Effects of Deer Exclosure Establishment and Subsequent Removal on Vegetation Diversity, Tree Regeneration, and Understory Biomass at Black Rock Forest

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May 5th, 2014

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Abstract

Deer populations well above their historical levels in northeastern forests decrease vegetation diversity, tree seedling regeneration, and the biomass of understory vegetation. These effects can be mitigated by the exclusion of deer browsing via installation of deer fences. However, deer exclosures require maintenance and, after a period of time, are removed by humans or deteriorate and became ineffective. This study evaluates the effects of deer exclosures on tree seedling regeneration, understory vegetation diversity, and understory vegetation biomass while the exclosures are present and after they have been removed. There was no effect on understory vegetation diversity or biomass. However, there was an increase in tree seedling regeneration. When exclosures are removed, vegetation diversity and seedling regeneration are likely to decrease as deer browse seedlings and saplings. Vegetation biomass will likely decrease as deer consumption increases. However, a limited data scope made it difficult to determine the effects of exclosure removal on vegetation diversity, tree seedling regeneration, and understory vegetation biomass. However, the increase in tree seedling regeneration within exclosures suggests that the establishment of exclosure fences will have long-term benefits for tree species. On a larger scale, this may benefit northeastern hardwood forest ecosystems.

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Introduction

Northeastern hardwood forests are facing a variety of changes in composition. These changes are driven by a myriad of factors, including newly introduced diseases and pests, an expanding human world, and deer grazing. This paper will address the compositional changes associated with deer grazing. Deer directly influence vegetation diversity, tree seedling regeneration, and understory vegetation biomass (McGarvey et al. 2013). In areas of high deer density, deer alter forest composition by diminishing, and in some cases eliminating, certain species within the understory and shrub layers (Latham et al. 2005, Diefenbach 2010, Aronson and Handel 2011). Deer consume seeds and seedlings, which severely limits tree and shrub regeneration in northeastern forests (Tilghman 1989, Waller and Alverson 1997, Aronson and Handel 2011, Abrams and Johnson 2012). When regeneration decreases, the understory becomes dominated by species avoided by the white-tailed deer, such as the grass, *Microstegium vimineum,* and an array of fern species (Goetsch et al. 2011, Abrams and Johnson 2012). Deer browsing also decreases the total biomass of herbaceous plants (Latham et al. 2005). All of these factors influence, and inevitably change, the understory composition of forests (Abrams 2012). Exclosures prevent deer browsing and allow the understory composition to begin to turn to its prior conditions (Latham et al 2005, White 2012).

History of Northeastern Forests

Twenty thousand years ago, vegetation in the Northeast United States was vastly different than today, primarily due to the climactic effects of a continental glacier (Russell et al. 2011). As the glacier receded, the land changed from open tundra, dominated by sedges and grasses, to a closed-canopy forest, composed of pine and birch (Watts 1979, Peteet 2000, Webb et al. 2004). A sudden warming in the early Holocene, about 10,000 before present day, brought oak, followed by hemlock, beech, hickory, and chestnut (Deevey 1939, Maenza-Gmelch 1997b, 1997a). There is little to no record of changes in herbaceous and shrub species within the forest as wind-pollinated trees dominate the pollen record (Russell et al. 2011).

When European settlers arrived, they kept written records of forests and land-use. This allows for a clearer picture of the past three hundred years (Russell et al. 2011). Settlers began clear cutting forests for fuel, timber, and agriculture. Settlers grazed farm animals, such as cattle, sheep, and horses in these cleared landscapes, which prevented forest regeneration (Zamora et al. 2001).

Beginning in the early 20th century, agriculture and logging diminished throughout the region as the industrial era began (Russell 1976, Bell 1989). As timber harvest and grazing diminished, forests began experiencing re-growth (Russell et al. 2011). By the late 20th century, wood growth rates were more than twice the rates of wood removal in the New York highlands (Phelps and Hoppe 2002). Though forests did recover, they were compositionally different than contiguous, old growth forests that existed prior to European settlement. Fragmented, young forests now dominate the northeastern United States (Laurance 1997).

In the past century, these young, fragmented forests have faced an array of challenges, which have been exacerbated by deer browsing. Early successional species are preferred food for deer, and deer browsing impedes forest regeneration (Johnson et al. 1995, Ballantyne 2000, Brown et al. 2000, Rooney 2001, Cote et al. 2004). Forest disturbances, including browsing, also create opportunities for aggressive, invasive species, like Japanese stilt grass (*Microstegium vimineum*). Deer avoid these invasive species, giving them a competitive advantage over native species (Goetsch et al. 2011, Abrams and Johnson 2012).

Disease outbreaks have seriously threatened some forest species. The American chestnut was nearly eliminated by a chestnut blight in the early 20th century and is now rarely seen in forests (Abrams and Johnson 2012). Presently, eastern hemlock trees are declining because of sustained damage from the hemlock wooly adelgid, a scale insect. Since the 1980s, when the insect was first introduced, hemlocks have experienced tree mortality rates as high as 80% (Schuster et al. 2011). Deer transport disease and insects between forests (McClure 1990).

Once a native species has disappeared from a particular landscape, it can take up to 80 years to re-colonize its former habitat (Flinn and Velland 2005). The native shrubs of the understory have decreased in abundance and diversity, generation by generation (Goetsch et al. 2011).

Deer population history

By the end of the 19th century, deer populations were low as a result of the loss of habitat to extensive agriculture and logging, and to hunting (Latham 2005, Abrams and Johnson 2012). Beginning in the early 20th century, conservation laws protecting does and fawns were established. Deer populations began to steadily recover as a result of deer management, the regeneration of forests, and a decline in predators (Diefenbach 2010, Abrams and Johnson 2012). Because of these factors, deer populations are dramatically higher than they were 50 years ago (McShea et al. 1997).

In places where deer densities are high, such as the northeastern United States, deer spread exotic pests, such as the hemlock woolly adelgid (McClure 1990, Eschtruth and Battles 2009). Dense deer populations can also reduce understory biomass, particularly the abundance of woody species (Rooney and Dress 1997, McGarvey et al. 2013). When deer browse leaves, shoots, seedlings and seeds in the understory, they impact aboveground growth and reduce photosynthetic capability (Tripler et al. 2002). This reduces seedling survival, which may alter the long-term successional dynamics of Northeastern forests (Putman et al. 1989, Healy 1997, Gill and Beardall 2001, McGarvey et al. 2013).

Exclusion of deer in today's forests

If deer exclosures were erected following a clear cut, the protected trees inside the exclosure are expected to regenerate in a typical successional sequence (Figure 1, Ballantyne 2000). This type of study has been done in many different locations and has yielded similar results (Latham 2005, White 2012, Abrams and Johnson 2012). After 11 years of exclusions, White (2012) found that growth rates of whole tree biomass within exclosures were up to two times higher than rates measured outside of exclosures. Latham et al. (2005) determined that the total biomass of herbaceous plants within exclosures could be as much as three times greater than the total herbaceous biomass outside of the exclosure. Abrams and Johnson (2011) found that both diversity and regeneration were higher inside of exclosures versus outside of exclosures. When diversity increased, Abrams and Johnson observed that the presence of the invasive species, *Microstegium*, was greatly reduced. Another study reported that this reduction in *Microstegium* is a result of tree regeneration, which shades out the grass. It hypothesizes that continued tree regeneration might limit the establishment of *Microstegium* with time (Beasley and McCarthy 2011).

Figure 1: A deer exclosure at Black Rock Forest in Cornwall, NY. Shrub and saplings are visible inside the exclosure, but are absent outside of the exclosure. The boundaries of the exclosure are outlined in blue. SOURCE: Diefenbach 2010

Thesis Statement

When deer are excluded from an area of forest, seedling regeneration, vegetation diversity, and vegetation biomass within that area are expected to be higher than in areas where deer browse freely. The first part of this study will test this idea within Black Rock Forest, a research forest in New York State, by comparing these three variables inside and outside of 13 exclosures. When vegetation inside and outside of the exclosures is compared, it is expected that there will be a significant increase in the vegetation diversity, tree seedling regeneration, and total cover of herbaceous vegetation inside of exclosure plots. However, deer exclosures are not permanent fixtures. They require frequent upkeep and repair. Eventually, the exclosure fences will either disintegrate or be taken down. Thus far, no studies have reported the effects of resumed deer browsing on regeneration, diversity, and biomass once the exclosures have been removed. In the past ten years at Black Rock Forest, exclosure fences were removed in staggered intervals. This study will provide a preliminary evaluation of how vegetation diversity, seedling regeneration, and vegetation biomass will change in the years after an exclosure fence is removed. Once removed, it is expected that diversity and tree regeneration will decrease. It is also expected that vegetation biomass will decrease. However, average Diameter at Breast Height (DBH) may increase in size, as smaller trees will be eaten.

Methods

Study Site

This study was conducted at the Black Rock Forest in southeastern New York State. The forest spans 1,538 hectares between the towns of Cornwall, New York and Highlands, Orange Country, New York (Figure 2). The forest was initially used for timber, but was converted into a demonstration forest by Dr. Ernest Stillman and

Richard Thornton in [year] (Trow 2004). Today, the forest is owned by the William T. Golden Family Foundation and is run as a not-for-profit. It is used as a location for field-based private and public research, as well as education.

At Black Rock Forest, controlled hunting is used to manage the deer population. Deer at Black Rock Forest remain a problem for a variety of reasons. Deer overabundance damages crops, causes car accidents, and spreads Lyme disease (Schuster et al. 2011). Deer also alter the vegetation composition of forests by lowering vegetation diversity, inhibiting tree seedling regeneration, and decreasing understory vegetation biomass.

Figure 2: A close up on the northeastern United States. Black Rock Forest lies about 50 miles north of New York City. Source: Black Rock Forest Consortium

i. Experimental Design

All of the data was collected at exclosures within Black Rock Forest. Several of the exclosures were originally intended for forest management and were therefore not standardized. For this reason, exclosures have a large range of sizes, from 6m to 8250m, and vary in structure. For this study, we will compare plots that were established inside exclosures with control plots that are located outside the exclosures (i.e., accessible by deer). Vegetation data for 13 exclosures and control plots were available (Table 1). All 13 sites used in this study were surveyed in 2012. There is also data available for six exclosures and associated control plots where the exclosure fences have been removed (Table 2). The data available for this part of the study are limited and the times when vegetation was sampled both before and after removal varies from location to location.

Table 1: Exclosures surveyed in 2012. Details the names of the sites, the number of surveys conducted at each location, and whether tree diameter data ("D"), tree seedling regeneration data ("R"), and percent of understory covered by vegetation data ("C") are available.

Exclosure Name	Year Installed	Size (m^2)	# of Surveys on Plot	Data
Hall Road Control			5	D, R, C
Hall Road Exclosure	1971	900	5	D, R, C
"Old Exclosure" Control			5	D, R, C
"Old Exclosure" Exclosure	1961	6	1	R, C
DO Control			5	D, R, C
DO Exclosure	2005	9625	5	D, C
Stone House 1 Control			5	R, C
Stone House 1 Exclosure	2004	2400	5	D, R, C
Stone House 2 Control			5	D, C
Stone House 2 Exclosure	2003	9000	5	D, R, C
Stone House 3 Control			5	D, C
Stone House 3 Exclosure	2003	600	5	D, R, C
Fire Tower Road Control			5	D, R, C
Fire Tower Road Exclosure	2004	600	5	D, R, C
Alec Meadow Control			5	D, R, C
Alec Meadow Exclosure	2003	600	5	D, R, C
Alec Meadow 2 Control			0	D, R, C
Alec Meadow 2 Exclosure	2003	600	0	D, R, C
Arthur Ross Control			5	D, R
Arthur Ross Exclosure	2002	1800	5	D, R, C
Big Blue Control			5	D, R, C
Big Blue Exclosure	2004	1200	5	D, R, C
A0 Pilot Control			5	D, R, C
A0 Pilot Exclosure	2005	8250	5	D, R, C
Black Rock Brook Unplanted Control			5	D, R, C
Black Rock Brook Unplanted Exclosure	2002	225	5	D, C

Table 2: History of the exclosures detailing the year exclosures were installed, removed, and surveyed. An asterisk indicates that exclosure was reduced in size instead of removed. The Arthur Ross data from 2013 was collected when the exclosure was taken down. Each number on the table is representative of the number of random plots surveyed within that area. The Hall Road 1 Exclosure data for all years is representative of the entire exclosure, as the exclosure is only 3x3m.

Exclosure Name	Year Installed	Year Removed	Size (m)	1999	2004	2010	2012	2013
Arthur Ross Exclosure	2002	Fall 2012	30X60				5	5
Arthur Ross Control			30X60				5	
Black Rock Brook Unplanted Exclosure	2001	Fall 2013	15X15			5	5	
Black Rock Brook Planted Exclosure	2001	Fall 2010	15X15			5		5
Black Rock Brook Control							5	
Stone House 1 Exclosure	2004	Fall 2012	40X60		6		5	5
Stone House 1 Control					6		5	
Hall Road 1 Exclosure	1971		30X30	1				
Hall Road 2 Exclosure	1988	2000*	30X30	6	3		5	
Hall Road Control				1	3		5	

iii. Data Collection

Vegetation surveys were conducted at the exclosure and control plots using five 1 meter squared quadrats. In some cases, fewer than 5 vegetation quadrats were sampled either because the exclosures were too small, data was lost, or standard procedures were not observed. Surveyors tried to take vegetation surveys at the same plots for every year data was collected. However, data markers were frequently lost or destroyed by natural processes. Therefore, the exact locations of of each plot are unknown. Random plots were sampled within each exclosure. For all of the 2012 and 2013 data, with the exception of the Black Rock Brook Planted Exclosure data from 2012, the percent coverage of trees, shrubs, ferns, grass, and moss below 1 m and from 1-2 m was recorded. Data collected in 1999 lists the numbers of individual trees, shrubs, ferns, grasses, and mosses by species. For all other datasets, the Braun-Blanquet scale was used for trees, shrubs, ferns, grass, and moss below 1 m, from 1-2 m, and >2 m. The Braun-Blanquet scale assigns a value of 1 for a plot with a percent vegetation cover between 0% and 5%, 2 for a plot with a percent vegetation cover of 5% to 25%, 3 for a plot with a percent vegetation cover of 25% to 50%, 4 for a plot with a percent vegetation cover from 50% to 75%, and 5 for a plot with a percent vegetation cover from 75% to 100%. If the percent coverage was less than 1%, the species was noted as "p" for present and assigned a value of 0.01 for analysis.

Stem diameter at 1.3 m from the ground, or Diameter at Breast Height (DBH), was recorded for trees with a diameter greater than 2.6 cm. These data were collected within a circular plot with a 3 m radius. Tables 1 and 2 indicate which years diameter data were collected.

Regeneration data was collected for all tree seedling species within the five quadrats sampled per location. Any individual of a tree species with a diameter less than 2.6 cm was considered to be a seedling. The numbers of individual seedlings below and above breast height were recorded by species. The regeneration data was collected in the same location as the vegetation surveys.

iv. Data Analysis

Vegetation Diversity

To quantify vegetation diversity, species richness was calculated. Species richness is the number of species present in a defined area. This was determined for all 5 exclosure and control plots at each location. Mean species richness and associated standard deviation for each location was then calculated inside and outside of each exclosure. An Analysis of variance test (ANOVA), was used to determine if the mean species richness varied between exclosure and control plots.

Tree Seedling Regeneration

To analyze tree seedling regeneration, tree diameter size classes inside and outside of the exclosures were compared using histograms. A Pearson's Chi-Squared Test was used to determine if there were significant differences in the distribution of size classes between exclosures control sites.

Understory Vegetation Biomass

Understory biomass was estimated by using the percent coverage of vegetation within and outside of each exclosure. The mean and standard deviation of total percent coverage of all species was then calculated. An analysis of variance (ANOVA) test was run to determine if total cover varied between the exclosures and adjacent control areas.

Individual Tree Counts

Surveyors counted all trees with a diameter greater than 2.6 cm within a circular plot. The circular plot had a 3m radius from the center of one of the five $1m^2$ quadrats. The location of the circular plot is unknown. The number of trees within each circular plot was divided by the area of the circle, or 28.27m^2, to determine the density of the trees. This was done for all control and exclosure plots.

Results

Understory vegetation across all exclosures

Mean species richness inside the exclosure plots ranged from 3.8 to 14.2 species. The range of mean species richness in the control plots was similar, from 2.8 to 11.2 species. There is no consistent trend in the data across all sites.

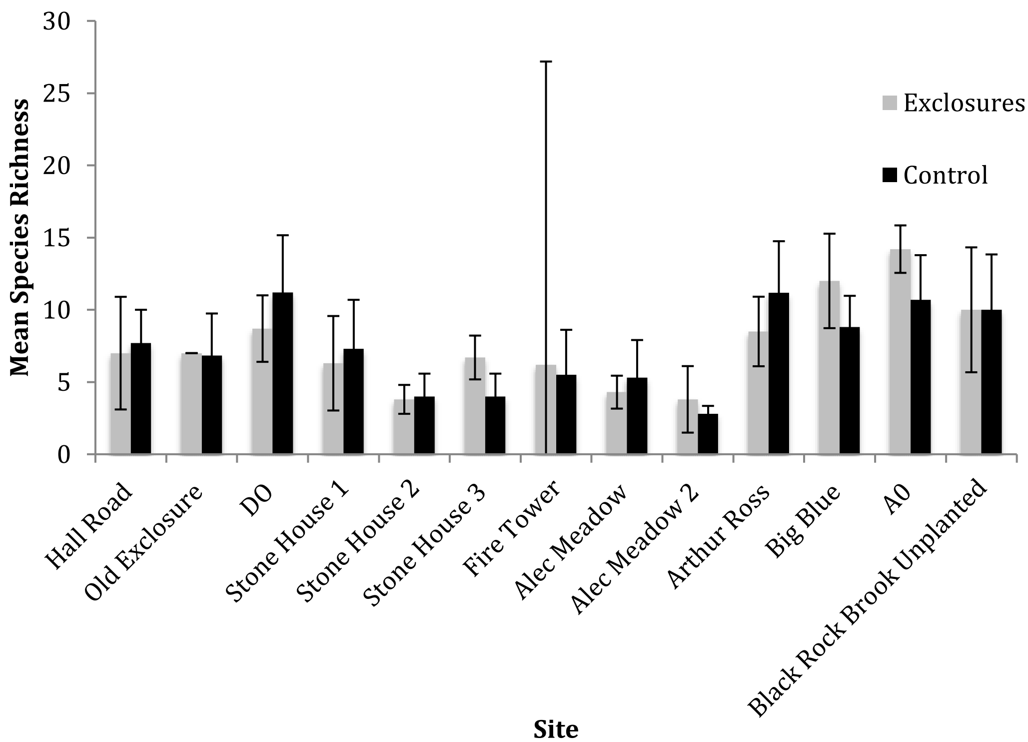
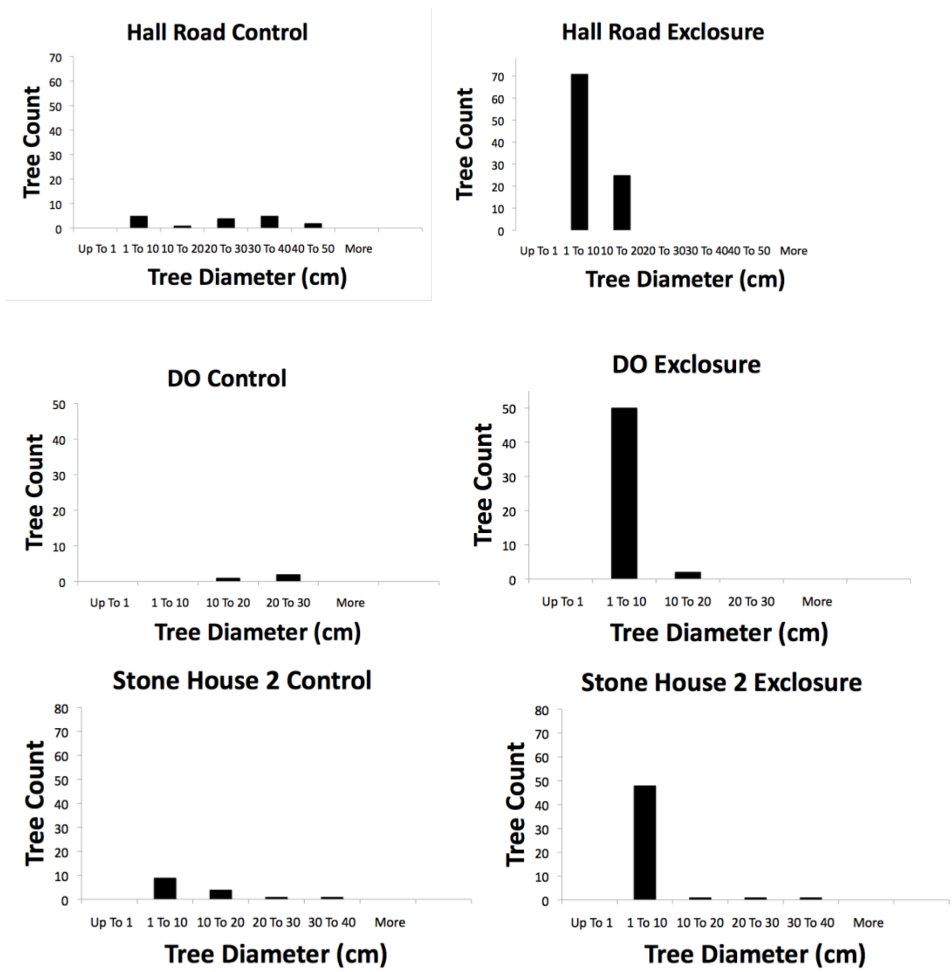
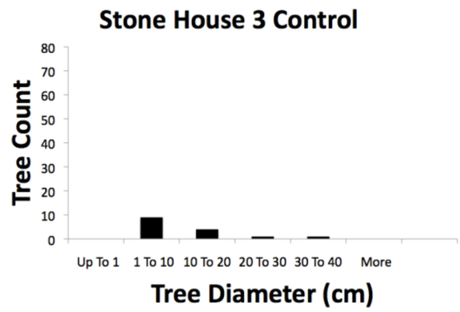


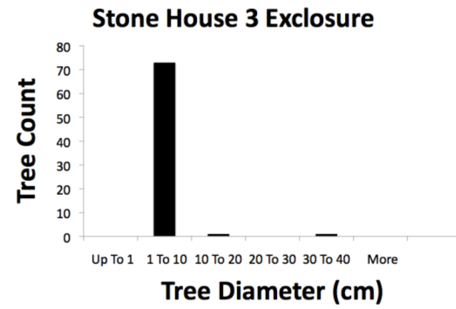
Figure 3: The mean species richness of the 5 plots per site. The error bars indicate standard deviation. The analysis of variance shows that the mean species richness in the exclosure is not different than the mean species richness in the control (p-value 0.65986).

The differences in mean species richness between the exclosure and control plots are not significant. Across all sites, the means of the exclosure and control plots are generally similar.

The distribution of tree size classes varied across the 13 exclosures and associated control sites (Figure 4).




Stone House 3 Control
Tree Count
0
10
20
30
40
50
60
70
80
Up To 1
1 To 10
10 To 20
20 To 30
30 To 40
More
Tree Diameter (cm)


Stone House 3 Exclosure
Tree Count
0
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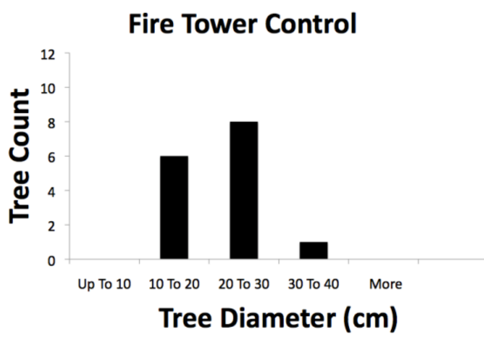
80
Up To 1
1 To 10
10 To 20
20 To 30
30 To 40
More
Tree Diameter (cm)


Fire Tower Control
Tree Count
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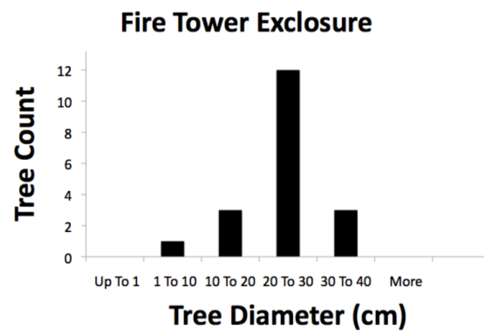
2
4
6
8
10
12
Up To 10
10 To 20
20 To 30
30 To 40
More
Tree Diameter (cm)


Fire Tower Exclosure
Tree Count
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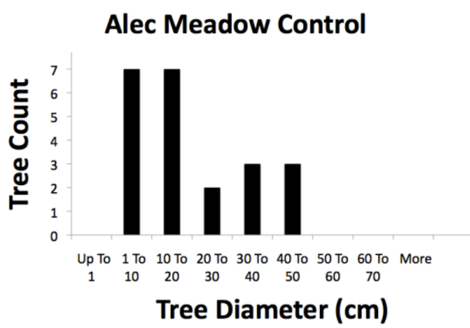
30 To 40
More
Tree Diameter (cm)


Alec Meadow Control
Tree Count
0
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2
3
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Up To 1
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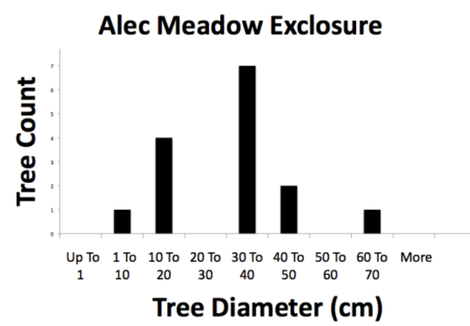
30 To 40
40 To 50
50 To 60
60 To 70
More
Tree Diameter (cm)


Alec Meadow Exclosure
Tree Count
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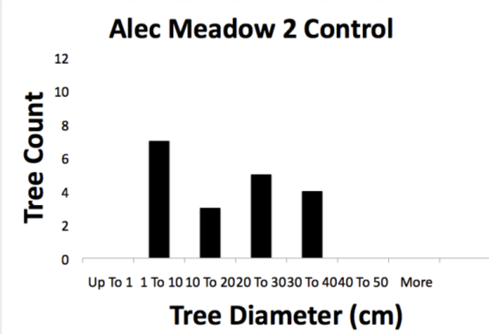
50 To 60
60 To 70
More
Tree Diameter (cm)


Alec Meadow 2 Control
Tree Count
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10
12
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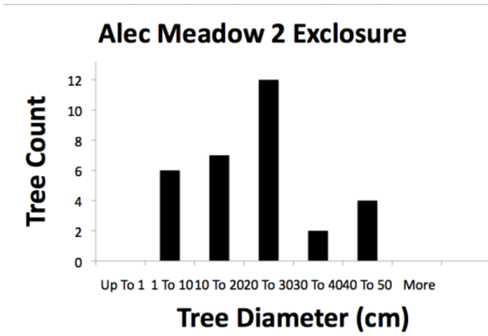
1 To 10
10 To 20
20 To 30
30 To 40
40 To 50
More
Tree Diameter (cm)


Alec Meadow 2 Exclosure
Tree Count
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Up To 1
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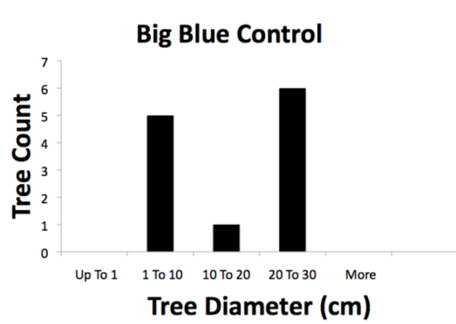
30 To 40
40 To 50
More
Tree Diameter (cm)


Big Blue Control
Tree Count
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1
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3
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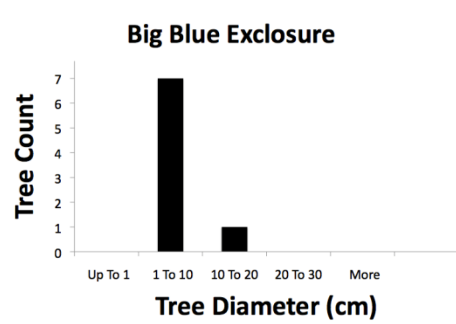
Up To 1
1 To 10
10 To 20
20 To 30
More
Tree Diameter (cm)


Big Blue Exclosure
Tree Count
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5
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7
Up To 1
1 To 10
10 To 20
20 To 30
More
Tree Diameter (cm)

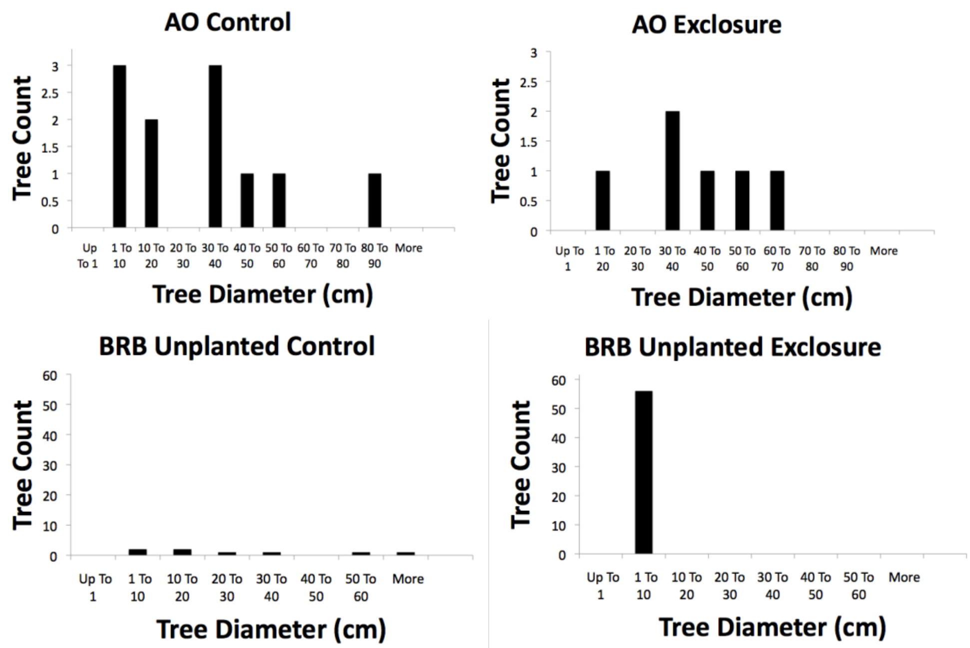


Figure 4: Size classes of diameters for control and exclosure plots. The analysis of variances shows that the exclosure plots are significantly different than the control plots for Hall Road (p-value <.0001), DO (p-value <.0001), Stone House 2 (p-value 0.0134), Stone House 3 (p-value 0.0001), and Black Rock Brook Unplanted (p-value <.0001). Differences between exclosure and control plots were not significant for Fire Tower (p-value 0.4964), Alec Meadow (p-value 0.1024), Alec Meadow 2 (p-value 0.1509), Big Blue (p-value 0.2178), and A0 (p-value 0.2588).

Five of the exclosures (Hall Road, DO, Stone House 2, Stone House 3, and Black Rock Brook Unplanted) had greater numbers of trees in the smaller size classes, resulting in significant difference in size class distributions (Chi-square values, all $p<0.02$). Five other exclosures (Fire Tower, Alec Meadow, Alec Meadow 2, Big Blue, and AO) showed no significant differences in size class distribution between exclosures and controls (Chi-square values, all $p>0.1$). The Arthur Ross Control only had 1 tree, so a histogram could not be made. However, the Arthur Ross Exclosure had 49 trees with a diameter between 1 and 10 cm. Histograms were not made for Old Exclosure or Stone House 1 because there were not enough trees.

In the exclosure plots, the mean total cover values ranges from 13.2% to 97.5%. In the control plots, the mean cover value ranges from 9.2% to 87%. There is a large amount of variation between each site. The differences in mean total cover do not significantly vary between exclosure and control plots. However, there is a general trend for larger mean total cover values outside of the exclosures rather than inside of the exclosures, as 9 out of 13 exclosures exhibit this pattern. 2 out of 13 exclosures have larger mean total cover values inside of the exclosures rather than outside of the exclosures. It should also be noted that two locations, AO and Black Rock Brook Unplanted, do not have overlapping error bars. The AO exclosure has a larger mean total cover value inside of the exclosure than outside of the exclosure, while the Black Rock Brook exclosure has larger mean total cover value outside of the exclosure than inside of the exclosure.

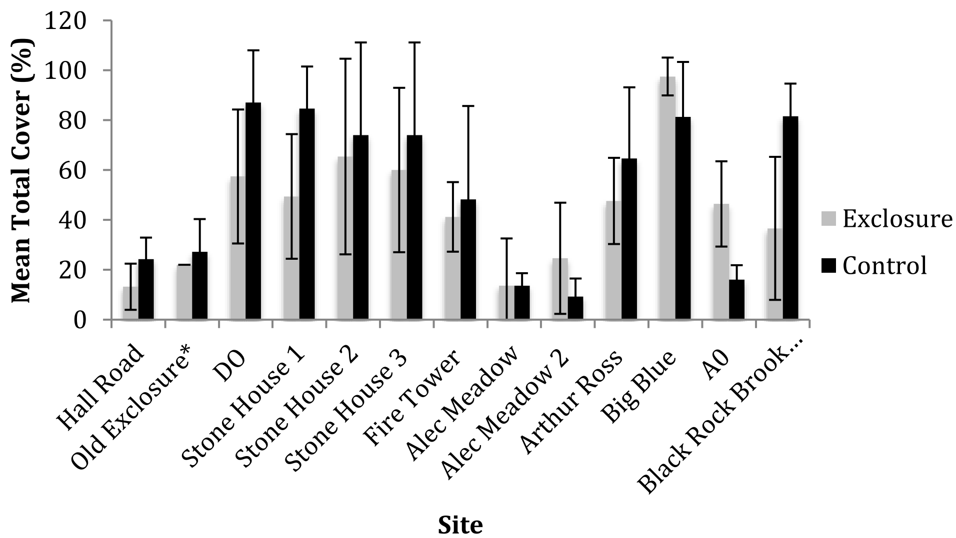


Figure 5: The mean percent cover of the 5 plots surveyed at each site. The control and exclosure means are compared. The error bars indicate standard deviation. Standard Deviation could not be calculated for Old Exclosure because only one plot was surveyed within the Exclosure. The analysis of variances shows that the differences in mean total cover do not significantly vary between exclosure and control plots (p-value 0.17327).

The Hall Road exclosure plot has the highest tree density, 3.4 trees/m^2, while the Stone House 1 control plot and the Old Exclosure exclosure plot have the lowest tree density, 0 trees/m^2. There is a general trend for more trees in the exclosure plots than in the control plots, as 9 out of 13 plots display this trend. There are 4 locations where there are more trees in the control plots than in the exclosure plots. There is a large variation in tree density between sites.

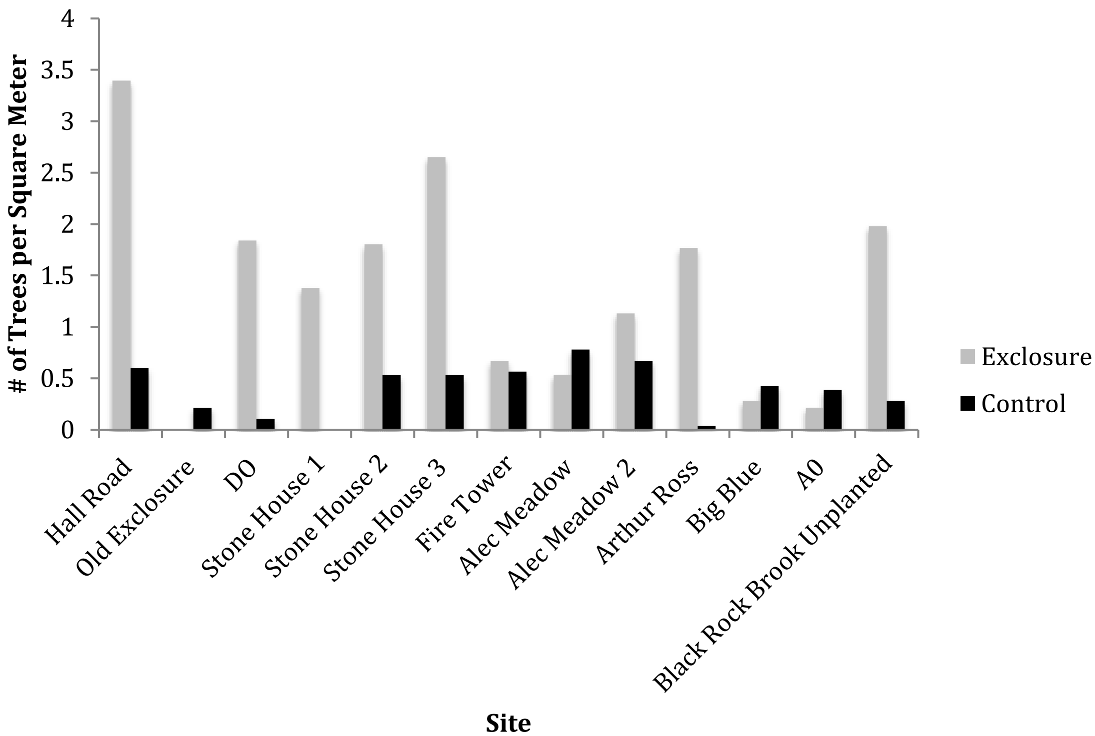
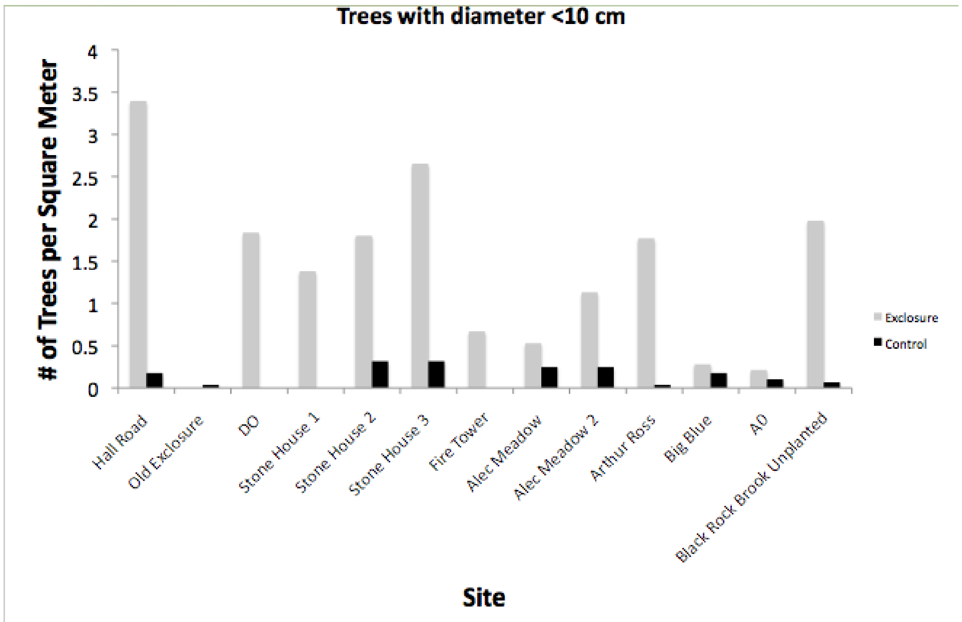


Figure 6: The mean number of all individual trees counted in the exclosure plots and the control plots at each site. The individual tree numbers for the Old Exclosure exclosure plots were not taken.

The density of trees with a diameter less than 10 cm (Figure 7) ranges from 0 to 3.4 tree/m^2 within the exclosures. In the control plots, the tree density ranges from 0 to 0.32 tree/m^2. For trees with a diameter less than 10 cm, 12 out of 13 locations have a higher tree density in the exclosure than in the control. The density of trees with a diameter greater than 10 cm (Figure 7) ranges from 0 to 0.88 trees/m^2 within the exclosure plots. In the control plots, the tree density ranges from 0 to 0.57 trees/m^2. There is a trend for higher density of trees with a diameter greater than 10 cm in the control plot than in the exclosure plot, as this is displayed in 8 out of 13 locations. There is a large variation in tree density between sites.



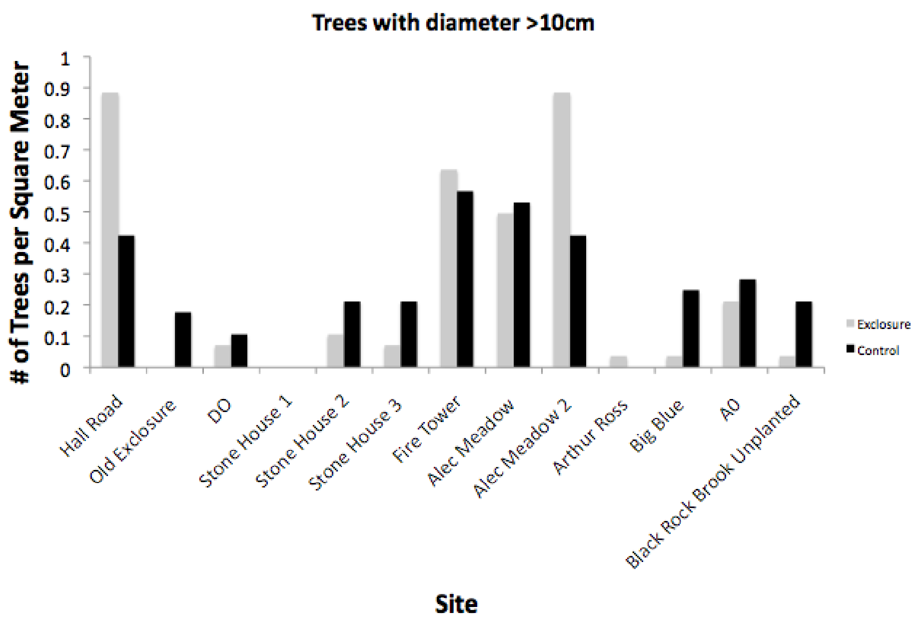


Figure 7: The mean number of individual trees with diameters greater than 10 cm and less than 10 cm counted in the exclosure plots and the control plots at each site.

Exclosure Removal Data

There are no consistent trends in average species richness across the locations. Black Rock Brook Unplanted and Black Rock Brook Planted both exhibit a species richness decrease within the exclosure and a species richness increase within the control after the exclosure fences are removed. There is no data available for Black Rock Brook prior to the fence removal in 2010. The Arthur Ross exclosure displays an increase in species richness over the course of one year. Only one year of data was taken within the Arthur Ross control. Therefore, there is no observable trend across time. Between 2004 and 2012, the species richness in both the exclosure and control plots at Stone House 1 increase. After the removal of the fence in 2012, the species richness within exclosure increases. This increase cannot be compared to the control plot because the Stone House 1 control plot was not surveyed in 2013. The Hall Road exclosure fence was removed in 2000, but not surveyed until 2004. The Hall Road control and exclosure plots both decrease between 2004 and 2012. However, in 2004 the Hall Road exclosure plot species richness, 12.33, is higher than the Hall Road control plot species richness, 10. In 2012, the Hall Road exclosure plot species richness, 6.2, is lower than the Hall Road control plot species richness, 6.6.

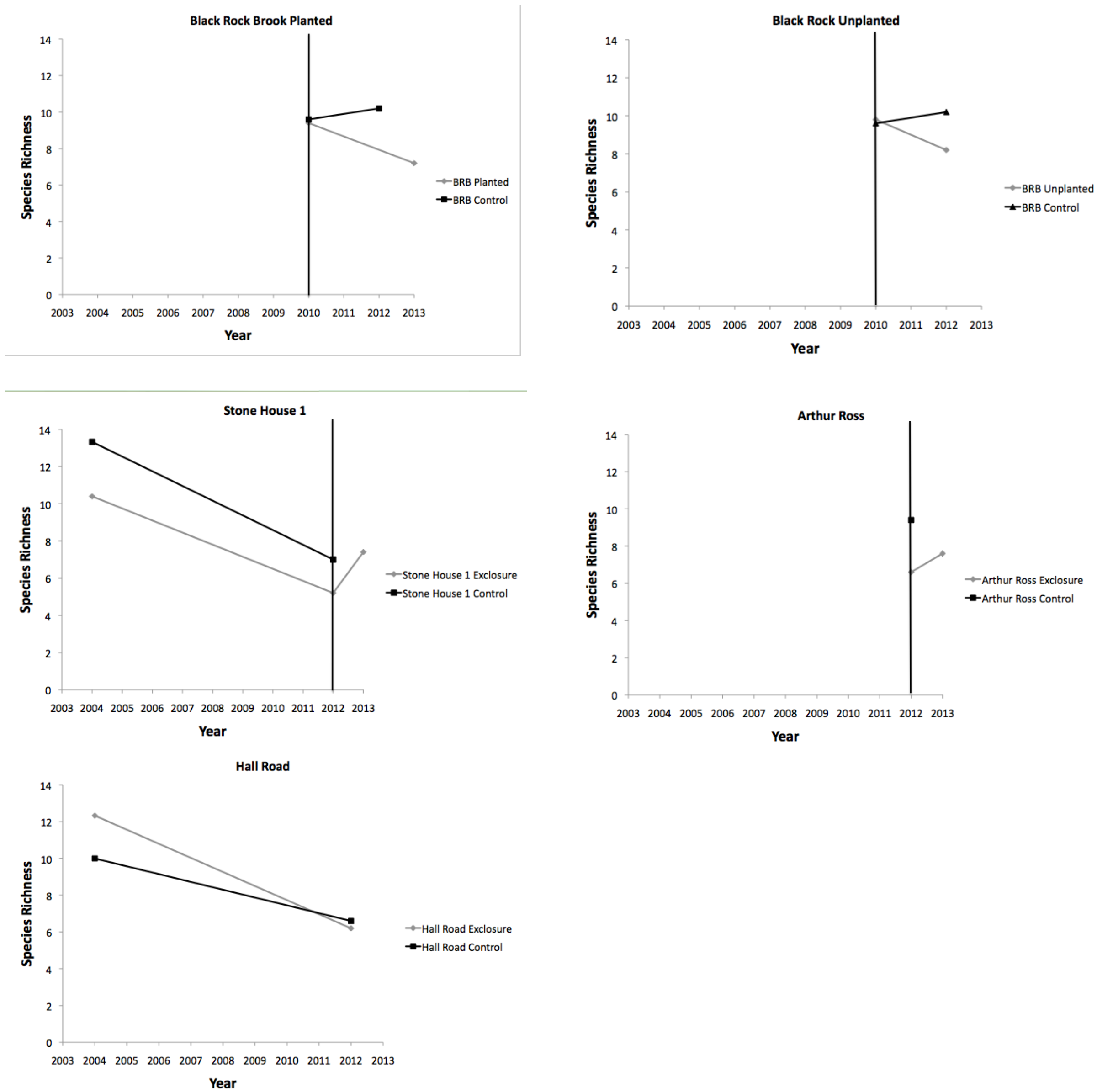


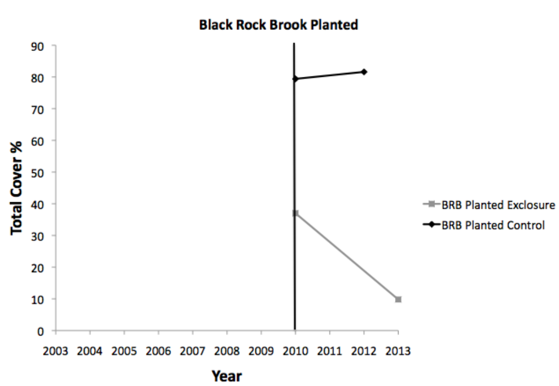
Figure 8: Mean Species Richness for Black Rock Brook Planted, Black Rock Brook Unplanted, Stone House 1, Arthur Ross, and Hall Road from 0-1m. The exclosure fences were removed in 2010 (indicated by black, vertical line). The Hall Road exclosure removal is not represented on the graph, as it was removed in 2000. Stone House 1 control and exclosure plots were surveyed 6 times (as opposed to the usual 5). Hall Road control and exclosure plots were surveyed 3 times.

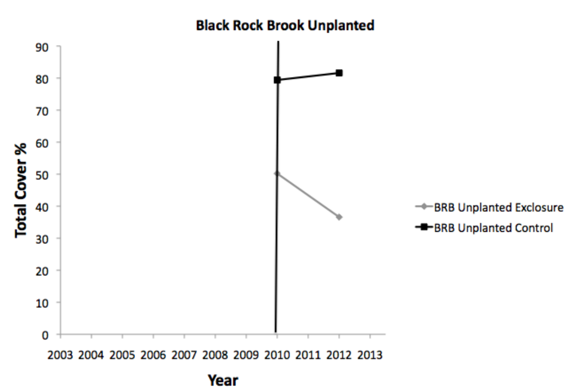
The mean total cover data follows similar trends to the species richness data. There are no consistent trends in mean total cover data across the locations. Black Rock Brook Planted and Unplanted follow similar trends, as in both locations the the total cover in the control plot increases and the total cover in the exclosure plot decreases after the removal of the exclosure fence in 2010. The total cover is higher in the control plot for both 2010 and 2012.

The Stone House 1 total cover data displays an opposite trend from the species richness data. Both the control and exclosure plots increase between 2004 and 2012. In 2004, both the control and exclosure plots have a total cover of 3.67%. However, in 2012, there is higher total cover in the control plot, 84.6%, than there is in the exclosure plot, 49.4%. After the exclosure fences are removed in 2012, the total cover in the exclosure plot decreases. The control plot was not surveyed in 2013.

After the exclosure is removed in 2012, the total cover in the exclosure plot decreases. The control plot was not surveyed in 2013.

At Hall Road, total cover increases in both the control and exclosure plot between 2004 and 2012. In 2004, the exclosure and control plot have similar total cover percentages, 2.5% and 1.7% respectively. In 2012, the control plot has a higher total cover, 24.2%, than the exclosure plot, 13.2%.





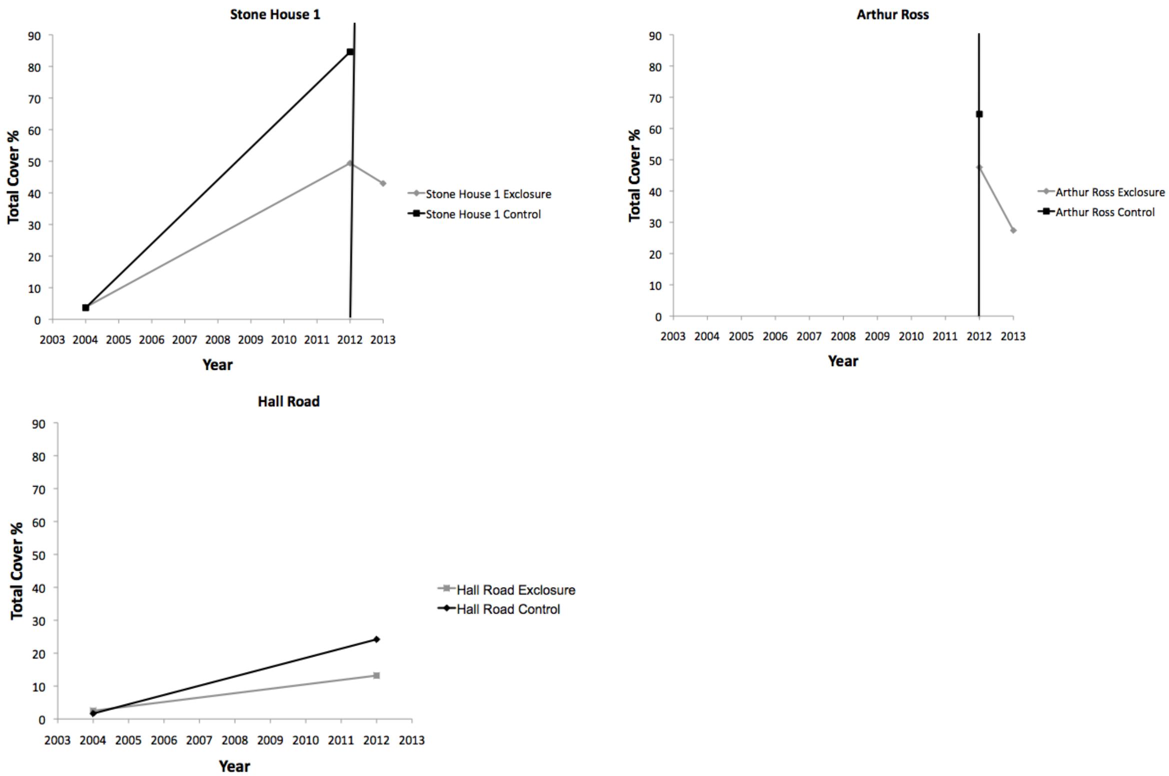


Figure 9: Mean Total Cover for Black Rock Brook Planted, Black Rock Brook Unplanted, Stone House 1, Arthur Ross, and Hall Road from 0-1m. The exclosure fences were removed in 2010 (indicated by black, vertical line). The Hall Road exclosure removal is not represented on the graph, as it was removed in 2000. Stone House 1 control and exclosure plots were surveyed 6 times (as opposed to the usual 5). Hall Road control and exclosure plots were surveyed 3 times

Discussion

The species richness data did not show any consistent differences inside the exclosures, suggesting there was no detectable effect of deer browsing on species richness in the understory layer. The trends illustrated by Figure 3 indicate that deer do not reduce understory species richness at Black Rock Forest. A study by Aronson and Handel found similar results (2011). However, it is also possible that variations with the data obscure an actual effect of deer browsing. There are many variations in the soil properties between each location at Black Rock Forest (Tedrow and Shaw 2011). Therefore, deer browsing is not the sole difference between each location. This makes it difficult to compare between locations.

Additionally, soil at Black Rock Forest is not ideal for understory growth to begin with. It's acidic nature, steep slopes, and shallow depth to bedrock make it difficult for vegetation to grow (Tedrow and Shaw 2011). The data may not be reflecting the effects of deer browsing and deer browsing removal, but instead the poor quality of soil for understory growth.

For the tree seedling regeneration data, 5 out of 11 exclosures had significant differences between the exclosure and control plots. The difference was for the amount of trees growing in each size class. There are more trees in smaller size classes, particularly in the 1-10 cm diameter range, within the exclosures. Trees with a 1-10 cm diameter are generally young trees, thus the presence of more small trees inside the exclosures suggests that deer exclusion will increase tree seedling regeneration. However, 5 out of the 11 exclosures did not show significant differences between the exclosure and control plots, thus the effects of exclosures on tree regeneration appear to be variable. Each of the 5 exclosures with insignificant results had a fairly even distribution of small to large trees in both the exclosure and control plots. When the deer are excluded, there is not a significant change in seedling growth between the exclosure and control plots. This suggests that deer browsing may not be playing a major role in tree growth at these locations. It has already been stated that there are large variations in soil quality between each location at Black Rock Forest (Tedrow and Shaw 2011). Other differences, including accessibility to deer, may also exist. Perhaps these locations are relatively inaccessible to deer or have high soil quality.

All of these locations have larger trees, which are older trees. Older trees were likely present before the exclosures were established. These trees may shade out tree seedling growth (Peet and Christensen 1987, Flinn and Velland 2005). Lastly, a histogram for the Arthur Ross control plot could not be created because there were not enough trees in the control plot. However, there were 49 trees with a diameter between 1 and 10 cm on the exclosure plot, whereas there was only one tree on the Arthur Ross control plot. It is likely that the exclusion of deer will increase tree seedling regeneration inside of the exclosure.

The total understory cover did not vary consistently between the exclosure and control plots. Therefore, we are not able to detect any obvious pattern of deer browsing decreasing total cover, and thereby understory vegetation biomass. On the contrary, the trend in the data suggests that deer browsing may increase mean total cover in the control plots relative to the exclosure plots, as 9 out of 13 exclosures had higher mean total cover in the control plots. Selective deer browsing will homogenize understory vegetation (Rooney 2009). This may lead to an increase in total understory cover in the control plots, as non-grazed species will flourish.

However, like the species richness dataset, there may be problems with the data that prevent the real effects of deer browsing from being detected. There also may be factors affecting mean total cover that this study did not consider. For example, if an exclosure protected a dense layer of tree seedlings or saplings, other understory vegetation may be shaded out (Peet and Christensen 1987, Flinn and Velland 2005). Beyond this, the diameters of sapling and tree seedling stems will not account for a large percentage of the observed space. If sapling and tree seedlings shade out forb and grass species, this will appear as a decrease in understory vegetation biomass, even though re-growth is occurring. Because only data below 1m was included in the cover estimates, it is unknown how canopy cover above 1m would vary, or what effect it had on the understory vegetation.

The density of trees was greater within the exclosure plots than in the control plots. Nine out of thirteen sites demonstrated this pattern.

When this was not the case, the density of trees within the control plot only exceeded the exclosure plot by, at most, .25 trees per (unit area). This was at Alec Meadow. When exclosure plots had higher tree counts than control plots, the excess was as high as 2.8 trees.

The density of trees with a diameter less than 10cm was consistently greater in the exclosure plots than in the control plots (Figure 7). Conversely, the density of trees with a diameter greater than 10cm was about equal in exclosure and control plots (Figure 7). This data is similar to that of the tree seedling regeneration data (Figure 4). Specifically, the removal of deer will contribute to an increase in tree seedling regeneration and young trees (Aronson and Handel 2011, Abrams and Johnson 2012). Deer browsing will not affect larger trees (greater than 10 cm in diameter), as they are already established. Therefore, the removal of deer browsing will not affect larger trees, and there will not be a significant difference between exclosure and control plots for larger tree numbers.

Over a longer period of time, the number of larger trees may increase as the tree seedlings mature. However, this pattern was not observed in this study.

Species richness and mean total cover were tested after the exclosures were removed (Figures 8 and 9). However, surveyors did not conduct enough surveys to generate meaningful results. At Black Rock Brook Planted and Unplanted, only two surveys were taken after the exclosure was removed. No surveys were taken prior to the exclosure fence removal. A number of factors other than deer browsing could have led to the changes in species richness and mean total cover between 2010 and 2013. The same issue applies across all locations. Surveyors conducted no more than three surveys over the course of 10 years at any location. Any number of factors, including drought, cold temperatures, or variations in deer population sizes may have led to gradual changes over the course of ten years. The limited scope of the data makes it difficult to ascertain which changes were happening regardless of deer browsing and which changes were happening because of deer browsing. Therefore, it is difficult to conclude whether the re-introduction of deer browsing is responsible for any long-term changes in species richness or total cover.

Conclusion

More tests will need to be run to determine the effect of deer exclosures on vegetation diversity and understory vegetation biomass. However, the results of this study indicate that the installation of exclosures will increase tree seedling regeneration and, potentially, the number of mature trees within an exclosure. Though the exclosure removal component of this study was inconclusive, it is likely that once trees reach a certain diameter or height, reintroducing deer browsing will not negatively impact the trees. Therefore, the installation of deer exclosures is likely to have some sort of lasting impact on the composition of the forest. It would be interesting to determine at what diameter or height trees could withstand reintroduced deer browsing. It would also be interesting to study the effects of removed deer browsing and increased canopy cover on understory vegetation.

Recommendations

Diameter histograms could not be made for Old Exclosure, Stone House 1, or Arthur Ross because diameter data was not available for these locations. The deer exclosure removal data could undergo only a limited analysis. The exclosures were erected for forest management purposes before they were used for scientific studies. For this reason, both the sampling methods and the frequency of sampling have been inconsistent. This made comparison between data sets hard. Furthermore, data was not collected every year, which severely limited the scope of the dataset. Surveyors tried to take vegetation surveys at the same plots for every year data was collected. However, data markers were frequently lost or destroyed by natural processes. Therefore, the exact locations of each plot are unknown. Future studies would benefit from a defined scientific goal before the exclosures are erected, a uniform method of data collection and entry, consistent data collection, and an organized naming system wherein one name is assigned to each exclosure.

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