesis.
5	The medians of Winter are the same across categories of Plot Year.	Independent-Samples Median Test	.000	Reject the null hypothesis.
6	The distribution of Winter is the same across categories of Plot Year.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
7	The medians of Moss are the same across categories of Plot Year.	Independent-Samples Median Test	.223	Retain the null hypothesis.
8	The distribution of Moss is the same across categories of Plot Year.	Independent-Samples Kruskal-Wallis Test	.376	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Figure 4. Table of pairwise comparisons for bracken fern and wintergreen over different plot years. Bolded terms are statistically significant at a p-value < 0.05.

Statistical Significance between years		
Pairs of years	Bracken Fern	Wintergreen
1911 vs. 1936	**0.002**	**0.000**
1911 vs. 1954	**0.048**	0.262
1911 vs. 1980	0.289	**0.006**
1911 vs. 1998	0.496	0.459
1936 vs. 1954	0.217	**0.000**
1936 vs. 1980	**0.052**	0.148
1936 vs. 1998	**0.001**	**0.006**
1954 vs. 1980	0.425	**0.001**
1954 vs. 1998	**0.029**	0.125
1980 vs. 1998	0.158	0.071

Figure 5. Average light readings taken 1 meter above ground for the burn plots in µmol of photons.

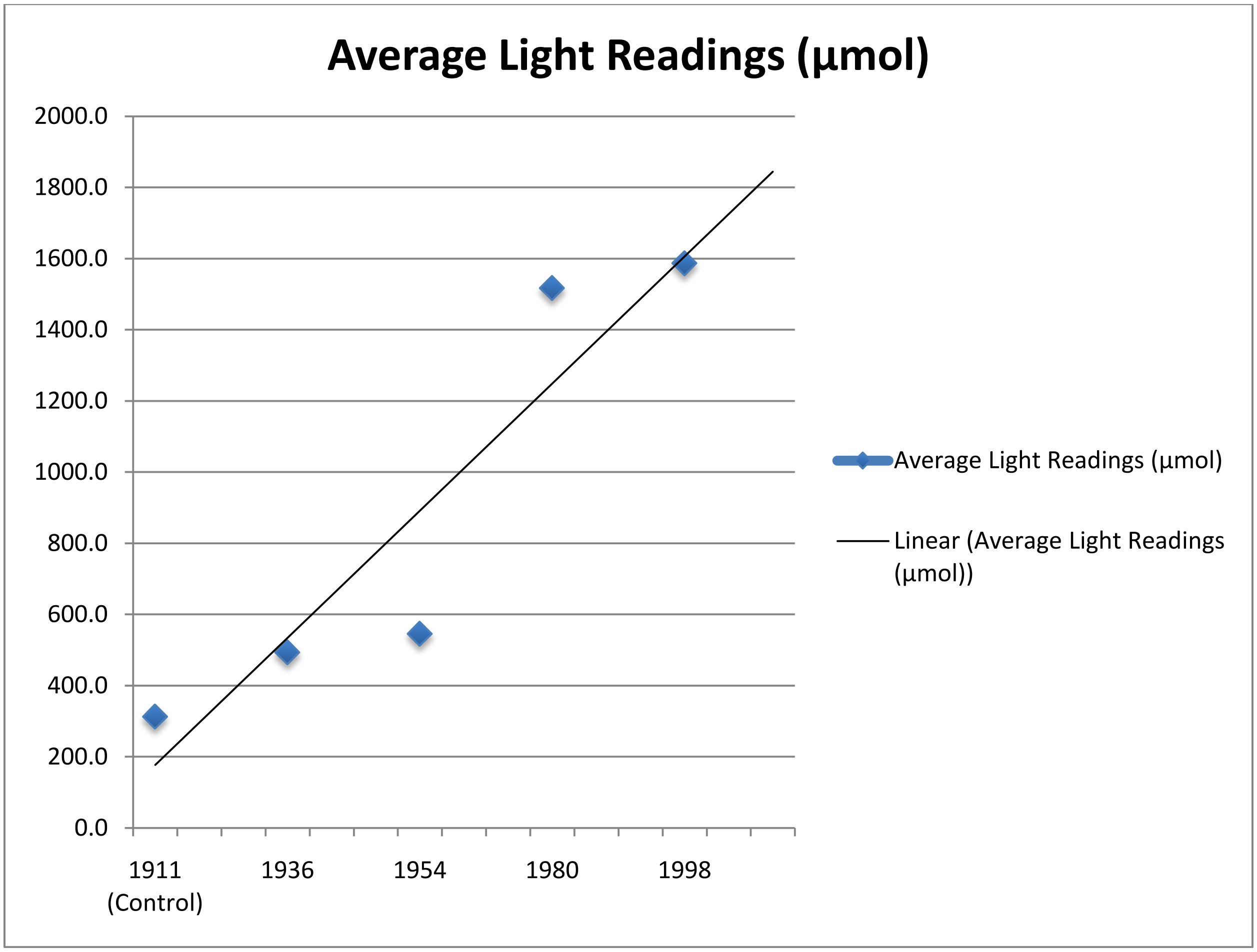


Figure 6. Average canopy cover in the plots, taken as a percentage of total sky.

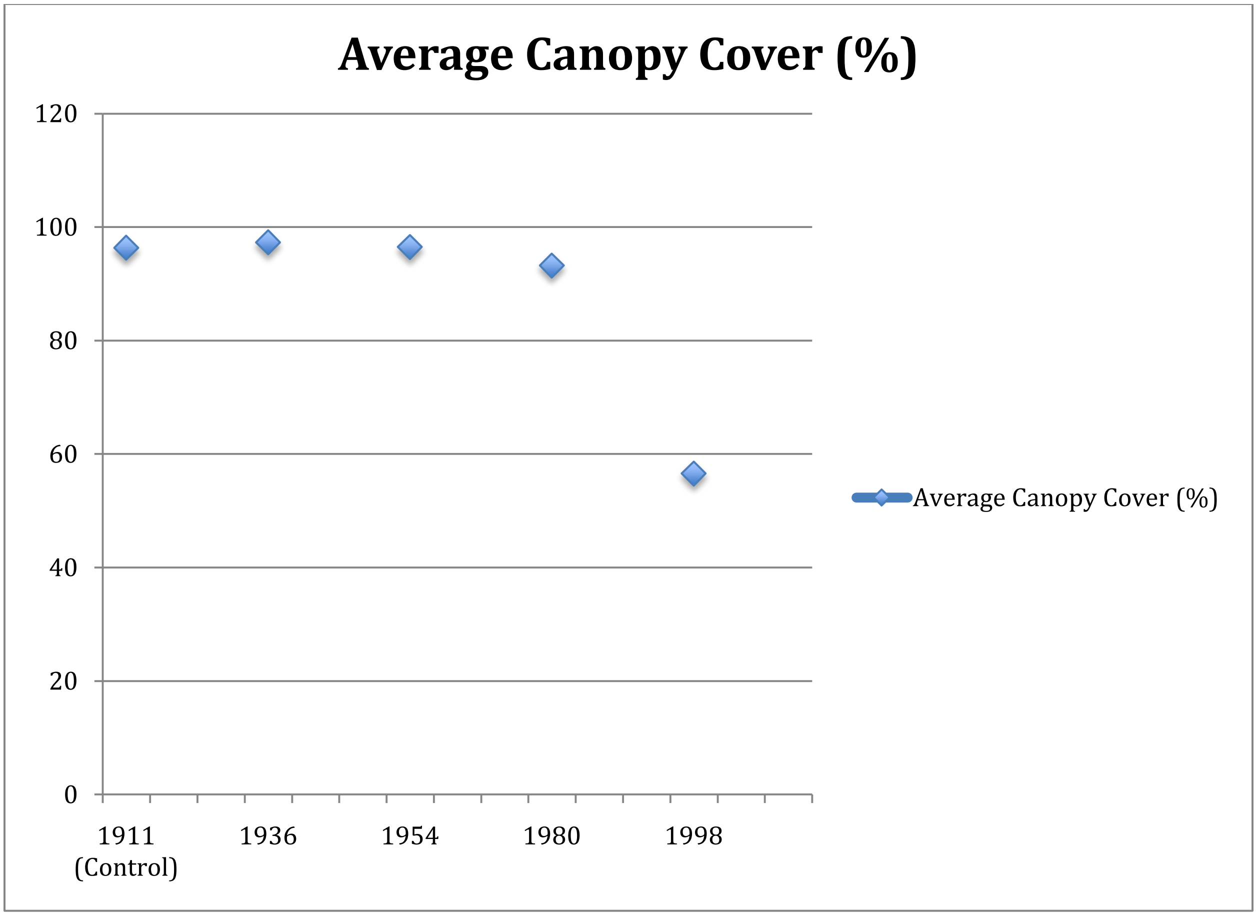
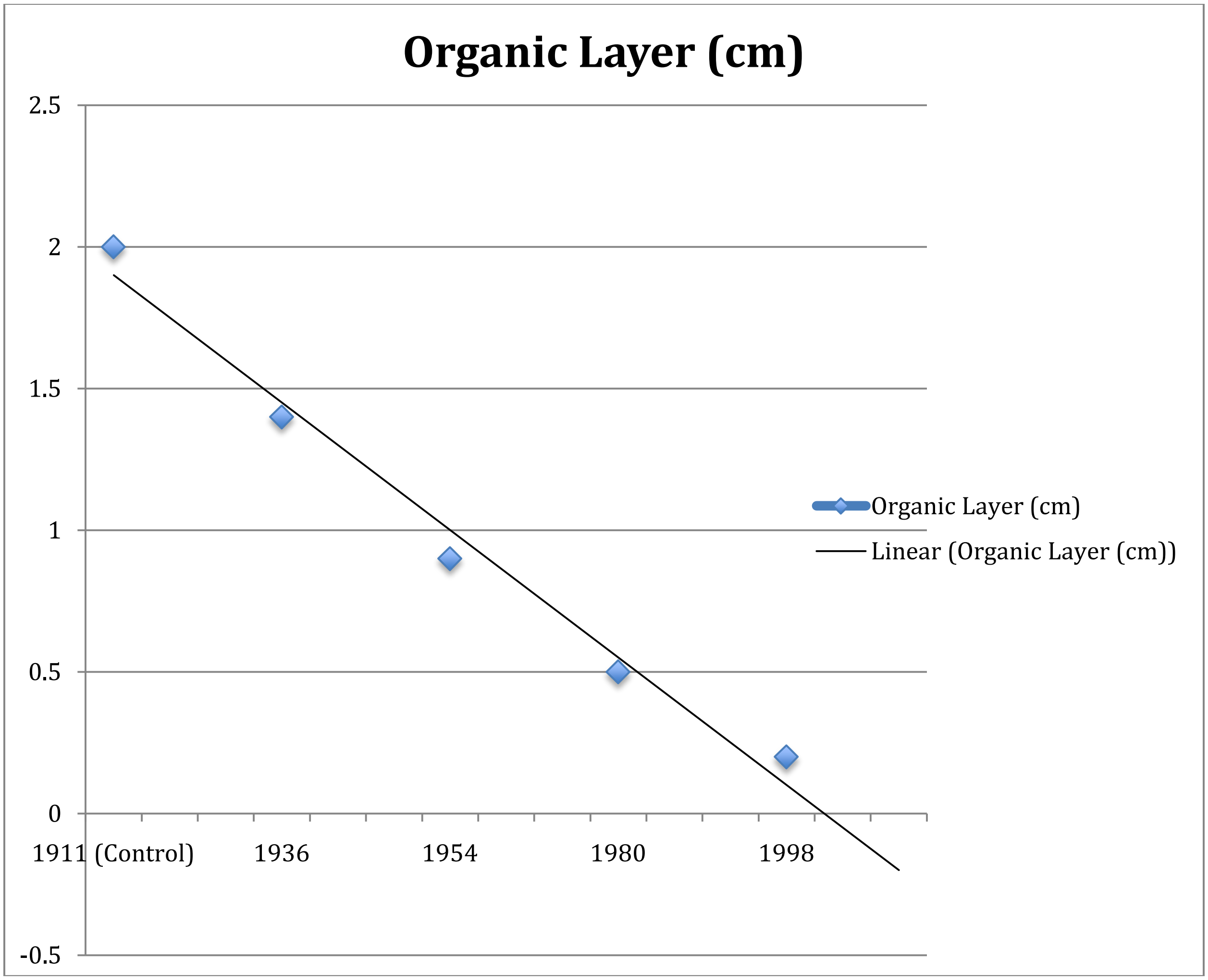


Figure 7. Organic layer thickness of the soil, measured in centimeters of depth.


Organic Layer (cm)
2.5
2
1.5
1
0.5
0
-0.5
1911 (Control)
1936
1954
1980
1998
Organic Layer (cm)
Linear (Organic Layer (cm))