The effect of deer browsing on forest composition in and around a deer exclosure plot at the University of Michigan Biological Station

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Abstract

In 1998, the University of Michigan Biological Station in Pellston, Michigan set up a deer exclosure plot in an outwash plain on the property. The plot was constructed on an old growth forest dating to 1911, while two similar plots were constructed on experimental burn plots dating to 1911 and 1998. We conducted a survey of species abundance and richness in the outwash plain deer plot to determine the effects of deer browsing on an old-growth forest. During our study we looked for differences between species richness, underbrush density and species evenness inside and outside the exclosure plot. We also looked for differences in sapling frequency and signs of recent browsing. We sampled a total of 39 2m x 1m plots inside and 40 2m x 1m plots outside the exclosure. In the plots, we recorded the frequency of all plant species and estimated percent cover of the underbrush. We also catalogued saplings along the transects as we recorded their species, height and whether they showed signs of browsing. We were able to support all of our hypotheses: there was a higher density of underbrush inside the exclosure, species evenness was different, species richness was equal, and there was a higher density and variety of saplings inside the exclosure.

1. Introduction

Exclosure plots are fenced-in areas of land constructed to keep large grazing animals, such as white-tailed deer (*Odocoileus virginianus*), out of an area in order to study what the area would look like in the absence of ungulate herbivory. However, these exclosure plots are permeable to smaller animals, such as rabbits, hares, etc. In 1998, three deer exclosure plots were constructed at several different sites on the University of Michigan Biological Station (UMBS) property in Pellston, Michigan in order to study the effects of deer and elk browsing on the land (Heinen and Vande Kopple, 2003). Two of these plots have previously been studied to find differences between the inside of the exclosures and the outside (Garthe et al., 2014; Bulthuis et al., 2015). These two exclosures were constructed on burn sites, whereas the plot we focused on had not yet been studied and was constructed on a dry and sandy glacial outwash plain located in a forest about 70 meters northwest off of Riggsville Road (Figure 1). A study by Dills (1970) showed that deer browse flourished in the short term after a controlled burn. This suggests that there may be variation in the species density and richness between the exclosure under study and the exclosures erected on the more recent burn plots, such as the 1998 burn plot.

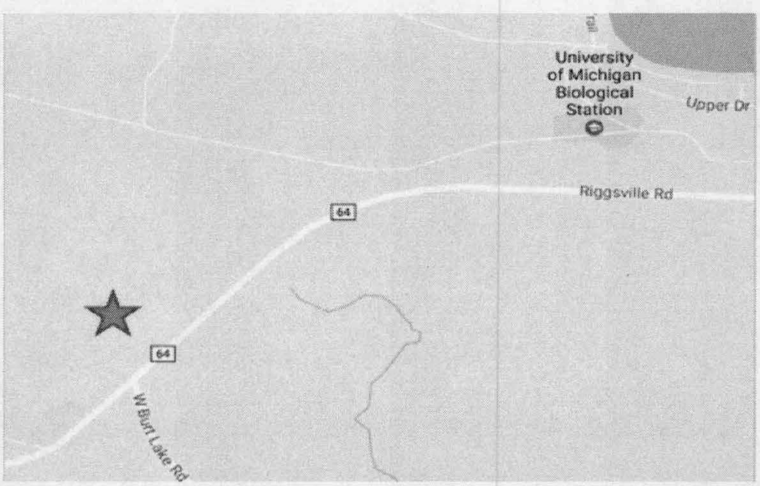

Figure 1: Approximate location of the deer exclosure in relation to the University of Michigan Biological Station. (45°33'3.7 N, 84°41'37.3 W) [Source: Google Maps]

In the absence of predators such as coyotes, cougars and wolves, the population of white-tailed deer continues to increase in northern Michigan (Rawinski, 2008). This population explosion has detrimental effects on the ecology of the area and studies have shown that mammalian herbivory on forest ecosystems negatively impacts the abundance and distribution of plant species (Urbanek and Nielsen, 2012). A forest exclosure study in Pennsylvania found that heavy deer browsing had caused a 60-80% decrease in species richness of the underbrush (Goetsch and Wigg, 2011). After 60 years in the absence of deer browsing, the density of the underbrush increased by 40% compared to an increase of less than 1% outside the exclosure plot (Goetsch and Wigg, 2011). A study conducted by Rooney (2001) found that an increase in deer was accompanied by a 40-80% decrease in underbrush plant species. Another study on deer in North America found that deer are a keystone species because their presence significantly impacts a variety of other species in the surrounding ecosystem (Rooney, 2001).

White-tailed deer have also been shown to impact the reproduction of trees outside exclosure plots by significantly reducing the number of tree seedling species (Anderson and Loucks, 1979). Tilghman (1989) found that while the number of established seedlings was not affected by browsing, deer browsing heavily cut the number of seedlings that reached maturity. This effect was especially apparent in species susceptible to browsing. However, other plant species can also be affected due to the cascading effects browsing can have on the local ecosystem (Beguin et al., 2011). In fact, a study by Stromayer and Warren (1997) revealed that deer browsing may have a permanent effect on forest ecosystems, creating an alternative "stable state," or an entirely new forest composition reflective of deer browsing. A study by Rooney and

Gross (2003) found that deer browsing affects species at all stages of growth–even those not yet flowering.

A study by Heinen and Sharik (1990) determined that in Michigan's Pigeon River State Forest, selective herbivory by elk (*Cervus elaphus nelsonii*) and deer –which prefer to eat bigtooth aspen (*Populus grandidentata)* over other vegetation–led to high browsing and mortality of the bigtooth aspen. A longitudinal follow-up study by Heinen and Currey (1999) at the Pigeon River found that selection for bigtooth aspen resulted in an abundance of the less preferred species: trembling aspen (*Populus tremuloides*). The complete disappearance of bigtooth aspen by 1999 suggests that a certain threshold was reached where the trees could not regenerate fast enough to overcome how heavily they were being browsed.

Although aspens were not present at our study site–the outwash plain exclosure plot–we hypothesized that deer prefer certain species over others in the forest outside the exclosure. According to the Michigan Department of Natural Resources, white-tailed deer in Northern Michigan prefer to eat white pine and maples. They will also feed on oaks, but only eat beech and red pine when no other food is available (DNR, 2017). During the winter, the bulk of their diet is woody browse, but as the snow melts, they begin to forage on wintergreen and other herbaceous plants (Rogers, 1981).

In our exclosure plot, we expected to see similar results as the previously mentioned studies on deer exclosure plots. We hypothesized that the density of the underbrush would be higher inside of the exclosure than outside. We also hypothesized that species richness would be the same inside and outside of the exclosure plot. Additionally, we hypothesized that species evenness would be significantly different inside and outside the exclosure due to the deers' browsing preferences for certain plants over others. Regarding saplings, we hypothesized there would be a greater number and variety of saplings inside of the exclosure due to the negative effects deer browsing has on seedling growth.

2. Methods and Materials

We conducted our research at one of the 80m x 50m (4000 square meters) deer exclosure plots on UMBS property. We first measured 10m from the fence perimeter of the exclosure plot, reducing the area of observation to 60m x 30m (1800 square meters). We began at 10 m in order to avoid recording observations from plants that have been browsed by smaller animals and edge plants that have cross-pollinated with plants outside the exclosure plot. We then split the 60m x 30m area into three separate transects 15m apart that ran 60m along the length of the exclosure plot east to west. Along the transects, we set up thirteen 2m x 1m quadrats, alternating sides every 5m (Figure 2).

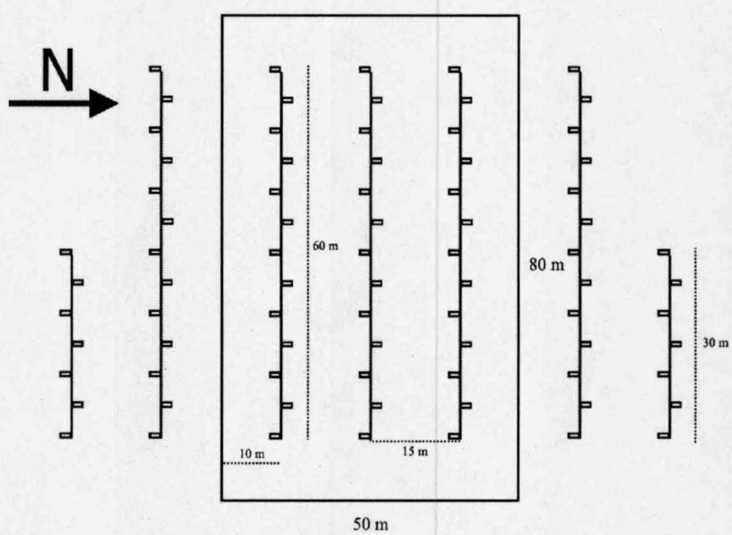

Figure 2: Transects inside and outside of the deer exclosure. (drawn to scale) Three 60-meter transects are located inside the exclosure, while one 60-meter transect and one 30-meter transect are located on the north and south sides of the exclosure. Each branch coming off of the transects represents a 2m x 1m quadrat.

We assigned a percent coverage category to each quadrat we observed in order to gauge the overall percent coverage of the underbrush. These category ranges were labeled as either less than ⅓, ⅓-⅔, or greater than ⅔. We determined our percent coverage category by observing the amount of forest ground in the quadrats that was not covered by plants or mosses. We then measured species richness by recording the amount of species present within each quadrat. We also recorded the frequency of each species in each plot to measure species evenness. To ensure consistency, each group member counted the same species for every plot. We also recorded sapling coverage by measuring two meters to the left and right of each 60m horizontal transect and marking down each sapling's species, height and location along the transect. A tree was categorized as a sapling if its height was measured to be greater than or equal to 1m, but less than or equal to 2.5m.

After completing the data collection inside of the deer exclosure plot, we executed similar procedures on the outside of the deer exclosure plot. We measured 10m from the fence's edges again and then measured one and a half transects outside of each the north side and the south side of the deer exclosure plot. We had one 60m transect with thirteen quadrats on alternating sides and one 30m transect with seven quadrats on alternating sides that ran east to west on the north and south side of the exclosure plot. Outside the plot, we measured the overall percent underbrush coverage, species density, species richness and sapling frequency with the same methods we used inside of the deer exclosure plot. As we went along each transect, we looked for signs of browsing on the plants and signs of deer scat. We considered plants to have been browsed if the terminal buds had been removed. We did not record plants that were dead, since we were only looking for evidence of browsing and were unable to determine how a plant may have died. We categorized plants as dead if they no longer produced any leaves and if their branches were easily breakable when bent.

Along with measuring the underbrush and saplings, we also compared the soil from inside the deer exclosure plot to the soil outside the exclosure plot. We took soil cores at each of these sites and recorded the depth of the O horizon, A horizon and B horizon. From each corner of the exclosure plot, inside and outside, we collected samples in order to compare the soil organic matter. Samples were freeze-dried, sieved and milled to a homogenous mixture. They were then analyzed using a cation and anion panel and were also tested for total carbon and nitrogen concentrations inside and outside the exclosure.

After compiling our data, we first attempted to test our hypotheses about species richness by comparing the total number of species outside the plot to those inside the plot. To test our hypothesis about underbrush density, we used a Chi-Square test for homogeneity. We performed five Chi-Square tests for goodness of fit to compare the frequency of different sapling species inside and outside the plot to test for species evenness. We also computed Chi-Square tests for homogeneity for the frequency of saplings and seedlings inside versus outside the exclosure. Finally, we computed a Mann-Whitney U test to test for a difference in phosphate and nitrate concentrations in the soil inside and outside the exclosure, and a Chi-Square test for independence to test for a difference in carbon and nitrogen percentages in the soil inside and outside the exclosure.

3. Results and Discussion

The underbrush species we found in this area were wintergreen (*Gaultheria procumbens*), blueberry (*Vaccinium angustifolium*), serviceberry (*Amelanchier canadensis*), bracken fern (*Pteridium*), starflower (*Trientalis borealis*), Michigan huckleberry (*Gaylussacia baccata*), moss (*Bryophyta*) and reindeer moss (*Cladonia rangiferina*). The trees and saplings present were red maple (*Acer rubrum*), red oak (*Quercus rubra*), red pine (*Pinus resinosa*), white pine (*Pinus strobus*) and beech (*Fagus grandifolia*). After analyzing the data, we were able to confirm all four of our hypotheses. Our data showed that while species richness was the same inside and outside the exclosure, there was a significant difference in underbrush density, species evenness and sapling frequency.

3.1 Underbrush Analysis

Both areas inside and outside the exclosure contained twelve species of woody plants. However, we found no Michigan huckleberry inside the exclosure and no starflower outside the exclosure. This difference may not have been due to the presence or absence of deer; it is possible that our transects missed them by chance. This supported one hypothesis in finding that species richness was equal inside and outside of the exclosure plot.

To determine whether there was a difference in underbrush density inside and outside the deer exclosure plot, we calculated a Chi-Square test for homogeneity. The results of this test showed there was a statistically significant difference between the density of the underbrush inside and outside the exclosure (p-value < 0.001), with a greater density of underbrush inside the deer exclosure plot. Based on these results, we were able to reject the null hypothesis and support our hypothesis that underbrush density is greater inside the exclosure than outside. This difference was likely due to deer browse because deer have been known to browse on several of the species that are present in our exclosure plot area, such as blueberry and wintergreen (DNR, 2017). We also noted signs of browsing on all underbrush species present outside the exclosure plot except the moss and reindeer moss, as browsing is difficult to determine for those species. Furthermore, we expected differences in underbrush density due to the relatively large size of the deer moving through the area and treading on small shrubs and seedlings.

To test for species evenness, we ran a Chi-Square test for homogeneity between the distribution of the species inside and outside the exclosure and found a statistically significant difference (p-value < 0.001). We then computed several Chi-Square tests for goodness of fit of each species frequency inside versus outside the exclosure. We found that the difference between the inside and outside of the exclosure plot was statistically significant for blueberries (p-value$<$ 0.05), bracken fern (p-value < 0.001), wintergreen (p-value < 0.001), starflower (p-value $<$ 0.001), and Michigan huckleberry (p-value < 0.001), whereas the difference was not significant for serviceberry (p-value > 0.50; Table 3). Some species were more abundant inside than outside, while others were more abundant outside than inside. Wintergreen was much more common inside the exclosure, and since deer are known to forage on wintergreen after the snow melts, this was to be expected. These data supported our hypothesis that species evenness would be different inside versus outside the exclosure. While this may be due to the presence of deer outside the exclosure, it could also be due to a number of other factors. For example, certain species, such as reindeer moss, grow in homogeneous clumps leading to either more or less of them being sampled, depending on whether our transects ran through those clumps.

3.2 Sapling Analysis

The data we collected on saplings inside and outside the exclosure plot showed there was a statistically significant difference between the frequency of saplings inside the exclosure and outside the exclosure (p-value < 0.01), with more saplings present inside. The only species of saplings present outside the plot were white pine, red pine and beech. Inside the exclosure, white pine, red pine, beech, red maple and red oak were present. Since we also found that the difference in species distribution of seedlings inside and outside the exclosure was not statistically significant (p-value > 0.25), the difference in saplings species could be due to the fact that deer prefer red maple and red oak over white and red pine. The chance of pines surviving past seedlings to become saplings would therefore be higher, as the deer browse negatively affects the other seedlings' chance of reaching maturity.

Of the three sapling species found outside the deer exclosure, 61% of white pine saplings showed signs of browsing and 57% of red pine saplings showed signs of browsing. The one beech tree found outside of the exclosure also showed signs of browsing. Our finding that white pine saplings were more heavily browsed than red pine saplings is consistent with deer's known preference for white pine (DNR, 2017). Beech and red pines are classified as "starvation" foods for deer, so we can infer that these deer were desperate for food (DNR, 2017). This also explains why there would be no other species of saplings outside the exclosure, as the deer would have already browsed on them as seedlings because of the limited vegetation available.

3.3 Soil Analysis

After receiving the soil sample analysis, we ran a Mann-Whitney U test on SPSS and found there to be no statistically significant difference in phosphate ppm or nitrate ppm between the samples taken outside and inside the exclosure (phosphate p-value = 0.686; nitrate p-value = 0.486). On average, samples contained 12.8 ppm nitrate and 22.81 ppm phosphate. We then conducted two Chi-Square tests for independence to check for differences in percentages of carbon and nitrogen in the soil, and we found no statistically significant difference in percentage of carbon or nitrogen inside and outside the exclosure (p-values > 0.50). However when conducting a Chi-Square test for goodness of fit, we found a statistically significant difference between the carbon-nitrogen ratio outside the exclosure and the carbon-nitrogen ratio inside the exclosure (12.7:1 and 38.8:1; p-value<0.001). The high carbon-nitrogen ratio inside the exclosure is likely due to lack of nitrogen - an average of 0.0215% - which could have been caused by the absence of animals inside the exclosure and therefore lack of fertilization.

Stable soil organic matter is vital to soil fertility because it contributes to soil structure, tilth and cation exchange (Fenton, 2008). A stable soil organic matter also provides important physical benefits to the ecosystem. These benefits include enhancing aggregate stability, improving water holding capacity, helping seedbed preparation and reducing runoff (Fenton, 2008). In all our samples there was a very low number of organic molecules. This suggests sandy and unproductive soil, which is typical for outwash plains. Low organic soil matter makes the soil more vulnerable to compaction thus reducing the water infiltration which in turn decreases plant production (Poindexter, 2011). A low organic soil matter and less species richness outside of the deer exclosure plot can be indicative of the presence of deer in the area because the trampling of the forest habitat by ungulates is known to directly increase soil compaction (Heckel, 2010).

3.4 Source of Error & Future Studies

A few problems arose that may have affected our data. Determining whether a tree has been browsed can be difficult, as it is sometimes unclear whether these plants were missing terminal buds due to browsing or because they were not fully grown. This may have caused inaccuracy in labeling plants as browsed or not browsed. Further error may have arisen when counting the frequencies of the underbrush, which could have imprecisely portrayed how much of the underbrush is covered. Some of the underbrush species, particularly the blueberries, could cover a large portion of the forest ground but were only counted as one plant if the blueberries came from a single stem. So one "patch" of blueberries could cover very different amounts of space. Although this was accounted for in our measurement of underbrush density by using a percent cover, we used the frequencies of individual species to compare species evenness.

There were also some general observations about the exclosure and surrounding area that may have affected the data. Our random sample was formed by pseudo-replications of several small plots in a large space. Therefore, the plots we observed may not have been representative of the area. Around the exclosure there were several patches of homogenous vegetation, including a large patch of reindeer moss that was not in our sampling range. Our area of sample was too small to show a completely accurate representation of the area.

Additionally, there were multiple confounding variables that were not accounted for within this study. One variable is that the other herbivorous animals inhabiting the forest may also be browsing the lower branches of saplings. Browsing can be difficult to distinguish between hares and ungulates, particularly in older plants (Heinen & Sharik, 1990). Although there was a significant difference between density underbrush, species evenness and sapling frequency inside and outside the deer exclosure plot, we cannot say definitively that these differences were caused by the presence or absence of deer. Since the exclosure plot is now 20 years old, we believe coming back in another 20 years would provide clearer insights into the effects of deer and deer browse. It would be useful to sample the area again after enough time has passed for new trees to grow inside and outside the exclosure so they can be compared.

5. Acknowledgements

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6. References

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7. Appendix

Table 1: Frequency and percent abundances of underbrush plants inside and outside exclosure and Chi-Square test for Goodness of fit

Chi Square test of goodness of fit (df=1)						
Underbrush Plants	**frequency inside**	**frequency outside**	**average freq**	**Chi Number**	**P-val**	Significant/Not Significant
Blueberry	539	608	**573.5**	4.15	0.025-0.05	S
Bracken Fern	129	238	**183.5**	32.37	<0.001	S
Wintergreen	157	20	**88.5**	106.04	<0.001	S
Serviceberry	13	10	**11.5**	0.3913	>0.50	NS
Starflower	78	0	**39**	78	<0.001	S
Michigan huckleberry	0	61	**30.5**	61	<0.001	S
Total	**916**	**937**				

Table 2: Degree of browsing on saplings located outside the exclosure

Type of Tree	Number Browsed	Number not Browsed	Ratio Browsed
white pine	23	15	0.6052631579
red pine	4	3	0.5714285714
beech	1	0	1

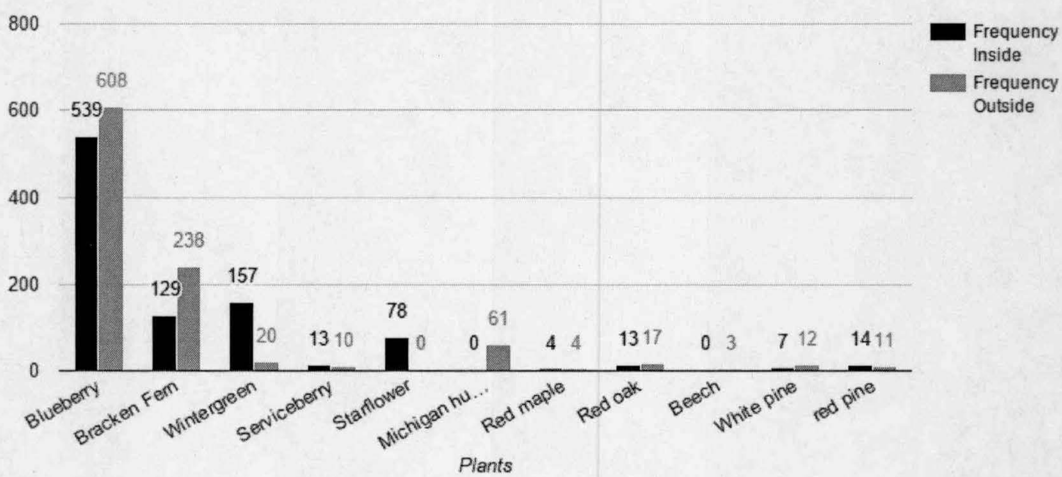

Figure 3: Frequency of underbrush plants and tree seedlings inside versus outside the exclosure

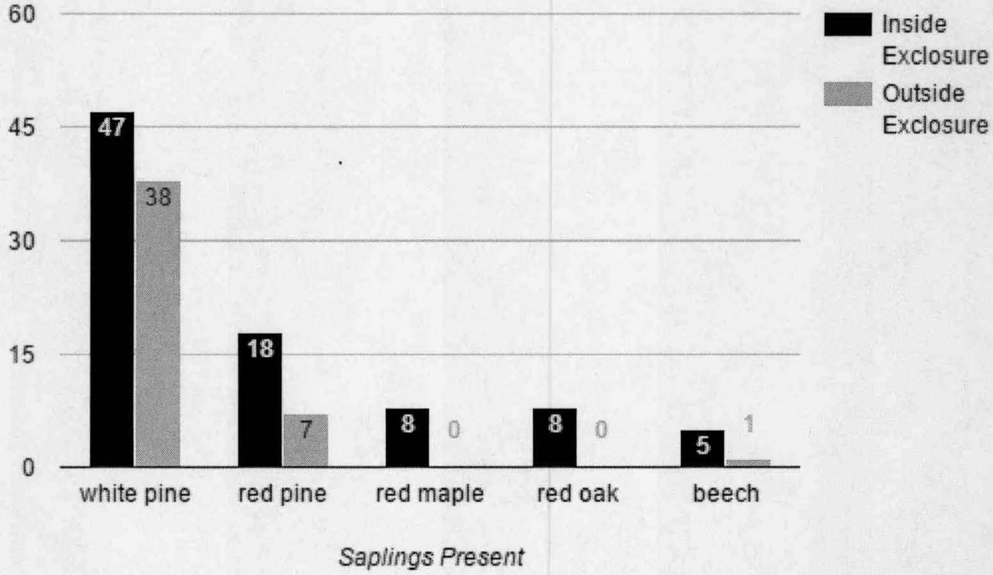

Figure 4: Frequency of Saplings inside versus outside the deer exclosure