

Assessing the Effects of Deer Herbivory on Forest Regeneration at Black Rock Forest

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Abstract:

Though lands were modified to some extent by Native Americans, since the arrival of European settlers in the 16th and 17th centuries, land use of the United States Northeast has been in constant and rapid flux. Although forests now occupy much of what used to be farmland, elimination of predators and previous regulation of hunting have meant that present deer densities are high in many areas, inhibiting the healthy regeneration of forests through over-browsing and causing unpleasant deer-human interactions, like car collisions, which cost upwards of 3.8 billion dollars and kill over 200 people annually. Because of this, it is important to manage deer populations when possible; doing so can assist in the restoration of ecosystems to a more sustainable balance and prevent negative repercussions of high populations. Black Rock Forest in the Hudson Highlands of New York state has been part of research initiatives examining deer and tree relationships since the 1930s. Hunting and the return of major predators like the coywolf have assisted in decreasing the deer populations from over 20 deer per square mile to around 12 per square mile. I will compile and analyze some of these data in order to find any relationship between changes in deer populations and changes in their habitat. Deer population estimates come from hunting data, which also provides useful information about the health of the deer population, and from overwintering deer density data, collected after snowfall when deer are mobile, and tracks are visible. Additionally, long-term plots have been maintained since 1931 and provide us with useful measures of the change of biodiversity and biomass in the forest and plots maintained since 2009, deer exclosures can help determine the present effect of deer browsing on the forest. In short, this study seeks to find a connection between decreasing deer populations and forest health in Black Rock Forest to promote and guide future management strategies at Black Rock Forest and beyond. However, because of delayed responses to the stabilizing deer populations, there is the possibility that no relationship between deer populations and forest regeneration is found. Nevertheless, such a finding would not preclude the existence of a relationship, and this thesis could serve as a precedent for future studies of deer and trees in Black Rock Forest and beyond.

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Introduction

Deer and Forest Ecology

The White-tailed deer (*Odocoileus virginianus*) is found throughout the Americas, from as far north as Canada to as far south as sub-equatorial South America (Heffelfinger 2006). Although some studies have shown that deer have a positive impact on forest health, others have established that the detrimental effects of deer exceed positive effects at a density of over 10 deer per square mile (Ramirez et al. 2018). Deer can impact the species composition and biomass of vegetation through selective browsing and the deposition of excrement, which can increase nutrient contents of soils and even assist in the growth of canopy trees (Lucas et al. 2013). However, throughout much of North America, deer populations exist at populations above the social and biological carrying capacities, impacting vegetation diversity, abundance, and structure and decreasing the abundance of native species preferred by deer. This can impair the ability of forests to maintain a sustainable and biodiverse composition, ultimately affecting even communities of other species, like birds, and human activities, like forestry (Morecroft et al. 2001).

Habitat and Diet

White-tailed deer (*Odocoileus virginianus*) are native to much of North America, from Canada to Mexico, and have played a role in forest ecosystems for between 3.7 million and 750,000 years (Heffelfinger 2006). There are a number of subspecies found throughout the whitetail range, and each subspecies is adapted to a somewhat different habitat and food sources. The subspecies in question here, *Odocoileus virginianus borealis*, lives mostly in forested areas throughout the American Northeast and Midwest and in southern Canada, though it is often

found in residential areas due to the abundance of food sources and suitable habitat (Heffelfinger 2006).

Deer are herbivores and concentrate selectors, since they consume mostly twigs, leaves, nuts, and berries. However, the diet of a whitetail deer varies greatly depending on habitat and season, with greater consumption of forage in the months preceding the winter. Depending on location, deer, generalist herbivores, can consume upwards of 100 different species of plants as part of their diets (Hewitt 2011). Nevertheless, usually, a few species make up the greatest portion of their diet, and deer do prefer certain vegetation types over others and sometimes native plant species over non-native ones, often assisting in the invasion of non-native species (Averill et al. 2016). For their proximity to both food sources (forbs and shrubs) and shelter, deer especially like habitat on the edges of forests, or where denser wilderness borders clearings (Innes 2013).

Effects of Deer Browsing on Forest Composition

Because of their patterns of consumption, deer impact the makeup of vegetation in their habitats. Some studies have shown that deer populations can have a positive impact on oak tree growth, possibly because of their role in seed dispersal and fertilization of soil with feces and urine (Lucas, 2013). Because of their selective browsing, white-tailed deer decrease the species diversity of the understory and often select for the incursion of invasive species because the deer often prefer native species over non-native ones (Averill et al. 2016). In certain environments, despite their browsing resulting in decreased understory vegetation diversity, deer were also associated with a decrease in insect herbivory (Stephan et al. 2017). Nonetheless, other studies have shown that deer browsing has a clearly negative impact on the understory species diversity

and richness of a forest ecosystem, shifting the canopy dominance away from oaks and toward beech (Rossell et al. 2007). That deer impact ecosystems is beyond question, but the nature and extent of this impact is highly variable.

Oak-dominant Forests and Forest Regeneration

In healthy forest ecosystems, invasive species are kept at bay, carbon is sequestered, cultural ecosystem services can be provided, nutrient circulation is optimized, and, most importantly, the forest is generally more resilient. Healthy ecosystems, i.e. those with greater species diversity and richness and those that have not been commercially thinned, are better able to return to their previous state after disturbances from disease or natural disasters (Ibáñez et al. 2019). Such resistance to negative change is something that is increasingly relevant as climate change impacts ecosystems throughout the world more acutely through temperature increases, drought, more heavy rainfall events, and more severe natural disasters (Hoegh-Guldberg et al. 2018).

A forest's resilience is also tied to its ability to regenerate. One of the aims of this study is thus to assess forest regeneration, a somewhat controversial topic, so it is necessary to first establish a working definition for forest regeneration specific to this study. In order for a forest to regenerate, it has to have been degraded from its "natural" state. Decreased biodiversity and other changes to a forest that result in decreased productivity are components of degradation (Figure 1). Restoration, then, is that which returns a natural area to the sustainable and healthy natural state. However, this natural state is often impossible to return to and is most often unable to be determined (Santurf 2005). Regeneration happens on different time scales and can be aided by human intervention or left to proceed organically. In the case of the latter, regeneration, including that related to deer over-browsing, recovery can be a lengthy process, taking more than

a decade for management efforts to become apparent (Pendergast 2016). Because there are paleo-vegetational data from pollen spores at Black Rock Forest, despite the extensive changes in land-use over time, the general (pre)historical species composition of the forest is known and the natural state, or the goal of regeneration may be determinable (Maenza-Gmelch 1997).

The study area of this thesis is Black Rock Forest, an oak-dominant forest, and the goal of current forest management is to maintain the dominance and regrowth of oaks in the forest (Schuster, personal communication, 11 December 2020). Both red and white oaks (*Quercus rubra, Quercus alba*, respectively) are a key part of the Black Rock Forest ecosystems, providing a host of ecosystem services. They produce acorns, a nutrient-dense food source for rodents and deer, serve as a habitat for birds, enable nutrient cycling and decomposition through their relationships with fungi, and sequester large amounts of carbon (Cavender-Bares 2016). Thus, the maintenance of an old-growth oak-dominant forest is essential for the health of the ecosystem. However, although oaks are resilient species, fungal infections like oak wilt and sudden oak death, though not originating in New York, are leading causes of oak mortality, and deer browsing can prevent the growth of young oaks to replace older trees and can eventually impact the persistence of oaks in the canopy.

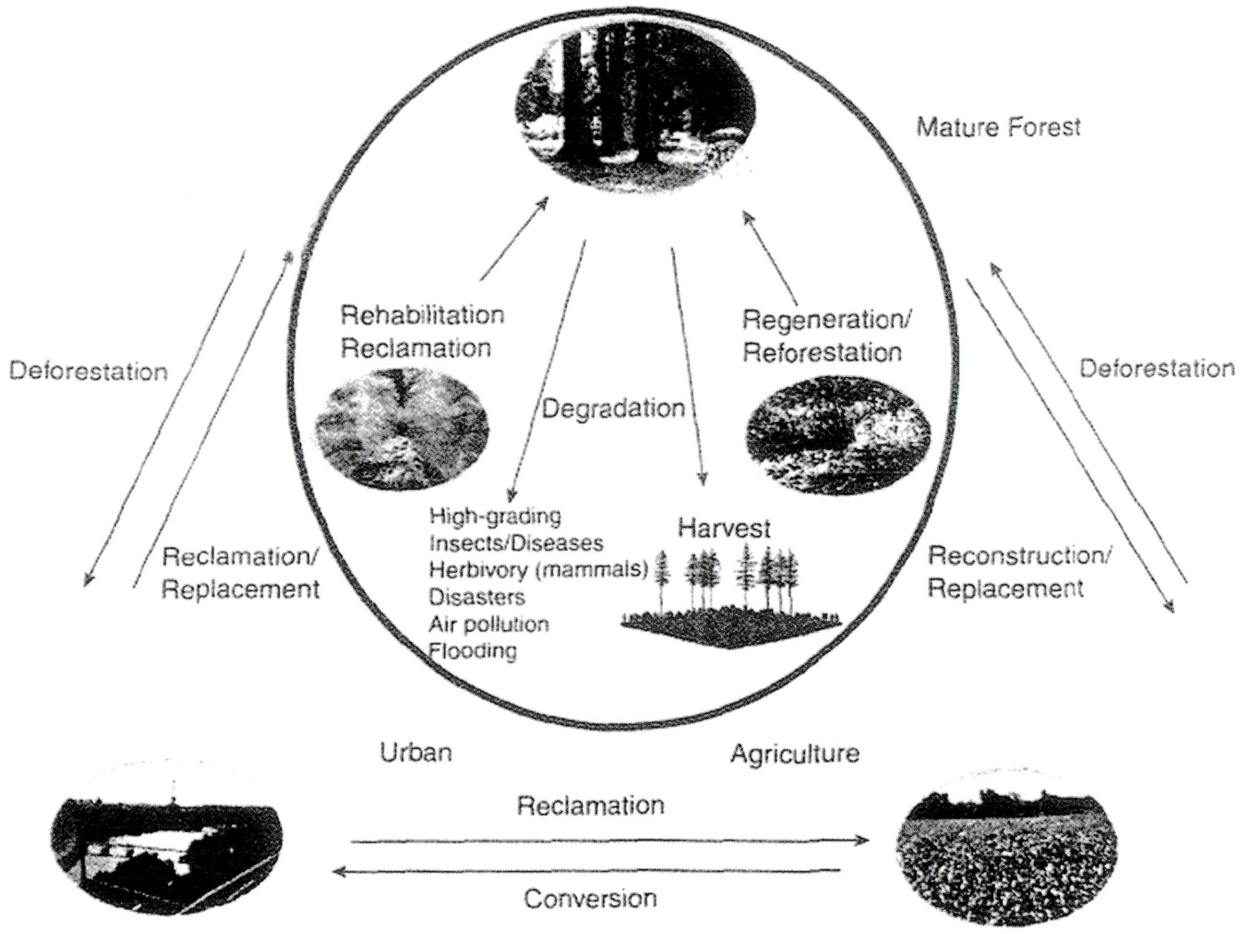


Figure 1. Trajectories between degraded and natural lands. The processes of recreation and degradation of forests is nuanced and can happen in a variety of ways, some of which are shown here. Source: Santurf (2005).

Deer in New York State

Deer Population Dynamics and Population Control Efforts in New York State

61% of New York State is covered by forests, both privately and publicly owned. Although the state is home to one of the largest and most densely populated cities in the world, it also supports large tracts of forested land, which contribute an annual $4.6 billion to the economy in forestry and over $1.9 billion in recreation. Furthermore, these forests, containing

over 100 different species of trees, are important in their ability to sequester carbon and support floral and faunal biodiversity (New York Department of Environmental Conservation n.d.b). Therefore, the conservation and preservation of the forests of New York is vital, and the degradation of forests could be detrimental for the economy, human wellbeing, and the ecosystems within them.

In part because of their influence on forest ecosystems but also because of their browsing of agricultural fields and private gardens and their involvement in car accidents and the spread of Lyme disease, the deer of New York have been relevant to policymakers, communities, and scientists alike for decades. Based on estimates from annual buck take, the population estimate for the state in 2018 is 950,000 deer (New York Department of Environmental Conservation 2020). The density is difficult to estimate exactly, but it is estimated that it varies from less than 15 to over 30 deer per square mile throughout the state.

Although deer populations have varied over time and by location, populations have not always been at the high levels they are at today. Due to varying primary historical accounts of deer populations in the New York region and lack of quantitative data, it is hard to provide an accurate and overarching trend for deer populations before deer take records were standardized in the latter half of the 19th century. Based on the comprehensive 1956 summary of deer populations in New York by Severinghaus and Brown, though, favorable conditions created by cultivated land and the elimination of predators lead to increases in population, though abundance decreased during difficult winters, which would often lead to mass starvation, especially if populations were too high or food too scarce. Starting in the mid-19th century, the size of many wild animal populations, including deer, wildcat, beaver, fox and rabbit, plummeted, reaching the danger of extermination in the region. Forests were flattened in order to

accommodate developing agriculture, dairy, and forestry industries, and hunting was taken up as a form of sustenance and protection (Severinghaus & Brown 1956).

In New York in 1861, the last deer was killed in Westchester County, and in 1878, there was excitement over the capture of a single deer in Orange County, where Black Rock Forest is located. By 1880, 75% of the state was occupied by farmland, and the deer population reached its smallest size. Nevertheless, beginning in the early 1900s, due partly to the increasing deer population in Connecticut by the 1890s and increasing populations within the small pockets in Orange County, as well as the abandonment of farms, deer slowly became more abundant (Severinghaus & Brown 1956).

Today, deer populations in the New York area-- and more specifically in the Hudson Highlands-- have begun to decline once again, due to increased hunting and, more importantly, the proliferation of predators, including the so-called coywolf (Figure 2). Due to hybridization with wolf populations, the coyote in the Northeast are heavier and larger than those in the southern and western United States, and a large part of their diet consists of white-tailed deer, assisting in a natural reduction of the deer populations (Frair et al. 2014).

Nevertheless, white-tailed deer remain overabundant in many areas of the state, causing deer-vehicle collisions, damage to landscaping plants, disruption of forest ecosystems and the proliferation of tick-borne diseases, among other types of damage. There are an estimated 70,000 deer-vehicle collisions annually, which incur a cumulative cost of upwards of $462 million, with an extra $59 million from crop damage alone (Booth-Binczik & Hurst 2018).

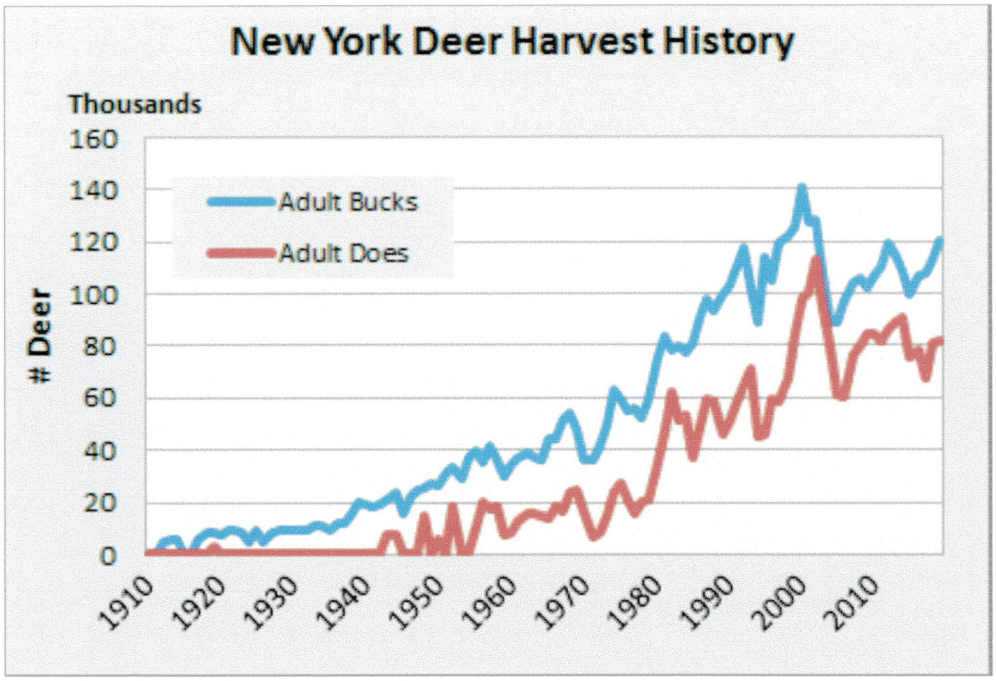


Figure 2. Trends in deer take in New York state between 1910 and 2019. Trends in the take of especially bucks can be used as reasonable proxies for deer population trends. Taken from Bifaro et al. 2020

Deer-Related Legislation and Management Techniques

It has long been recognized that with human modification of the landscape, human measures are also needed to help ensure the stability of deer populations. Legislation has thus been a part of deer population control in New York State since the first deer-related law was passed in 1705, prohibiting the taking of deer between January and August (Severinghaus & Brown 1956). These early laws were not effective in increasing the shrinking deer populations, and it was not until 1895, when the New York State Fisheries, Game and Forest Commission was founded, that deer populations were comprehensively protected, namely by the reduction of antlerless deer harvest and closed seasons (Bifaro et al. 2020). Increasing populations led to the re-establishment of hunting as a means of recreation and population control in New York. By the

1940s, deer were once again abundant in most of the state, and permits began to be issued in the 1960s, allowing for a more exact control of the population by determining the number of deer of each class (antlerless, doe, buck, etc.…) able to be killed (Bifaro et al. 2020).

Today, the public plays a large role in determining deer population management goals. Licensed hunters are granted permits and must apply to be selected for a doe tag, which are so limited in number because of the direct correlation between does and the population growth rate (New York Department of Environmental Conservation 2018). New York issues more doe tags when the population is determined to be too high, but populations remain high in many areas of the state where hunting is not possible (New York Department of Environmental Conservation n.d.).

As part of its deer management initiatives, the Department of Environmental Conservation also surveys residents of New York, allowing them to be a part of the management process. The response of a given community to deer management is thus highly varied throughout the state (New York Department of Environmental Conservation 2018).

A History of Black Rock Forest and its Deer

Since the settlement of the Northeast by Native Americans, who burned tracts of land to attract deer for hunting, deer have played a significant role in the ecological balance of the Northeast, and as land-use and human geography have changed, the role of deer in the ecosystems has changed as well (Abrams & Nowacki 2008). Black Rock Forest is near Cornwall and Highlands in Orange County, north of New York City by about 50 miles (Figure 3). The forest consists of 3,800 acres of deciduous, mostly oak-dominated stands; approximately 70% of the forest consists of red oak and chestnut oak (Brady 1994, Schuster 2008).

Neil Maher's history of Black Rock Forest provides insight into the changing biotic and abiotic composition of the land. Before the land was purchased in 1885 by James Stillman, the land was part of a long history of human-animal-land interactions. During the Precambrian Era, long before the evolution of humans and deer, what is now known as the Hudson Highlands was uplifted after a series of tectonic collisions, which, combined with periods of glaciation, created an environment with steep-sided valleys and thin, rocky soil that supports the oak-dominated forests that exist today (Maher 1996).

Sediment cores from Sutherland Pond in Black Rock Forest show evidence of the gradual shifts in the Black Rock Forest ecosystem since glacial retreat around 12,500 years ago. Warming conditions aided the progression from tundra to boreal forest to temperate deciduous forest, and because of the presence of charcoal within the last 10,000 years of the record, it can be inferred that oak dominance and eastern hemlock recession was assisted by frequent fires (Maenza-Gmelch 1997).

As European settlers moved into the New York area in the 17th and 18th centuries, they cleared patches of forest for building homes and farms and for harvesting lumber, a high-demand export. Such land clearance caused an increase in ragweed, grass and composites, and resulted in a decrease of pollen deposits of oak, pine, and hemlock (Maenza-Gmelch 1997). This deforestation also created space and sunlight necessary for the growth of herbaceous plants, a deer's preferred food source. These same settlers also killed the deer's main predators, including the panther, wolf, and coyote, which reduced predation pressure and allowed for the growth of deer populations. The Hudson Highlands area, however, was too mountainous and had too poor soil to attract large numbers of farmers, instead favoring subsistence settlers and later ushering in the forestry and dairy industries; at peak land usage, only 7.5% of the forest was being

extensively cultivated, though it is estimated that around half of the current Black Rock Forest was cleared at some point for use as lumber (Maher 1996).

In 1928, Richard Thornton Fisher, then the director of the Harvard Forest and proponent of forest management and forestry method research, visited Black Rock Forest. Over 20 years later, the forest was officially turned over to Harvard University, although the University put the Forest up for sale forty years later, when it was assumed by a consortium of New York-based universities and organizations, which formed the Black Rock Forest Consortium, an organization that focuses on education and research (Maher 1996).

Since its inception, there have been over 700 publications featuring Black Rock Forest, many of which delve into the topic of deer populations and ecological changes (BRF website). The Black Rock Fish and Game Club was founded in 1923 and provides members with the exclusive rights for hunting in the forest, which has served as a primary means of deer population control (Brady 1994).

Related Studies

There have been a handful of studies conducted at Black Rock Forest that have looked at the trends in deer populations and changes in forest composition. A study in Black Rock Forest examining the differences between basal area in fenced exclosures and exclosures with removed fences and unenclosed areas over a five year period found that above breast height saplings were only found within fenced exclosures and that in a previously clear-cut area, there was no regrowth that resulted in tree regeneration. The basal area remained 0 because of the lack of trees with a DBH greater than 2.54 cm, suggesting that deer browsing remained a significant inhibitor to forest regeneration (Roth & Law, 2004). However, this study was conducted in the years

proceeding 2004, when the deer densities were well above their current levels, at more than 20 deer per square mile.

In a 2008 study, Schuster found that over the time of the study, 11 new species entered the forest, the mean tree density decreased and the aboveground biomass increased at a rate of 1.3 Mg/ha/yr. The changes in species richness came from non-native species and were also consistent with changing ranges due to climate change (Schuster 2008). The analysis did not include ties between changes in deer populations and the changes in biomass and species composition and richness. Additionally, Diefenbach's 2010 thesis on hunting and natural influences on deer populations at BRF found a significant negative correlation between snow depth and deer populations but did not analyze tree data beyond acorn masts. In 2019, another thesis looked at coyote scat composition and found that whitetail deer make up a significant part of the studied coyotes' diets, possibly supporting the importance of coyotes in deer population management, though not establishing a definite link (Vaughan, 2019).

Another study published in 2019 used data from Black Rock Forest in conjunction with data from Harriman and Bear Mountain State Parks, Sterling Forest and West Point Military Reservation to determine the effects of active deer population management on forest composition (Kilheffer et al, 2019). The study found that in areas, like Black Rock Forest, where deer populations were actively managed, there was a significant and positive impact on the recovery of a forest formerly degraded by chronic herbivory. More tree seedlings and understory vegetation and fewer species generally not eaten by deer were found in the case sites, supporting the positive impact (Kilheffer et al, 2019).

However, although the aforementioned research is relevant to my own project, none of the studies look explicitly at decreasing deer populations within Black Rock Forest and the ensuing ecological changes that may be accompanying this decrease.

Thesis statement

The aim of this project is to assess the ecological trends of deer and vegetation in Black Rock Forest in order to determine whether there is ecological evidence that parallels the decrease of deer populations in Black Rock Forest. I will examine connections between vegetation (i.e., tree abundance, species composition, and new tree growth) and deer populations and density. I will also be comparing the understory vegetation diversity and cover of deer-browsed and non-deer-browsed forest stands. Finally, I will be incorporating into my discussion information acquired during interviews from those who have spent decades in the forest and have observed changes in the forest, some of which have been due to changes in deer populations.

Approach and Methods

The data being used in this thesis project have largely already been collected by staff and students at Black Rock Forest. It falls into two general categories, vegetation data and deer data. Additionally, I will be conducting interviews, namely with the staff of Black Rock Forest, to assess human perception of changes in the forest ecology over time.

Deer Data

The deer data are useful for determining trends in the deer population at Black Rock Forest and come from a variety of sources. The first is the hunting record. Hunters in Black Rock Forest have been required since 1970 to record sex and number of deer killed and since 1984 to

record weight, sex, age, antler beam diameter, or and zone in which the deer was taken. In order to determine age of the deer, the teeth are examined, and based on wear and presence of certain teeth, the age of the deer can be accurately estimated (Figure 4, Ramsey *et al.* 1993). The staff of Black Rock Forest collect and compile these data each year into a deer harvest report. The figures can also be used to reconstruct population size, when deer of each age class are tallied.

Overwintering deer density is calculated separately from the hunting data. Within 12 to 24 hours after periods of snowfall between December and April, a vehicle is driven over roads within Black Rock Forest?, and number of deer tracks and visible deer are counted. Deer generally sit out periods of snowfall in a specific location and will leave that location after the snowfall has ended, usually crossing an area only once. Data collected during this census include direction of travel, number of deer per group, and number of deer per mile. These are used to estimate the density of deer in the forest, or number of deer per square mile (Diefenbach 2011). Spring deer pellet count has also been monitored since 2014, but those data will not be used in this study.

Forest Data

Forest data in Black Rock Forest have been collected since 1930, with the inception of the long-term plots between 1931 and 1936. Of 16 original plots, now only eight remain (Schuster 2008). Four of the eight plots have been thinned, and the others have not. Before 1994, diameter at breast height (dbh), of trees in each of the plots was measured at 1.37 meters above the ground and recorded, and for those with a dbh greater than 2.54 cm, a crown class, or vertical position within the stand, was also recorded. Tree species and year of ingrowth were also

recorded. I will likely be examined these data in conjunction with the deer data and population reconstruction since 1970 in order to identify any trends.

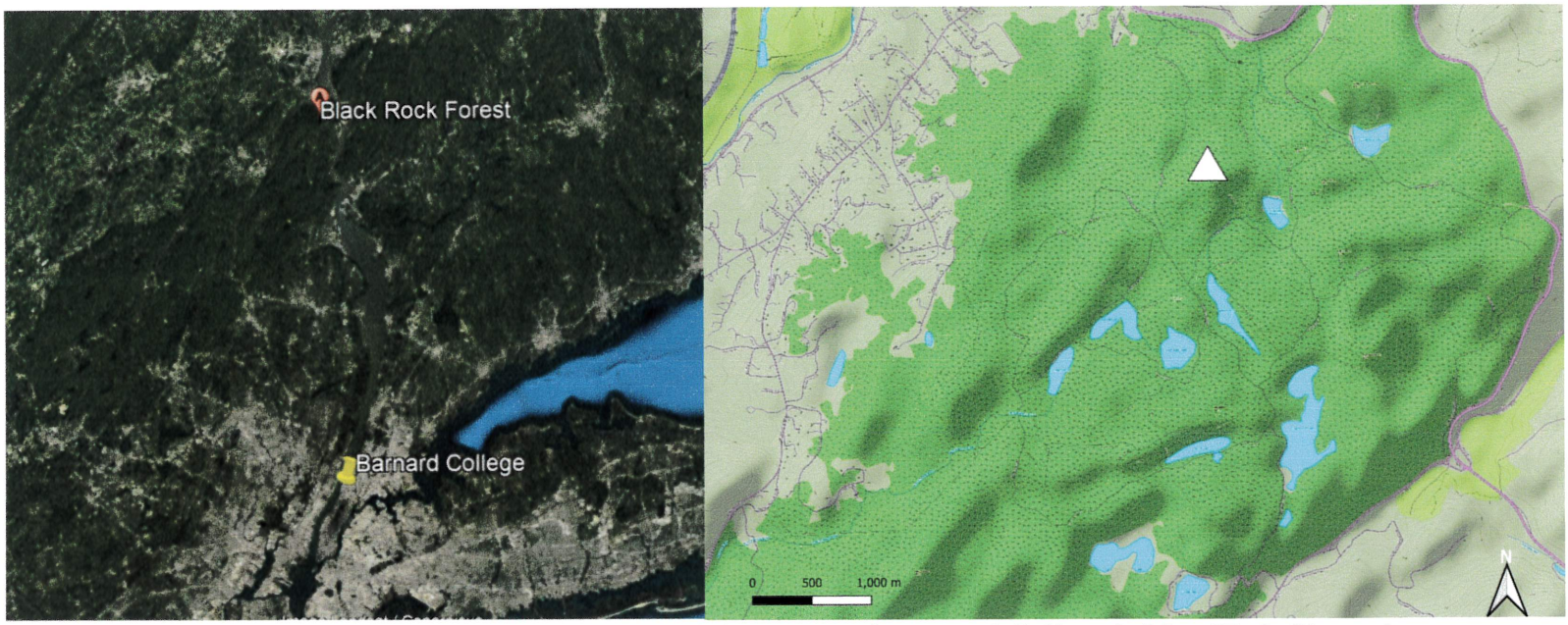


Figure 3. Black Rock Forest location and site map. Left: Barnard College in New York City and Black Rock Forest. Right: Terrain map of Black Rock Forest. Location of Future of the Oak Forest plots indicated by white triangle.

I will also be using the "Future of the Oak Forests" data set, which, though it has only been maintained since 2009, contains an enormous variety of data. It consists of 12 different plots, each 75 meters by 75 meters, four on the bottom of the north slope of Black Rock Mountain, four on the middle, and four higher up. In each set of four, one plot is the control plot, and three received treatments initially (Figure 3). These treatments are centered around girdling, the cutting of a strip of bark horizontally around the tree, to mimic diseases like sudden oak death and oak wilt, both of which kill trees rapidly. One plot in each set has girdled oaks, one has girdled non-oaks, and the final has half of the oaks girdled. This dataset includes information about trees, much like that in the long-term plot dataset, with dbh, species, and year of ingrowth. It also contains information about understory vegetation, small mammals, and deer exclosures.

Each of the 10 deer exclosures is one meter squared, and all vegetation species have been recorded and monitored during the period of study. For the seedling data, plants less than 1.3 m tall were recorded in early to mid-August every year.

Aside from the plot data, there is also acorn crop data. These data are collected annually in September, when the acorns drop from the trees along transect lines with 15 sampling sites. Acorn species, number, and percent viability are recorded each of the 10 times a 34-inch hoop is thrown. Acorn crop, or mast, is tied both to deer populations, in that it serves as an important food source, and to regeneration of oak trees (Figure 4).



Figure 4. Deer age determination technique. A hunter at Black Rock Forest examines the inside of a taken deer's mouth to determine its age. Photo courtesy of Dr. Peter Bower's 2007 Field Methods class.

Anecdotal Data

To supplement the quantitative data, I will also be interviewing the staff at Black Rock Forest, some of whom have been working there for over four decades, to determine whether

there have been any noticeable changes at the forest in the time during which they have worked there. For the two interviews already conducted, I used the semi-structured interview format. Semi-structured interviews follow a list of flexible guiding questions that are open-ended enough to permit digression from the interviewee. Because of the lack of concrete questions, subjects are able to take the interview in a desired direction, making the format useful when interviewing a pool of people with different areas of expertise (Magaldi & Berler 2020). The following questions were used as guidelines for the type of information I wanted to receive, but they were not used exactly, and not in the order shown below:

1. **What is your role at the forest? How long have you been working there for? What different jobs have you held/performed?**
2. **What were deer populations like when you first started working at the forest? Did you see evidence of these population levels in the forest?**
3. **Deer populations have clearly been diminishing; what evidence is there to show for this? What ecological trends have you observed that parallel the decrease in deer populations?**
4. **What do you think are the main influences on deer population levels? Have these influences changed over time?**
5. **What has oak regeneration been like since you started working at the forest? Have there been any recent changes in regeneration?**
6. **How many deer exclosures are there at Black Rock Forest? What do they show about recent trends in decreased deer browsing?**
7. **Are there any factors other than deer browsing that significantly impact forest composition at Black Rock?**
8. **Have there been any changes in management strategies or attitudes at the forest since you started working there? Have these changes been propelled by or have led to decreases in deer populations?**

The interviews were conducted on Zoom and were recorded, allowing for future playback. The information collected from the interviews will be incorporated into the introduction and discussion sections of my thesis.

Data Analysis

I plan on continuing to use R and Excel to perform regression analyses on plot and deer data. So far, I have organized the understory sapling data based on plot and year, tracking the number of saplings counted for each year in the three control plots and three oak-girdled plots. A preliminary poisson regression analysis was preformed on the control plot data in R and it was determined that there was a statistically significant ($r<0.01$) difference between number of saplings in exclosure and non-exclosure plots. Further analysis will be performed, possibly to look at relationships between sapling count and number of trees in exclosures and non-exclosures, differences in species diversity, differences in control and oak-girdled plots, and changes over time. These results may also be compared with those from previous findings from earlier exclosure plots at the Forest.

Additionally, I will be compiling the deer population data with deer taken from each age class in each year to create a population reconstruction from 1970 to present. This will assist in further establishing the decrease of deer populations in the forest.

Preliminary Results and Discussion

Although not much data analysis has yet been performed, a decrease in hunting take since 1970 is evident (Figure 5). The present population count methods were not implemented until the 1970s, but there were an estimated 40 deer per square mile in the 1960s (Brady 1994). Maturing oak trees and clearings from silvicultural activity provided ample browse and an abundant acorn crop to sustain populations during these years. The density decreased to approximately 30 deer per square mile by the 1980s and have now settled to a much lower 12 deer per square mile. The

aforementioned population construction will be useful for obtaining a more complete view of the populations in flux.

Additionally, the entry of new trees into forest plots, especially since 2016 can be observed in the data. These new trees mostly occur in plots closer to the bottom of the slope in the Future of the Oak Forest data, where the soil has a higher moisture content and there is generally more exposure to sunlight. Especially after reaching maturity, oaks are largely shade-intolerant, and they grow slowly compared to other trees, like black birches (Johnson & Shifley 2003). Birch trees are shade-intolerant, meaning that they do best in sunny or partly shaded environments. Because of the speed at which they grow when young, birches are often called pioneer species, growing at the earlier stages of succession and becoming less abundant with the dominance of later successional species (North Carolina State University n.d.).

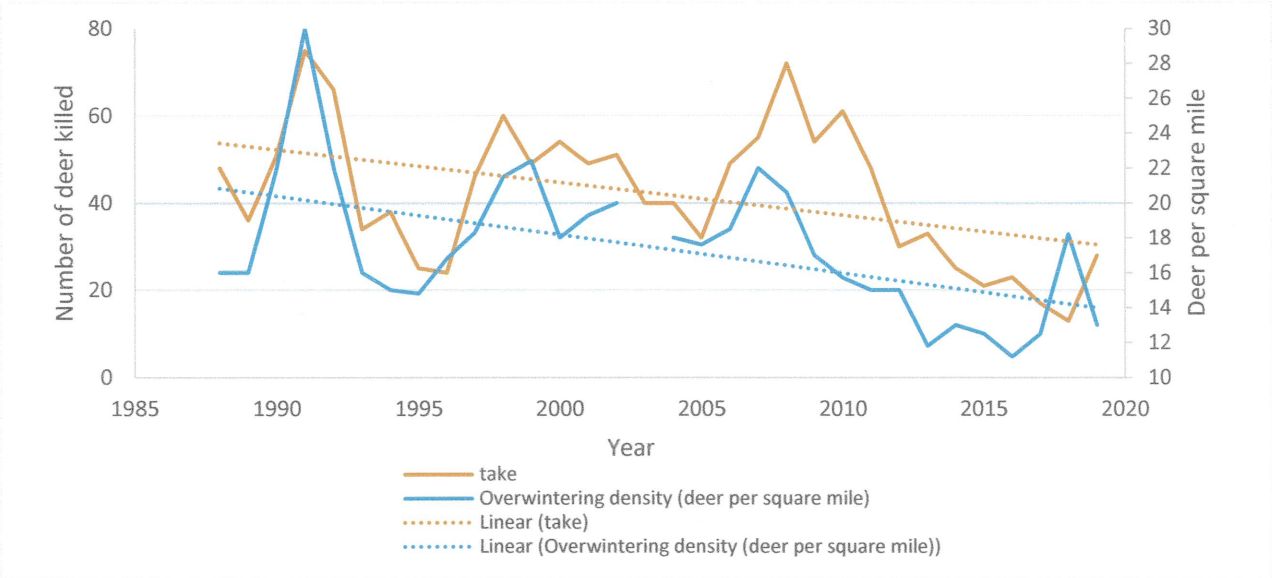


Figure 5. Trends in deer take and population density at Black Rock Forest between 1988 and 2019. Data since 1988 were plotted and linear trendlines were added to display trends in the data. The orange line represents the number of deer hunted and the blue represents the overwintering deer density in number of deer per square mile.

Further analysis will be required, but the statistical significance of the seedling numbers of the deer exclosures and non-enclosed areas suggests that although deer densities have

decreased, deer densities are still high enough to inhibit sapling growth at the same levels of areas not browsed by deer. Nevertheless, though there might be significant differences between and among the plots, it will be difficult to classify these differences as having positive or negative effects on the forest as a whole, since deer also play an ecologically important role in the forest.

My discussion will also include possible explanations for the decrease in deer density. According to William Schuster, executive director of the forest, and John Brady, forest manager and historian, although hunting of does has played a significant role in the deer population decline, an increase in natural predator—most notably coyote—populations and availability of food resources during harsh winters are thought to have been responsible for the negative trend. In the 1980s and '90s, there was a pronounced browse line from deer browsing and very little regrowth of oak trees. Now, there is much less of a visible impact of deer browsing, hunting take has decreased, and growth of young trees, including oaks, from saplings has been observed.

Work Plan

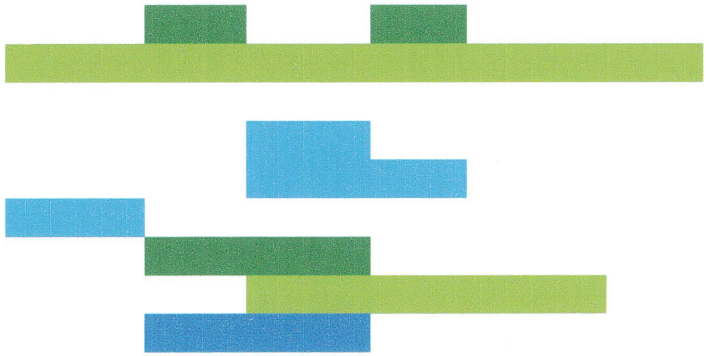
For the rest of this semester and the first part of next semester, I plan on continuing to meet virtually with the staff at Black Rock Forest, both to proceed with data analysis and to conduct interviews to examine the anecdotal changes in forest composition over time. Two of these interviews were conducted on December 11th, and the rest will occur during the months of December and January. Additionally, I will be going to the Empirical Reasoning Center office hours to help with my data analysis, and I will also be continuing review of the literature. I will be meeting on a regular basis both with my thesis mentor and my advisor. Next semester, I will also be fleshing out the thesis proposal into what will eventually become my thesis draft and

final product and working on a poster for the final presentation of the thesis. Of course, I will also be continuing with data analysis and compilation, which will be the bulk of my results, and I will also continue meeting with my mentor and advisor over the duration of the semester. Specific timeframes are shown on the Gantt chart.

Because the data have largely already been collected, my main challenges will lie in the organization of the data and the data analysis. I envision having difficulties finding concrete evidence in the data of the decreasing deer populations, especially because there may be a lag between population decrease and the response of the forest.

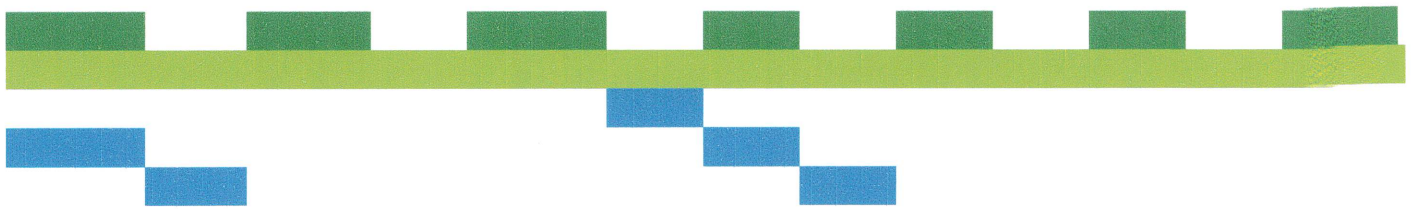
Senior Thesis Time Table, Fall 2020

Class meetings	11/17	11/24	12/1	12/8	12/15
Milestones	1st draft of thesis proposal		Peer review. Poster draft		final thesis proposal
Task/subtask					
1.1 Meeting with mentor					
1.2 Meeting with advisor					
2.0 Data Analysis					
2.1 Center for Empirical Reasoning					
2.2 Preliminary Analyses on R and Excel					
2.3 Meet with Katie to discuss analysis					
3.0 Interviews					
4.0 Thesis Proposal editing					
5.0 Additional Literature Review					

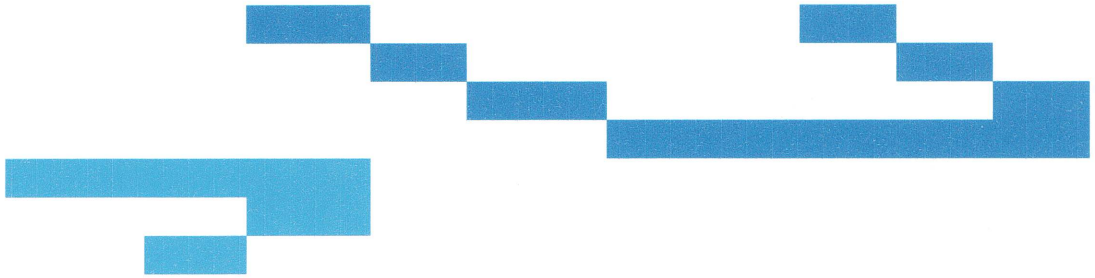


Senior Thesis Time Table, Spring 2021 (draft)

Class meetings projected)	1/11	1/18	1/25	2/1	2/8	2/15 1st draft	2/22	3/1	3/8	3/15 Mini conf	3/22 2nd draft	3/29	4/5 Peer review
Milestones													
Task/subtask													
1.1 Meeting with mentor													
1.2 Meeting with advisor													
2.0 Expansion of Thesis Proposal--> Draft													
2.1 Introduction													
2.2 Methods													



2.3 Results
2.4 Discussion
2.5 Other sections
2.6 Editing of draft and poster creation
3.0 Continued Data Analysis
3.1 Help from the ERC, if necessary
3.2 Meet with Katie from BRF



Research Implications

Although prior studies have been conducted to evaluate the flux of and impact of deer populations in Black Rock Forest and in other regions, no studies have provided a comprehensive summary of the of deer population dynamics, as well as forest ecology implications of the population changes in Black Rock Forest. If the analyses produce conclusive results, a connection between reduction in deer populations and forest regeneration could be established. If such connections are established, management techniques used in Black Rock Forest could be applied to other natural and potentially residential areas struggling with elevated deer population levels. If no conclusive results are produced, the findings would not preclude a relationship between deer and vegetation in the forest, and the project could serve as a precedent for future explorations and serve as a guide for further data collection and research.

Furthermore, although the scope of this research is somewhat narrow, it has broad implications, especially in forest management, since keeping deer populations at sustainable levels is necessary for a thriving forest ecosystem. The study also has applications in the realm of climate change. Carbon sequestration, augmented in trees of healthy, old-growth forests, has the ability to slow climate change through the removal and storage of atmospheric carbon from anthropogenic emissions. Since deer browsing has the potential to impact forest vegetation composition, it may also impact the ability of forests to optimally store carbon (Luyssaert et al. 2008). Understanding how to optimally manage deer populations for maintaining a healthy forest is thus instrumental not only in supporting the health of the herd and its habitat but also in preserving the countless ecosystem services the habitat provides.

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