The Influence of Natural Events and Hunting on a Small White-tail Deer (*Odocoileus virginianus*) Population at Black Rock Forest, New York State

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4 May 2010

Abstract

In the northeast United States, white-tail deer populations have risen from near extinction to levels that may be too high for the environment to sustain. This study aims to determine quantitatively if hunting or natural events influence deer density and what annual factor most influences densities to use it to predict and manage deer populations in the future. This study focuses on a small white-tail deer population at Black Rock Forest in New York State, on which hunting has been used as a population management technique since 1970. The relative abundance of this population fluctuates annually, which may be in response to an intrinsic factor such as hunting harvest or extrinsic factors such as natural events related to winter severity, precipitation, and acorn availability. It was hypothesized that the total amount of female deer killed during the hunting season and the number of days the snow depth was greater than twelve inches would have a strong negative correlation with the following year's deer density. SPSS was used to perform the data analysis for this study, primarily stepwise regression analysis at various time lags. Results indicate that hunting and natural events both influence deer density. The combined influence of acorn abundance and snow depth may be used to estimate the size of the current overwintering deer density whereas particular hunting data and snow depth may be used to estimate predicted densities for the following year and in two years. These findings suggest that a continuation of regulated hunting and monitoring of snow depth and acorn

abundance are necessary in order to predict and manage deer density particularly at Black Rock Forest and possibly at other locations in need of deer management.

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Introduction

Study Overview

White-tail deer population management is important principally because of the species' popular involvement in sport hunting and the damage they cause to the ecosystem (Figure 1). White-tail deer is the most popular game animal in North America, annually producing an approximate economic value of $14 billion (Guynn *et al.,* 2006). In contrast, this species generates an estimated $1 billion in damage by deer-vehicle accidents in the United States per year (Guynn *et al.,* 2006). In addition to inflicting human injuries via car collisions, high deer densities in areas have been shown to alter the composition of the environment by diminishing or eliminating the diversity of the canopy, understory, and shrub layers (Latham *et al.,* 2005). This risks the survival of smaller animal species which are exposed to predators and weather-related threats due to the reduced canopy and competing for limited food in response to the altered vegetation. In addition, the continued suppression of particular tree and shrub regeneration over time can be detrimental to the forest industry on which many northern local economies rely (Doig, 1967). However, deer also are influenced by environmental factors, relying on food resources and weather conditions for survival. Amount and distribution of potential deer habitat is not stable and should be monitored to assess the highest density possible that the environment can support without detrimental effects (Roseberry and Woolf, 1998).

The archived data at Black Rock Forest, a preserve and field station promoting scientific research, are unique because they contain information about the weather, flora, and fauna that have been collected extensively. However, no previous studies at Black Rock Forest have been performed that quantitatively analyze the deer population data. This is the first in-depth analysis seeking to determine if hunting influences the Black Rock Forest deer population density and what, if any, extrinsic or intrinsic factors may influence the population as well. The results of this study will provide insight as to the necessary changes, if any, that should be made in order to manage the deer population more effectively at Black Rock Forest.

Figure 1: White-tail Doe and Fawn

This picture was taken from the National Geographic website < http://animals.nationalgeographic.com/animals/mammals/white-tailed-deer.html>.

White-tail Deer

History

White-tail deer (*Odocoileus virginianus)* are native to North and South America. There are approximately seventeen subspecies of white-tails in North America (Rue, 1989). The subspecies of white-tail in New York State is *Odocoileus virginianus borealis*, or the northern woodland white-tail (Kozower, 1992). In the past, as a result of unregulated hunting and exploitation of the species for skin, white-tail deer populations reached minimum levels by the beginning of the nineteenth century (Halls, 1984). With extensive farming in New York State, populations continued to decrease during the 1800s and by 1880, deer were not observed in the Catskill region west of the Hudson River. This was the same year that farming peaked in New York State with about seventy-five percent of the total land area being farm acreage (Kozower, 1992). Conservation efforts, such as the regulation of hunting, were enforced in several states with the hopes of returning white-tail deer populations to healthy levels (Predl *et al.*, 2009). Populations increased gradually in the Catskill region between 1910 and 1950 (Kozower, 1992). Deer in other regions also responded quickly to these conservation efforts and in the northeast United States particularly, where white-tails do not encounter interspecific competition and their predators have been greatly reduced in number, the deer populations continued to rise unchecked (Halls, 1984; Kozower, 1992; Alverson, 1997).

Biology

White-tail deer are a K-selected species that are generally large, mature slowly, have low reproductive rates, and live a relatively long life (Odum and Barrett, 2005). Male deer have a shorter life expectancy than female deer, and few individuals live to be older than 11 or 12 years of age in the wild (Griffen, 1991; Latham *et al.*, 2005). In the northeastern United States, females are capable of pregnancy as early as six or seven months of age; an age that varies across the United States depending on the environment and the nutrients available (Porter and Underwood, 2001). Reproductive maturity influences the number of young a female produces at birth (Griffen, 1991). Age can influence breeding rates as well. A female can be bred by a male as young as a fawn, as long as he is sexually mature (Halls, 1984). Typically, a female will have twins or, if well-nourished, may give birth to mostly male triplets (Halls, 1984). If this continues without hunting or natural predation, populations can double in size in one year (Predl *et al.*, 2009).

Deer have four-chambered stomachs with each chamber containing rumen bacteria that vary in morphology and quantity in response to the nutritive value and amount of digested food (Pearson, 1965; Griffen, 1991). A study by Allen *et al.* (1986) found that interspecific differences in ruminant digestive systems can determine the adaptability to grazing conditions. Barboza and Bowyer (2000) affirmed that the physiology of deer rumen and of deer digestive systems adjust according to diet. This is an important aspect of deer biology because if individuals are able to adapt to various grazing conditions, then they may be able to survive and maybe even thrive as forests and other food sources change over time. Ever-increasing white-tail deer populations can be one factor that causes these future forest and food changes.

Behavior

During the day, deer remain in wooded or protected areas. Deer are most active at night, however, and start to forage in open-fielded areas at dusk (Griffen, 1991). Not sleeping more than two hours at a time, deer predominately spend their time in the search for and consumption of food sources. Home ranges, areas defined by seasonal movements of deer, are larger for males than females (Kozower, 1992). During the spring and summer months, males have a separate home range than the females given that the females stay with newborn fawns after giving birth. Female deer are philopatric, or inclined to remain in the same place of their birth, with only five percent of females in the northeastern portion of North America that disperse from the location of their birth (Porter and Underwood, 2001). Roseberry and Woolf (1998) found no evidence that habitat fragmentation or human presence adversely affects habitat use at the county level.

Poor vision, primarily in greys and blacks, makes deer dependent on the senses of smell and hearing and the use vocalizations for communication (Griffen, 1991; Kozower, 1992). Bucks are more social than does and generally are in groups of two or three surrounding themselves around other males, except for the breeding season. In early autumn, the rutting season or breeding season starts (Griffen, 1991). During this time, there is more social interaction between males and females and less than average between males (Kozower, 1992). Contact between males during this season is limited to sparring contests with each other for dominant status and for female mates (Griffen, 1991). This is a time of high hormones and antler growth that makes the bucks' behavior erratic (Halls, 1984). While the bucks are mid-rut, the does are focusing their energy on finding acorns to create a fat reserve for surviving the winter.

Diet

White-tail deer are herbivores. Eating habits, or browsing, include eating vegetation close to the ground and tree saplings that are tender and green (Griffen, 1991). Deer are an edge-species that prefer to browse along the edges of forests or woods that are next to open fields and meadows (Halls, 1984; Griffen, 1991; Predl *et al.*, 2009). It is observed that deer prefer certain food sources during different seasons (Pearson, 1965). Yellow Birch and Red Oak are preferred in the spring season, while Striped Maple and Red Maple are favored in the winter season (Bramble, 1951). In addition, acorns provide an important fat resource for deer before the winter months (McShea, 1993). Hay-scented fern, New York fern, and American Beech are vegetation or tree species that deer do not prefer to eat or that have proven to be resilient when subject to continuous deer browsing (Latham *et al.*, 2005).

Population Dynamics

Population Growth and Carrying Capacity

The three main types of carrying capacities are ecological, nutritional, and cultural (Latham *et al.*, 2005). The ecological carrying capacity focuses on the maximum number of deer that the environment can sustain. The nutritional carrying capacity or sustained yield theory focuses on identifying the sustained yield; the maximum amount of deer available to harvest with the population maintaining constant abundance (Roseberry and Woolf, 1991; Porter and Underwood, 2001). This theory progressively is being accepted and used in game management

(Roseberry and Woolf, 1991). Lastly, the cultural carrying capacity identifies the maximum amount of deer that can be hunted, considering the concerns of the surrounding community (Latham *et al.*, 2005). Regardless of which definition of carrying capacity is used, the idea behind the deer population growth remains fairly similar, as described next with information from Odum and Barrett (2005).

Theoretically, deer populations should undergo logistic population growth, with a fast population growth rate when the population is small, a slower population growth rate over time, and finally a limit to the population growth rate when it finally reaches a constant population level, the carrying capacity. The population grows at a fast rate when there are not many individuals because there is an abundance of resources per individual. At this point, the population can continue to grow at a fast rate because the deer are obtaining unlimited preferred food resources and are healthy, which are key elements for productive reproduction. However, as the number of individuals in the population continues to grow, the amount of resources per individual decreases. When the population density reaches a certain size, the amount of resources should be evenly distributed among the individuals in the population. It would be difficult for the population density to continue past this point and continue to grow because some deer will not get any resources and will not be able to reproduce or even survive. Theoretically the population density should maintain at a level that is constant with the amount of deaths equaling the recruitment or new deer introduced into the population.

Two important aspects of a population are natality and mortality; the ability of the current population to increase by reproduction or decrease by death, respectively. Maximum natality refers to the maximum amount of individuals produced under ideal conditions. Since the only limits to the maximum natality are the physiological factors influencing reproductive rates, it is a constant for a population. On the other hand, in wild populations, ecological natality exists commonly, which incorporates environmental factors limiting population growth. Ecological natality and mortality are not constant for a population and vary with habitat conditions and population attributes (Odum and Barrett, 2005).

Influences on Population Growth

Extrinsic Factors

Extrinsic factors influence population growth but are independent of population interactions (Odum and Barrett, 2005). Some suggest that improved forage conditions by increased rainfall can stimulate an early onset of estrus in female deer (Kie and White, 1985). Another natural event that can be considered an extrinsic factor influencing population growth is the food supply, which can affect size and growth rate of deer (Doig, 1967). Nutrition also is thought to influence the number of young a female produces each birth (Griffen, 1991; Porter and Underwood, 2001). If nutrition is improved, especially in autumn, it can significantly increase reproductive productivity and decrease chances of nonfertilization and embryonic mortality. If females are poorly-nourished, they are likely to resorb embryos and use the additional nutrients for themselves (Kie and White, 1985). Lastly, winter conditions can influence deer populations. There exists an inverse relationship between snow depth and deer density in which a severe winter with extended days of deep snow results in a dramatic drop in deer numbers (Severinghaus, 1972). Snow depth typically is regarded as the most important factor causing deer to move to shelter, but because cold weather can necessitate shelter as well as snow fall, winter temperature is considered an extrinsic factor influencing population growth (Gysel and Ozoga, 1972).

Another important factor extrinsically influencing population growth is the means by which the hunting harvest is controlled. Managers can regulate either the number of deer removed, the amount of effort in removing individuals, or the proportion of the population harvested (Roseberry and Woolf, 1991). The regulation of the removal of individuals is a precarious strategy in that it can have unforeseen consequences to the population such as the possible result of a severe population decline. The third method of regulation is preferred but in order to control the proportion of the population harvested to maintain an environmentally-sustainable population, extensive information must be known about the population. Such information necessary includes absolute population size and numerical harvest (Roseberry and Woolf, 1991). One specific example is the quality deer management approach to regulating hunting harvests by shooting more young males and an adequate supply of females during the hunting season. This approach seeks to enrich the amount of available nutrition, increase the number of older bucks, and decrease the number of females in the population (Moore, 1995).

Intrinsic Factors

Intrinsic factors that influence population growth are variables that are controlled by population dynamics. Unfavorable changes to food availability and nutrition levels can lead to poor body condition, reduced reproductive rates, and increased mortality. If these adverse changes continue, a population crash can result (Kie and White, 1985). The ratio of age classes, the age distribution, is an important aspect of populations that aids in the prediction of natality and mortality (Odum and Barrett, 2005). In general for fur-bearing mammals, a stable population is characterized by an even distribution of age classes, an expanding population by a large proportion of young individuals around their first year, and a declining population by a large proportion of older individuals (Odum and Barrett, 2005).

Summary of Annual Population Trends

Deer are present at Black Rock Forest every month of the year. The average population trend is an increase between late May and late July, and a gradual decrease between August and late May (Figure 2). Most doe are impregnated during the first rut and their fawns are born in late May and early June with May 20 as the average birth day (Brady, 1994). The population tends to be largest in June. With bucks focusing mostly on scratching the velvet off of their antlers and finding a mate, the number of car accidents involving bucks increases greatly in November (Brady, 1994). Hunting also reduces population size between October and December. Deer density continues to decline through winter, which is a time at which deer are at their

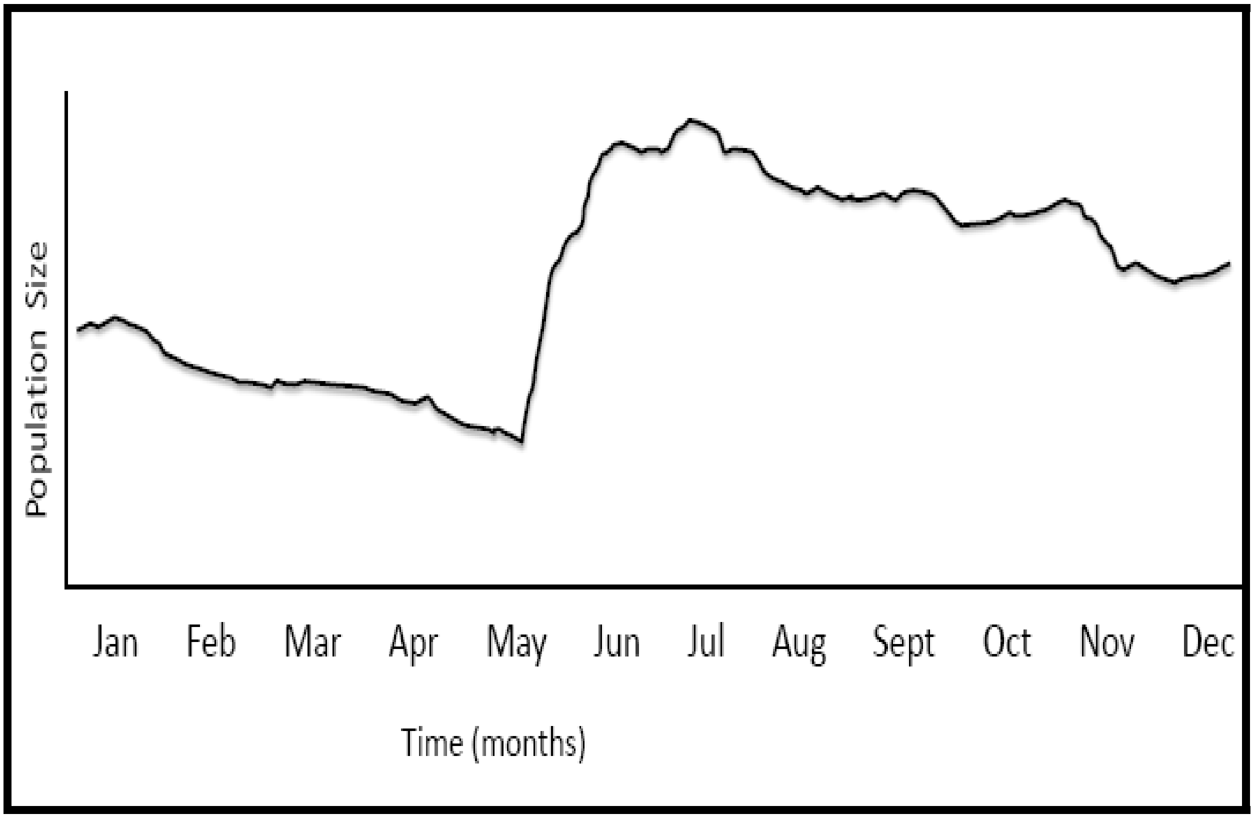

Figure 2: Theoretical Annual Population Trend

Theoretically, deer populations should follow a general trend annually. Above this theoretical population trend is graphed for January to December.

weakest and most susceptible to illness and predation (Griffen, 1991). Severe winters with deep snow cover disable deer from accessing fat reserves during the winter months, which increases the chances of starvation (Severinghaus, 1972). In addition, a large number die in the spring between April and mid-May because they are only strong enough to make it through the winter but do not have enough energy to forage for food after the snow melts. Over and above the melting snow, if the average precipitation increases at this time, the mud can be thick making it harder for individuals to travel and find food, further increasing the death rate. The population is at its lowest level right before fawn day on May 20th (Brady, 1994).

Need for Management

Deer Influence on Flora

In general, high deer densities result in diminished canopy diversity and understory tree and shrub layers (Latham *et al.,* 2005). Several studies affirm that deer diet and browsing prevent forest regeneration and alter certain vegetative characteristics (Eckert *et al.*, 1976). High densities of deer have affected many plant species such as Pennsylvania sedge and white-flowered trillium, resulting in altered forest composition (Anderson, 1994; Nagel *et al.,* 2009). For northern hardwood forests such as Black Rock Forest, high deer densities have been correlated with low numbers of tree saplings and low sapling species diversity (Nagel *et al.,* 2009). A study at Black Rock Forest found that, if deer browsing was removed, in this case by exclosures, the forest could regenerate (Ballantyne, 2000).

Long-term exclosures, or high-fenced areas, have been constructed at Black Rock Forest to observe changes in plant growth when deer browsing is eliminated (Figure 3). In some locations, the total biomass of herbaceous plants inside exclosures can be three times as great as the biomass outside exclosures (Latham *et al.,* 2005). A study performed in 2004 by Fowler and Russell used exclosures to show that deer browsing significantly decreases survival rates, height growth, and biomass of Texas Red Oak transplants. Furthermore, Eckert *et al.* (1976) demonstrated that deer consumption of acorns and browsing on planted seedlings, in addition to rodent and acorn insect predation, contributes to oak regeneration failure in Pennsylvania. It should be noted that deer browsing does not negatively influence flora all of the time. The regeneration of some plant species such as maples, dogwoods, and viburnums, actually is enhanced with browsing (Doig, 1967). When deer eat the terminal buds of the plant, the growth of lateral buds is stimulated. However, when deer overbrowse, eating the terminal and lateral buds, regrowth of plants is stunted. Also, an excessive amount of canopy trees can inhibit growth of understory. It is in this way that some deer browsing, resulting in regeneration failure and fewer canopy trees, can be beneficial to smaller tree and shrub layers. That being said, excessive browsing and high-densities can eliminate canopy layers, which also adversely affects smaller plant species.

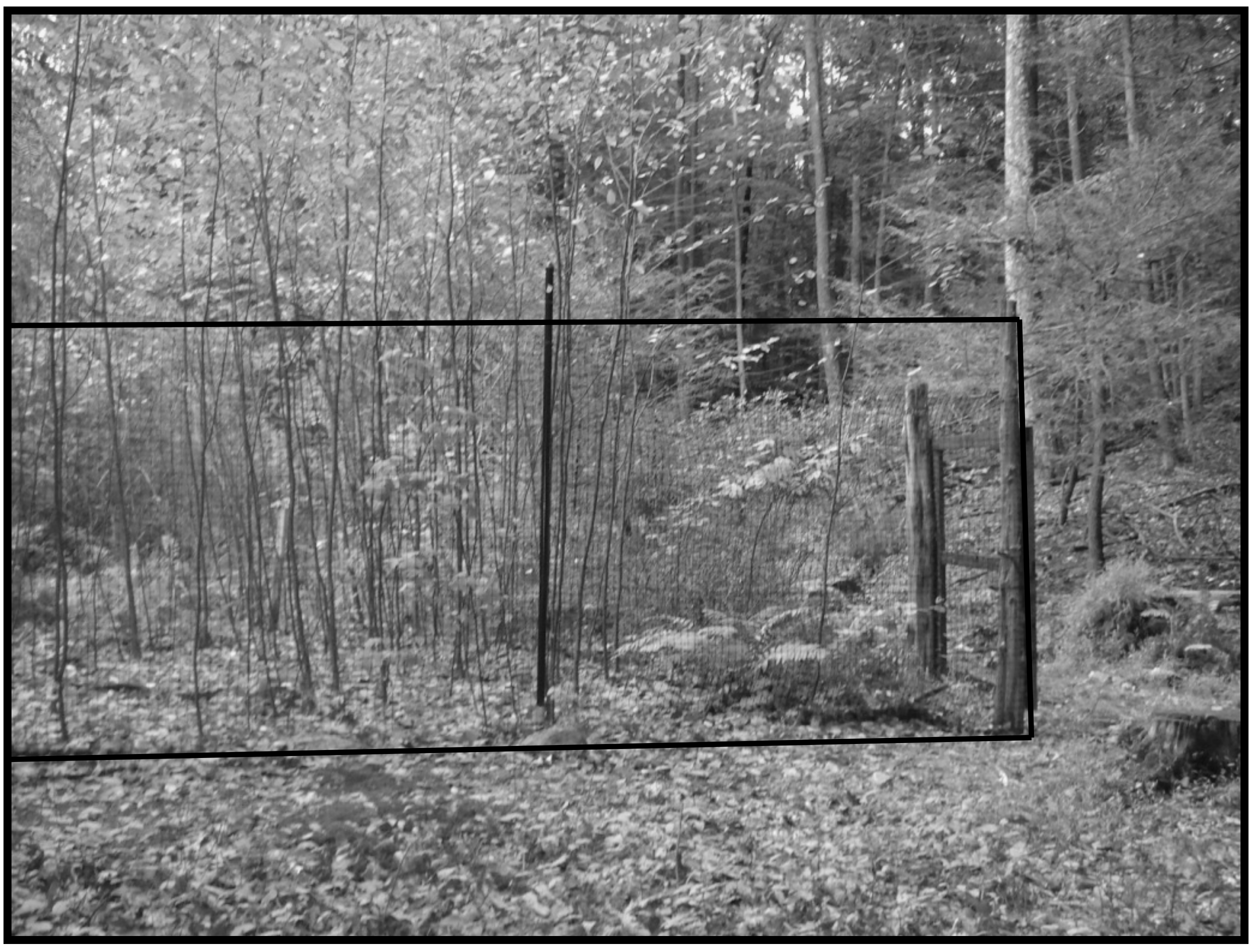

Figure 3: Long-Term Exclosure at Black Rock Forest

This exclosure, or high fence to prohibit deer from entering, is outlined in black. A difference can be seen between the amount of trees and understory growing inside the exclosure where deer are not allowed and outside of the exclosure where deer regularly browse, or eat.

Deer Influence on Fauna

As reviewed by Latham *et al.* (2005), changes in vegetation due to deer browsing can affect other animals in the forest. Browsing prevents saplings from turning first into seedlings and eventually into trees, reducing the forest canopy. This reduction in forest canopy allows for more light to reach the ground and stronger winds to enter the sub-canopy layers. These effects reduce the amount of humidity at the forest floor, affecting animals that live in moist environments. These animals then have to relocate to moist areas elsewhere in the forest, exposing them to predators. In addition, the acorn crop that deer rely on to survive winter months is also critical for the survival of other animals in the forest such as the wild turkey, blue jay, gray squirrel, and white-footed mice. An overabundance of deer in the forest can result in fewer acorns available for other species.

Deer Management Techniques

Despite the devastating effect deer diet can have on the environment, numerous people do not support management efforts (Diefenbach *et al.*, 1997). Deer management techniques can be divided into two categories; lethal and non-lethal. However, before management plans can be made, the absolute or relative size of the current population needs to be determined as well.

Assessing Population Abundance

Absolute Abundance

In nature, it is difficult to ascertain the absolute number of individuals in the population. One way of determining population abundance is by visual counts using aerial surveys (Kie and White, 1985). The actual number of individuals in a population can be recorded theoretically from this method but the amount of error in the population estimate varies. If the deer habitat has a dense canopy cover it can range from difficult to impossible for the aerial surveyors to see and account for individuals below the canopy layer. In addition, there is always the chance that one or two deer are not counted or counted more than once by the surveyor. Lastly, this method using helicopters or another flying device can be costly for areas in which regular population estimates are desired.

Relative Abundance

When the assessment of an absolute number of individuals is not feasible, an estimation of relative abundance can be made. These indices, although quantitative, are not an exact number of deer in the forest but are thought to reflect the changes in the population that is in the forest over time (Moore, 1995; Latham *et al.*, 2005). A direct assessment of an index of abundance can be a survey over a known distance and the number of individuals seen per distance measurement recorded (Kilpatrick and Walter, 1999). This method can also be an indirect method of obtaining relative population abundance if the individual is not seen but the number of individuals can be estimated through visible tracks or pellet counts. However, these pellet group counts lead to a conservative population estimate and are not thought to correlate to the true population size (Moore, 1995). Another direct method of obtaining a population index is by the use of infrared cameras to monitor the number of individuals that pass a certain site in a given amount of time. Also, population reconstruction can be used to estimate deer density (Doig, 1967; Roseberry and Woolf, 1998). This consists of using ages from harvest data, or information from individuals killed particularly during sport hunting, in order to recreate the size of the population at the time those individuals were born. Some of these methods of assessing relative abundance, as well as other indices of hunter success rate and buck take, are discussed further in the methods of this study.

Non-Lethal Methods

No Interference

The approach of allowing nature to take its course is supported by several people. However, human activities have caused changes in primarily in landscapes, predator populations, and native flora, all of which influence deer populations (Predl *et al.*, 2009). Prior to the nineteenth century, naturally unregulated deer populations could remain healthy without destruction of the environment (Halls, 1984). Therefore, natural approach to management involving no human interference will not result in the healthy deer populations that once existed in the wild prior to these detrimental anthropogenic alterations (Predl *et al.*, 2009).

Fencing

Fences can be constructed in order to protect seedlings from deer browsing. A study by Marquis (1977) found that in terms of cost and effectiveness, the two most promising devices for this are a 4 to 6-inch diameter plastic tube and a 12-inch diameter tube made of chicken wire. The plastic tubes are more expensive but also provide defense against rodents, whereas the chicken wire tube does not. In addition, fences can be constructed around gardens or homes in order to keep deer away from the area (Figure 4). Two common materials used to build these fences are polypropylene mesh and electric fencing. One suggested method of fencing is to use polytape electrical fencing with smeared peanut butter on top, which aims to entice deer to smell the fence and after which the deer receive an electric shock and learn to avoid the fenced area (Predl *et al.,* 2009).

Figure 4: White-tail Male Jumping a Fence

The above picture was taken as a white-tail male jumped a barbed-wire fence. Deer can jump from standing over a 7-foot fence and over an 8-foot fence from running (Halls, 1984). This picture was taken from <http://www.thesportsglobe.com/Wildlife/Images/whitetail_deer_02.jpg>.

Supplemental Feeding

Supplemental feeding is used when deer are malnourished, even sometimes if the cause of poor health is due to over-abundance. For a population under those conditions, supplemental feeding will permit population growth but will not address the poor habitat due to overbrowsing of the over-abundant population or the health of the entire population. In addition, supplemental feeding in order to prevent winter mortality has not been effective and it is suggested that areas where supplemental feed is distribution may facilitate the spread of diseases (Predl *et al.*, 2009).

Contraceptives

A common non-lethal technique for managing deer population densities is through immunocontraception. Immunocontraception works through the deer's immune system and involves injecting the deer with a protein, commonly the Porcine Zona Pellucida (PZP) protein from eggs in pig ovaries (Porter and Underwood, 2001; Predl *et al.,* 2009). The introduction of this protein causes the deer's immune system to create antibodies that recognize and attack the protein. When the deer's ovary releases an egg, these antibodies will attack the egg and the deer does not become pregnant. Contraception delivered through a dart rifle is a viable option but would not work on many free-ranging populations (Porter and Underwood, 2001). The use of

PZP also extends the breeding season for females, which can increase deer activity later into the early winter months when energy conservation is important for survival (Predl *et al.,* 2009). Lastly, the use of PZP and other vaccines are classified by the Food and Drug Administration (FDA) as investigational drugs with concerns of human consumption and animal safety and the recreational use of them is not allowed (Porter and Underwood, 2001; Predl *et al.,* 2009).

Trap and Transfer

All of the information regarding the trap and transfer technique is obtained from Predl *et al.* (2009). This method of management is complex, expensive, and difficult to ensure the safety of deer and people by hiring trained personnel. Recorded costs of such management programs have ranged from $400 to $3200 per deer. The high death rate of trapped and transferred deer, during or shortly after the procedure, causes some debate about whether this method should be considered non-lethal or lethal. Cases in California, New Mexico, and Florida have reported mortalities of 85, 55, and 58 percent, respectively, up to 15 months after relocation. Lastly, the process of relocation facilitates disease transmission.

Lethal Methods

Reintroduction of Predators

This method of management focuses on the reintroduction of predators such as wolves and mountain lions that once were found in large numbers throughout much of the United States and eastern Canada but are not currently (Predl *et al.,* 2009). Other white-tail predators include bobcats, bears, and coyotes; all of which have not demonstrated the ability to control natural deer populations (Halls, 1984; Predl *et al.*, 2009). Various research studies indicate that there is no conclusive understanding as to the influence coyote presence has on deer populations (Kie and White, 1985; Predl *et al.,* 2009). Primary concerns with this management technique are human safety and predation of non-target species. Although the predator-prey interactions are variable, they have been shown to stabilize high-density populations.

Sharpshooters

Hiring snipers is costly and not effective if the deer population is large and not contained. Snipers could reduce the population level to an environmentally sustainable size but, in addition to being expensive, one large-scale reduction in the population is not a long-term management plan. The population would thrive after the event, allowing for more resources for each surviving deer, which would lead to increased reproduction rates in the following spring (Pedl *et al.*, 2009). Hiring snipers could control deer populations if it is used continuously from year to year as a management technique (Pedl *et al.*, 2009).

Regulated Hunting

Hunting, although a controversial topic, is a widely-used management technique that stabilizes deer populations (Pedl *et al.*,2009). In areas within towns or where there are ordinances prohibiting the use of firearms, bow hunting is a preferred management practice in place of hunting with firearms (Pedl *et al.*, 2009). Bow hunting has been shown to be effective in managing deer herds in urban environments (Kilpatrick and Walter, 1999). One-hundred years of research has proven that hunting is a ecologically sound, socially beneficial, and feasible method of deer population management (Pedl *et al.*, 2009).

Black Rock Forest

Black Rock Forest (BRF) is located in the northeast United States in the southeastern part of New York State (Figure 5). This 3,800 acre forest is a mere 50 miles upstate from New York City (Figure 6). BRF is located on the northwest side of the Hudson Highlands between the New York villages of Cornwall-on-Hudson and Highlands, Orange County (Figure 6). Rockland, Passaic, and Westchester counties as well as interstates I-84 and I-87 are nearby Black Rock Forest as well. There are over 25 miles of trails and roadways in the forest. The road outlining the forest, 9W, separates Black Rock Forest from West Point Military Academy (Figure 7). Black Rock Forest initially was acres of clear-cut land for the timber industry. In 1928, Dr. Ernest Stillman inherited the forest with the goal to restore it, and after consulting with his friend, Richard Thornton Fisher of Harvard University, established Black Rock Forest as a demonstration forest (Trow, 2004). The forest was given to Harvard University in 1949 and later purchased by William T. Golden’s Golden Family Foundation in 1989, which made it the not-for-profit Black

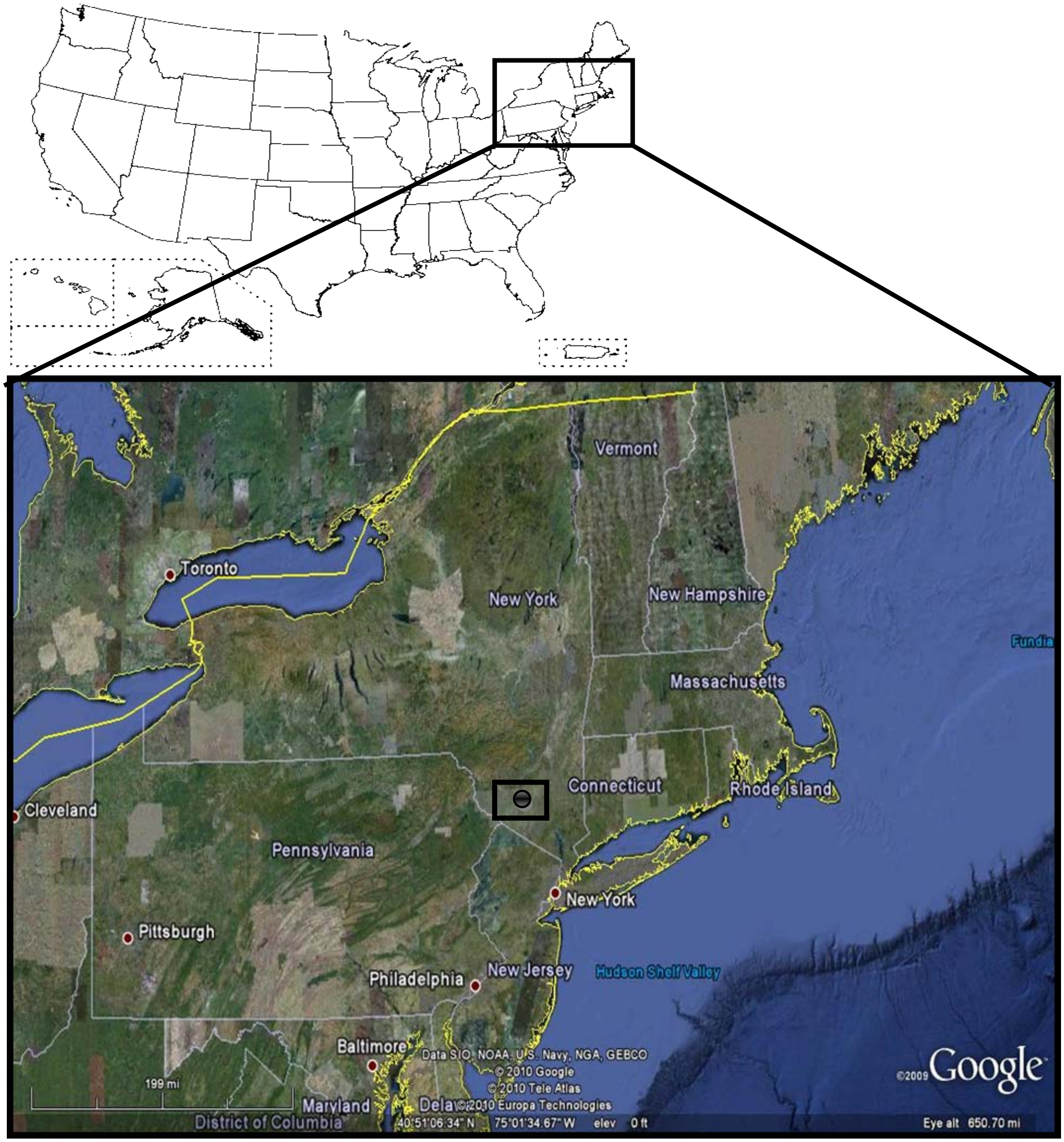

Figure 5: Location of Black Rock Forest within the United States

This figure shows the general location of the study site, Black Rock Forest, in the northeast United States. The exact location of BRF, in the southern tip of New York State, is marked by a dot enclosed within a square. The picture of the unlabeled U.S. is taken from <http://drupal.miriamsexton.com/files/images/

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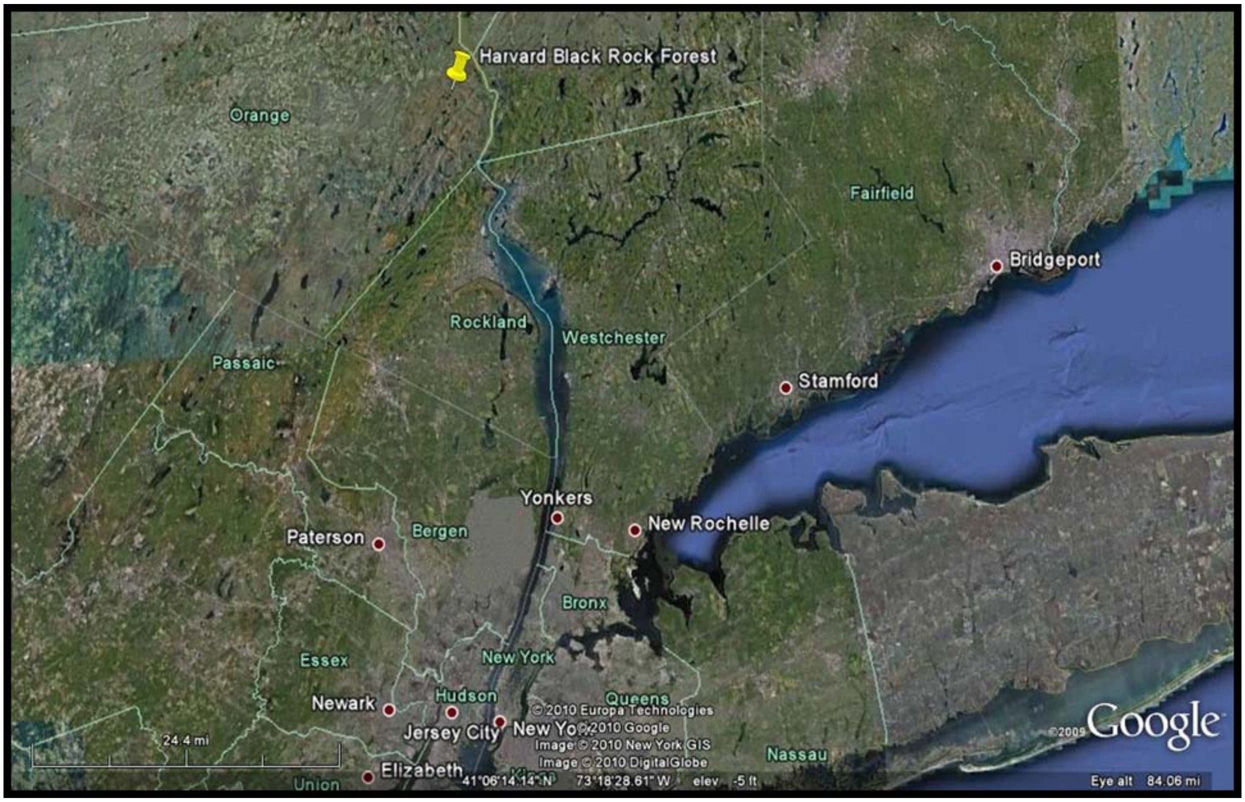

Figure 6: Location of Black Rock Forest with Respect to New York City

The location of Black Rock Forest is marked by a push pin. The forest is located near Orange, Westchester, and Rockland counties. Manhattan is about 50 miles south of BRF.

Rock Forest Preserve. Today, the forest is leased by the Black Rock Forest Consortium, consisting of private and public research and educational institutions that use the forest for field-based research and education (Black, 2009). Also in 1989, the forest management plan was reevaluated, determining that white-tail deer required active, annual management (Brady, 1984). Since that decision, the forest manager has been responsible for tracking and managing the small deer herd at Black Rock Forest. Because of the effect of deer browsing reducing both plant species diversity and forest regeneration, it is essential to continually assess and regulate the deer population (Latham, 2005).

Black Rock Forest as Deer Habitat

Seventy percent of the mountainous terrain of Black Rock Forest is above eleven-hundred feet in elevation (Black, 2009). The highest elevation of 1,461 feet at Spy Rock is positioned only two miles apart from the lowest elevation of 450 feet found at Peck's Pond. There are seven ponds in total throughout the preserve, creating a collective water source of about one-hundred acres (Figure 8).

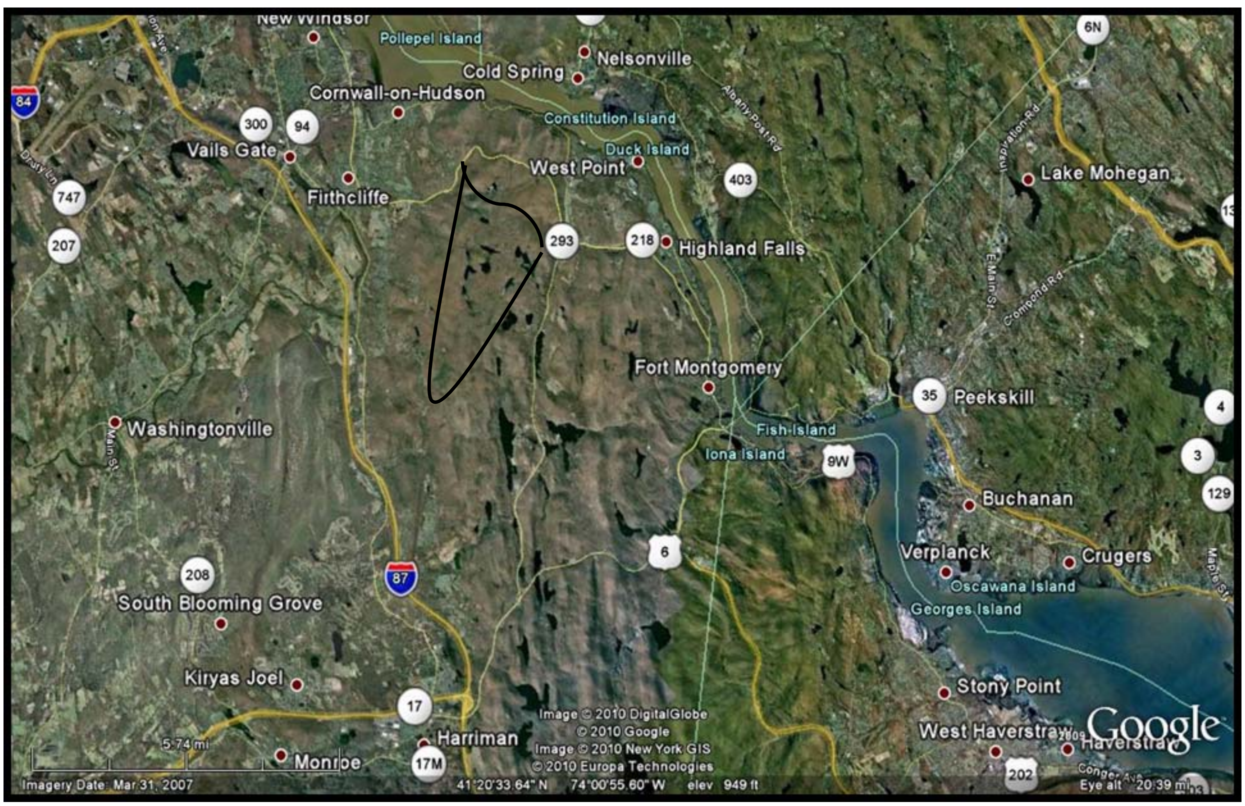

Figure 7: Village-Level Location of Black Rock Forest

Location of BRF between the villages of Cornwall-on-Hudson and Highland Falls. The forest boundary is marked by a black line. The scale is about 5.74mi per inch.

The forest is comprised mainly of oaks and hardwoods; sixty percent of which, due to burning and cutting, is at an equal stage of succession. This stage of succession represents dominant trees as seventy to one-hundred years old with an average diameter at breast height (DBH) of twelve to sixteen inches. Oaks are the most abundant species in the forest, followed by maples. The seven species of oaks at Black Rock Forest are, in order of abundance, Northern Red Oak, Chestnut Oak, White Oak, Black Oak, Scarlet Oak, Scrub Oak, and Swamp White Oak (Brady, 1994). The acorns of these oaks are a principal source of food during preparation for winter (Forbes *et al.*, 1941). Deer favor browsing at edge habitats; therefore the trails and other field areas at Black Rock Forest serve as an opportune place (Northeast, 2009). The proximity of

Figure 8: Sutherland Pond

Sutherland Pond, located in the northwest quadrant of Black Rock Forest, is ten acres and the only natural pond at BRF. The picture is taken on top of Split Rock, an elevation of 1400 feet. The picture is from <http://www.blackrockforest.org/ docs/about-the-forest/index.html>.

the forest to the neighboring towns allows the deer easy access to garden plants and other planted vegetative species (Figure 9). Nonetheless, deer do not migrate across large acres of land and tend to exhibit site fidelity, returning to the same seasonal ranges year after year (Porter and Underwood, 2001). These ranges, however, are not far from each other. Porter and Underwood (2001) found that movement of individual deer associated with seasonal dispersal was less than 0.7 miles. However, the difference in elevation and the U.S. highway, 9W, are additional reasons that suggest the possibility of limited to no immigration or emigration between the deer population in the forest and that of the nearby towns, Cornwall and Cornwall-on-Hudson (Figure 9). Therefore, little to no immigration or emigration is assumed between the population at Black Rock Forest and the population in the nearby towns because these locations are on average 2.5 miles apart, which is larger than the estimated movement of deer seasonally (Figure 9).

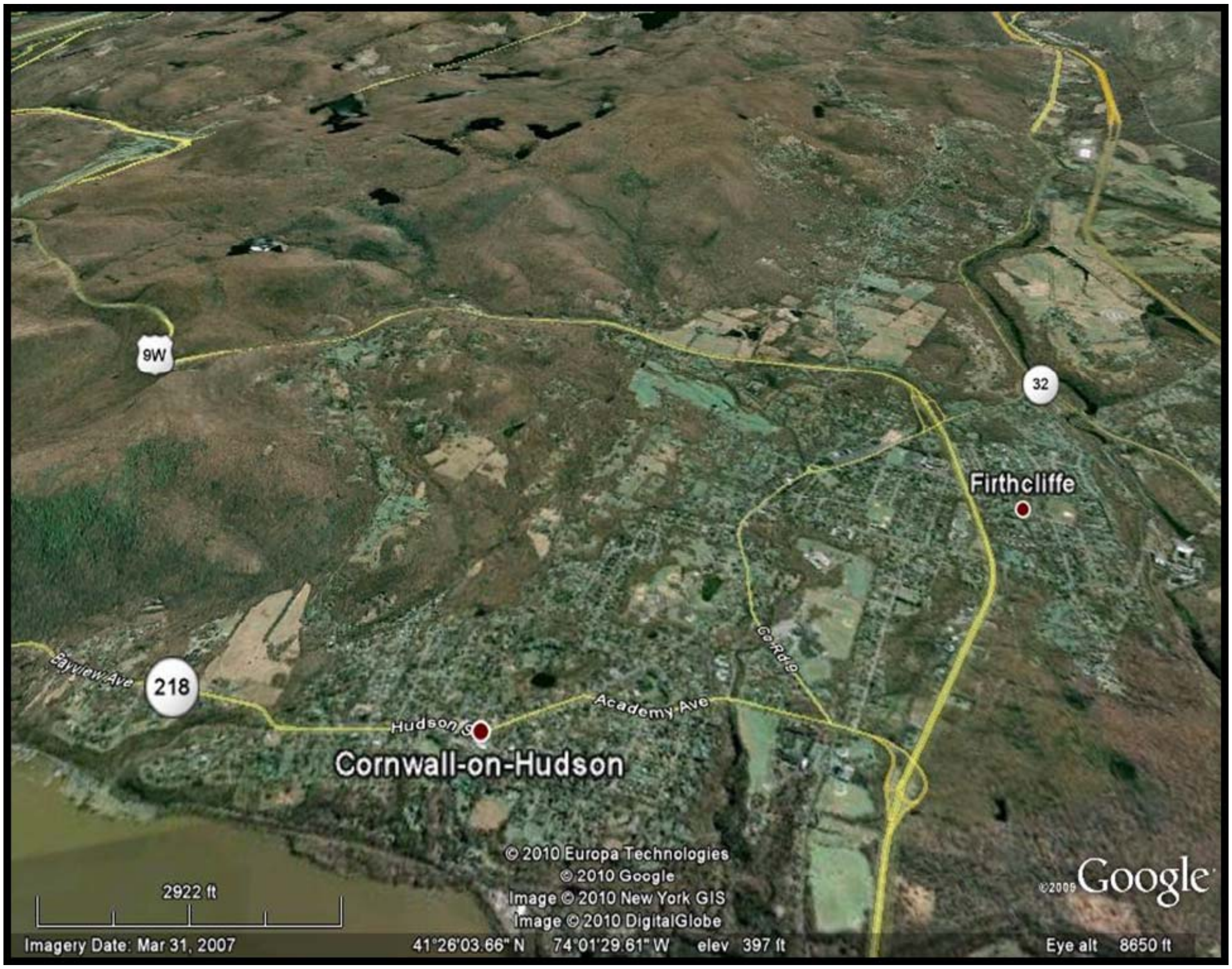

Figure 9: Black Rock Forest and Cornwall-on-Hudson

This shows the elevation of BRF with respect to that of the village of Cornwall-on-Hudson. The road 9W and mountainous terrain separate the town from the forest.

Management History at Black Rock Forest

The following information regarding management history at Black Rock Forest is all taken from Brady (1994). Hunting has been the primary deer population management policy at Black Rock Forest since 1970. Hunting and fishing is limited to members of the Black Rock Forest Fish and Game Club. The hunting season, starting on the second Monday after November tenth, is twenty-three days and ends on the second Tuesday in December. Starting in 1989, Black Rock Forest was divided into ten hunting zones. The first biological data recorded from deer killed during the hunting season were in 1981. Annual information collected about the deer killed includes weight, age, sex, and the number of antler points or spikes. In 1976, does were allowed in the hunting take for the first time as a way to decrease population size.

Thesis Statement

Upon completing the data analyses for this thesis, I hypothesize several results. For my conclusive results, I expect to find that the total amount of female deer killed during the hunting season and the number of days the snow depth was greater than twelve inches would have a strong negative correlation with the following year's deer density. I also expect a combination of acorn abundance to have a positive correlation with the current overwintering density and snow depth to have a strong negative correlation with the current overwintering density. This suggests that a plentiful acorn supply and a mild winter with few days of deep snow would result in a large overwintering density. On the contrary, an insufficient acorn supply and severe winter will result in a low overwintering density. I am prepared for a lack of significant results due to the small data set focusing on years only with data for all variables (1995-2006).

Methods

Data Collection

All data were collected at Black Rock Forest except for January to March temperature data (NOAA, 2001). Beginning in 1970, the forest manager has collected annual data for snowfall, overwintering deer density, hunting take, and viable acorn crops. Two summers ago, I participated in several of the data collection techniques used in this study. Some time periods of these data were published in annual Black Rock Forest Harvest Reports, but most of the data were not in a current digital form. Last summer was spent compiling the collected data into an Excel database and running analyses.

Indices of Abundance

Due to the difficulty in determining the exact number of deer at Black Rock Forest, several indices of abundance were used to represent trends in population density. The following dependent variables are the indices of abundance determined by five methods.

Overwintering Deer Density

The number of deer in the forest over the winter, the overwintering deer density, was determined from the observations made during the Deer Tracking Census (DTC). The DTC is performed annually between the first of December and the first of April. An all-terrain vehicle is driven on predetermined routes, in Black Rock Forest during the day, at either 12 or 24 hours after each snowfall and the number of deer seen and deer tracks observed is recorded (Figure 10).

Figure 10: White-tail Deer Tracks in Snow

The picture was from the Loudoun Wildlife Conservancy.

This lag time after the snow has fallen allows time for deer to become active after the snowfall, which increases the chances of seeing tracks or individual deer. Information recorded from the DTC is the distance traveled by the researcher, direction deer are traveling, number of groups of deer, number of deer per group, and number of deer per mile. Brady then estimates if any of the deer were counted more than once and adjusts the number of deer per mile accordingly. The number of deer per mile first began to be recorded annually in 1986. This number of deer per mile is then converted to deer per square mile (Gallina and Mandujano, 1995). The number of deer per square mile has been recorded annually since 1994. Other popular population estimate methods that could have been used for this study are the pellet group or aerial counts, line transects, mark-recapture, and change-in-ratio methods (Conner *et al.*, 1986), but none of these is performed annually at Black Rock Forest.

Reconstructed Population Size

Data for reconstructed population size have been recorded since 1983. At the deer check station, data are collected from each killed deer, especially age. By the end of the hunting season, the ages for all male and female deer killed are recorded and the year of their birth identified. It is in this way that the population is reconstructed. For example, there were 4 male fawns and 3 female fawns killed in the 1999 hunting season. During the next hunting season, 15 male and 2 female yearlings were killed. Next, in the 2001 hunting season, 10 male and 7 female 2.5 year olds were killed. These numbers are added to indicate that thus far, a total of 41 deer were born in 1999. This process continues until no more deer born in 1999 are killed during a hunting season. The result is a minimum estimate of the number of deer in the forest in 1999.

Buck Take and Hunting Success

Generally, the primary source of information about a deer population is gathered from the annual hunting harvest (Roseberry and Woolf, 1991). The buck take refers to the total number of antlered males killed during each hunting season, recorded at the deer check station. It has been recorded annually beginning in 1970. In association, the hunting success rate refers to the average number of deer shot per hunter. The deer used in calculating hunter success for this study included bucks, does, and antlerless deer. Hunter success rate is calculated using the information gathered annually, such as the number of hunters, the number of visits per hunter, and the number of deer killed. This success rate has been recorded at Black Rock Forest after each hunting season starting in 1991.

Density-Dependent Variables

Total Hunting Take

At the deer check station, data from the killed deer or hunting take is retrieved, such as the age, weight, sex, and number of points or spikes on buck antlers (Figures 11 and 12). These variables have been used as indicators of herd health (Brady, 1994). From these annual data, the total harvest calculated by adding bucks and antlerless male deer killed, and the total harvest calculated by adding bucks and does killed were used.

Figure 11: Measuring Buck Antler Beam Diameter (ABD)

John Brady is measuring the ABD of a male white-tail deer, which can be used to estimate weight and age of a male deer (McCullough, 1982). The picture was taken by Dr. Peter Bower's Field Methods in Environmental Science 2007 class.

Doe Take

Doe take is the other density-dependent variable used in this study. This information is recorded annually along with the other harvest data at the deer check station.

Density-Independent Variables

Acorn Abundance

Acorn crop sampling at Black Rock Forest began in 1995. Acorns drop from trees in the fall between the end of September and beginning of October (Figure 13). During this period,

Figure 12: Deer Jaw-Aging Technique

John Brady is using the deer jaw aging technique to age a buck, which consists of observing the wear on the teeth and the height of the enamel crests (Ramsey *et al.*, 1993). The picture was taken by Dr. Peter Bower's Field Methods class in 2007.

acorn sampling was performed weekly along predetermined transect lines that are reused each year. These transect lines were traveled via vehicle and contain 15 sampling sites (Brady, 1994). At each sampling site, a hoop 34 inches in diameter was thrown randomly 10 times and the number of acorns, species of acorns, and percent viable acorns were recorded for each time the hoop is thrown (Eckert, 1976). The viability of acorns was calculated by taking all acorns counted within the hoop and dropping them in a bucket of water to see if they float (Brady, 1994). The ones that float were considered nonviable in that they did not have enough matter within the nut for deer to obtain. Viability was determined only for knowing how much fat reserves were available to deer before the winter. However, there was no evidence thus far

Figure 13: Northern Red Oak Acorns

Picture from the USDA Forest Service

showing that deer avoid nonviable acorns (McShea, 1993). From this acorn sampling, a total annual number of viable acorns per acre could be determined. Other methods of acorn crop collection such as using seed traps were not used because the initial acorn data collection used at Black Rock Forest, described above, was continued through the years for purposes of consistency (Greene, 1994). The method of determining annual acorn crops at Black Rock Forest was more accurate than using seed traps and because it did not have a finite counting speed, it was slightly more accurate than a visual survey (Carmen *et al.*, 1994).

Temperature and Precipitation

The depth of snow was measured in inches after each snowfall and an average was determined for the year. Precipitation was also collected after each rainfall and measured at several locations in the forest. Snowfall and precipitation data was recorded daily and hourly. The average daily snowfall and precipitation were used for this study. Any precipitation data that failed to be collected at Black Rock Forest was obtained through the Department of Commerce, National Oceanic and Atmospheric Administration.

Summary of Data Collection Timeline

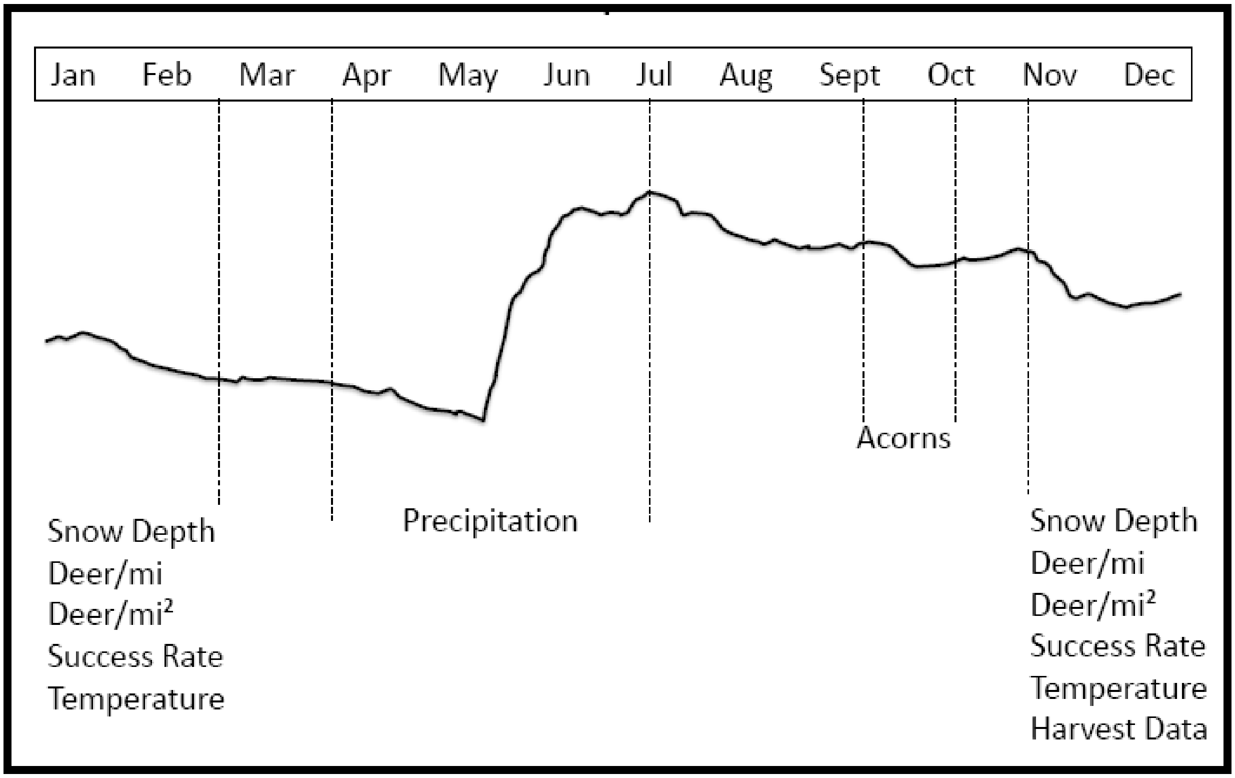

Figure 14: Data Collection Timeline

The time that data were collected were graphed using dotted lines. The bold line that spans the months represents the theoretical population growth.

The precipitation data used were collected for the months of April and July and the acorn abundance was recorded between September and October (Figure 14). The data collection for indices of abundance (deer per mile, deer per square mile, success rate, and buck take and reconstructed population from harvest data) occurred in winter months between November and February (Figure 14). Other data collected during these months were temperature data and snow depth data. The main collection for snow depth, deer per mile, and deer per square mile took place after the calendar year change between December 31st and January 1st. It is for this reason that the data for snowfall, deer per mile, and deer per square mile were moved from year N to year N-1 in order to create a time frame appropriate to the lifecycle of a deer rather than analyzing according to calendar year. For example, the acorn abundance, temperature, precipitation, reconstructed population, hunter success rate, and hunting take data from September 2003 to January 2004 were analyzed with the data for deer per mile, deer per square mile, and snowfall from the winter of 2004 to 2005.

Data Analysis

Tests for Normality

Each variable used in the analyses was tested for normality using the Shapiro-Wilk and Fisher kurtosis statistics. The Shapiro-Wilk statistic could be thought of as the correlation between data and the normal distribution. Because it represented a correlation, the statistic should have been a number between 0 and 1.0. A Shapiro-Wilk statistic of 0 indicated that the data were not correlated with the normal distribution and therefore were non-normal. On the other end, a Shapiro-Wilk statistic of 1.0 signified that the data had the strongest correlation with the normal distribution and were perfectly normal (Garson, 2010). The Fisher kurtosis statistic identified skew. SPSS centered the normal distribution on 0 as opposed to some programs that center it around 3.0. Interpretation of the Fisher kurtosis statistic varied from a lenient range of -3.0 to 3.0 to a rigid range of -1.0 to 1.0. A statistic that fell within the chosen range, be it anywhere between -3.0 and 3.0, was characteristic of normally distributed data (Garson, 2010).

Pearson Correlations

Pearson correlation matrices were performed in order to assess the relationship between variables. Correlations were first performed for all the dependent variables and then another correlation was performed for all of the variables; dependent and independent.

Stepwise Regressions

Stepwise regressions were performed using the quantitative analysis program, SPSS. A total of five stepwise regressions were completed at each time lag (no time lag: T0, one-year time lag: T1, two-year time lag: T2, three-year time lag: T3). A regression was completed for each dependent variable with all of the independent variables and all four indices of abundance for the previous year. This test should show if there was a relationship between a dependent variable and any independent variable or previous year's index of abundance and at what time lag this relationship was strongest (Norusis, 1991). The results should indicate any factors that may help explain the variance in the population size (Kerlinger and Pedhazur, 1973). It should be noted that only the overlapping years (1996-2002, 2004, 2005), those for which all data were collected, were used in the analyses.

Results

Trends in Indices of Abundance

The trends for each of the dependent variables were graphed for each year data were collected from 1970 to 2009 (Figure 10). All of the data show variability throughout this time period. White-tail population growth at Black Rock Forest more correlated with a logistic population growth model than an exponential (Figure C.1, Table C.2) and resulted in an estimated carrying capacity is about 19 deer per square mile (Table C.2).

Deer per Mile

The highest average number of deer per mile (8.7) was in 1997 and the lowest, 3 deer per mile, was recorded in 2008. The fastest rate of change occurred from 2001 to 2002 when a density of 7.8 deer per mile was reduced to 3.2 deer per mile, respectively. Generally, there was little fluctuation between 1987 and 1996 as compared with the larger fluctuation patterns between 1997 and 2008.

Deer per Square Mile

The largest deer per square mile (22) was recorded for 2006 and the smallest (14.8) in 1994. The largest change in deer per square mile from year to year occurred between 1998 and 1999, when the density dropped from 21.6 to 15.8 deer per square mile.

Buck Take

The lowest buck take (7) was in 1982 and the highest (56) was recorded four years later in 1986. The average buck take was 31. There were five successive years of decline in buck take from 1977 to 1982. The highest rate of increase or decrease in buck take was an increase of 17 bucks taken from 35 taken in the 1990 hunting season to 52 taken in the hunting season of

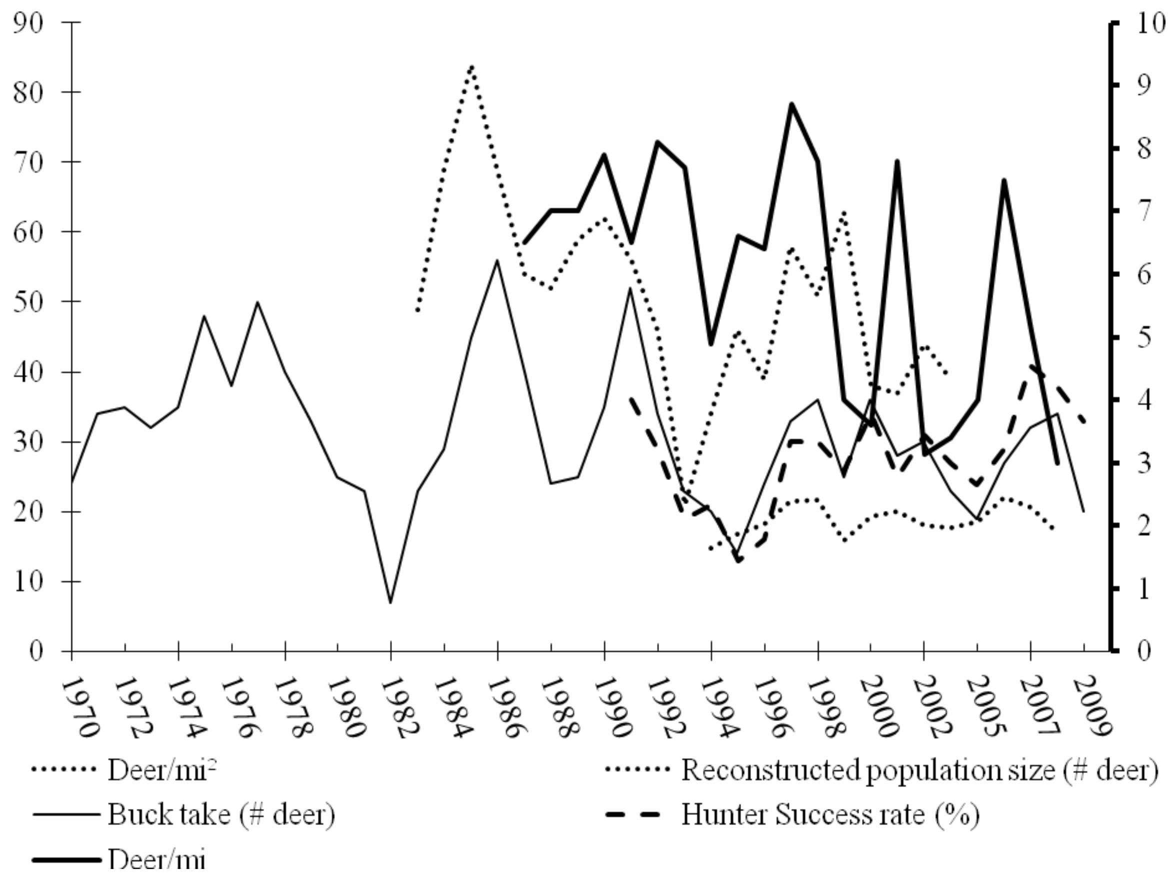

Figure 15: Trends in Indices of Abundance

Data for the five indices of abundance, the dependent variables, were graphed for all of the years that data was collected for each. The unit for the axis on the left is as described in the legend for all variables except for deer per mile which is on the secondary axis on the right.

1991. An increase of 16 bucks taken was observed between the hunting seasons of years 1982 to 1983, 1984 to 1985. Conversely, a decrease of 16 bucks taken occurred between 1981 to 1982, 1986 to 1987, and 1987 to 1988 hunting seasons. There was little change in the amount of bucks taken per hunting season between 1971 and 1974, and between 1997 and 2002.

Reconstructed Population Size

The largest reconstructed population size (84) was for 1986. The lowest reconstructed population size (21) was for 1994. The average population size reconstructed was about 51 deer in the forest. The fastest rate of change in reconstructed population size was a rate of 25 deer decrease observed from both 1993 to 1994 and 2000 to 2001.

Hunter Success Rate

The highest hunter success rate (41%) was in 2007 and the lowest (13%) in 1995. In the 1995 hunting season, there were 14 bucks, 0 antlerless deer, and 11 does taken. The number of bucks taken was less than the 1970-2009 average (31) and the number of does taken was less than the 1976-2009 average (21). Also this hunting season, there were 190 hunters, which was greater than the 1993-2009 average of 188 hunters. The total number of hunter visits for 1995 (543) was lower than the 1993-2009 average of 601 hunter visits. Finally, in 1995 the average number of visits per hunter was 2.86, which was lower than the 1993-2009 average (3.39). In 2007, the hunter success rate was 41%. This year, there were 32 bucks, 2 antlerless deer, and 23 does taken during the hunting season. The number of bucks killed was greater than the 1970-2009 average (31) and the doe take also was larger than the 1976-2009 average (21). For the 2007 hunting season, 140 hunters participated, which was less than the 1993-2009 average (188).

Although the total number of hunter visits (489) was less than the 1993-2009 average (601), the average visits per hunter (3.49) was slightly greater than the 1993-2009 average (3.39).

Age Distribution of Population

In 1995, the age class that comprised the largest percentage of the population was the yearlings, comprised more than half of males (Figure 16). The 2.5, 3.5, 4.5, and 6.5 year-old age classes were the next largest to the least percentage of the population, respectively. There was no percentage of the population in the age classes of fawns, 5.5, or 7.5 year-olds. The yearling age class was predominately male. Females accounted for slightly larger than half of the total percentage in the age class of 2.5 year-olds and made up the entire percentage of 4.5 and 6.5 year-old age classes. The age class of 3.5 year-olds had about an equal amount of males and females. The largest percentage of females in the population was seen in the 4.5 year-old age class and the least in the 6.5 year-old age class. The age classes of 1.5, 2.5, and 3.5 years had an average percentage of females when compared to the percentage of females in the other age classes. The largest percentage of males was observed in the yearling age class and an equal percentage of males in the other two age classes of 2.5 and 3.5 year-olds.

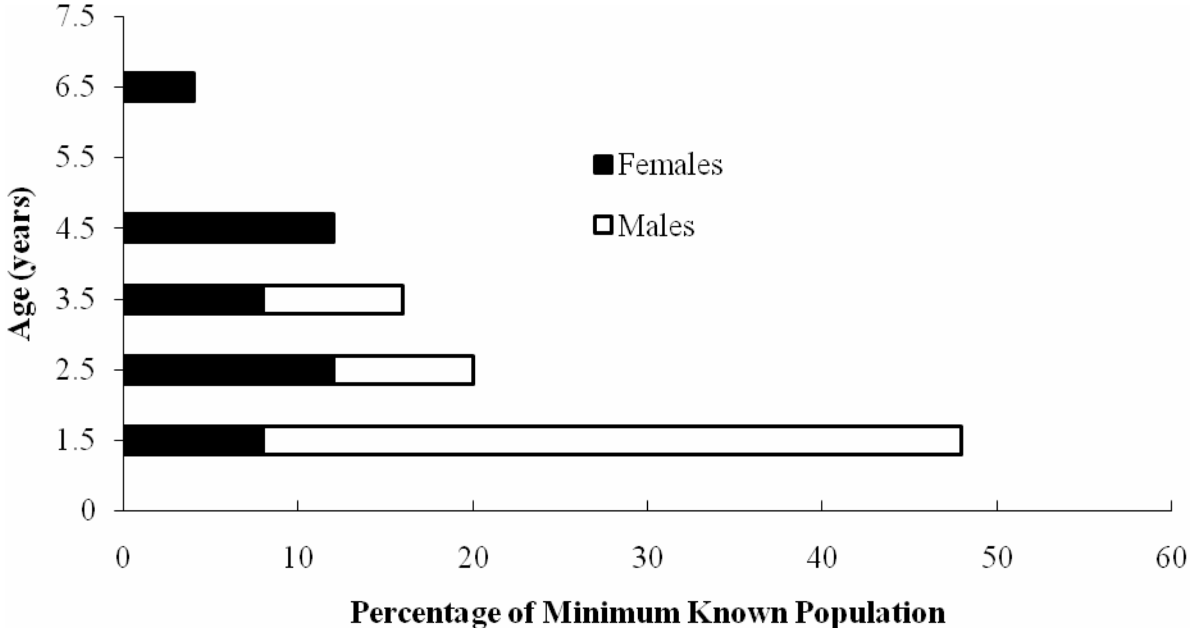

Figure 16: Age Distribution of 1995 Population

Total harvest data were divided into male and female percentages and graphed. Observed was the percentage of various age classes that made up the current 1995 minimum known population.

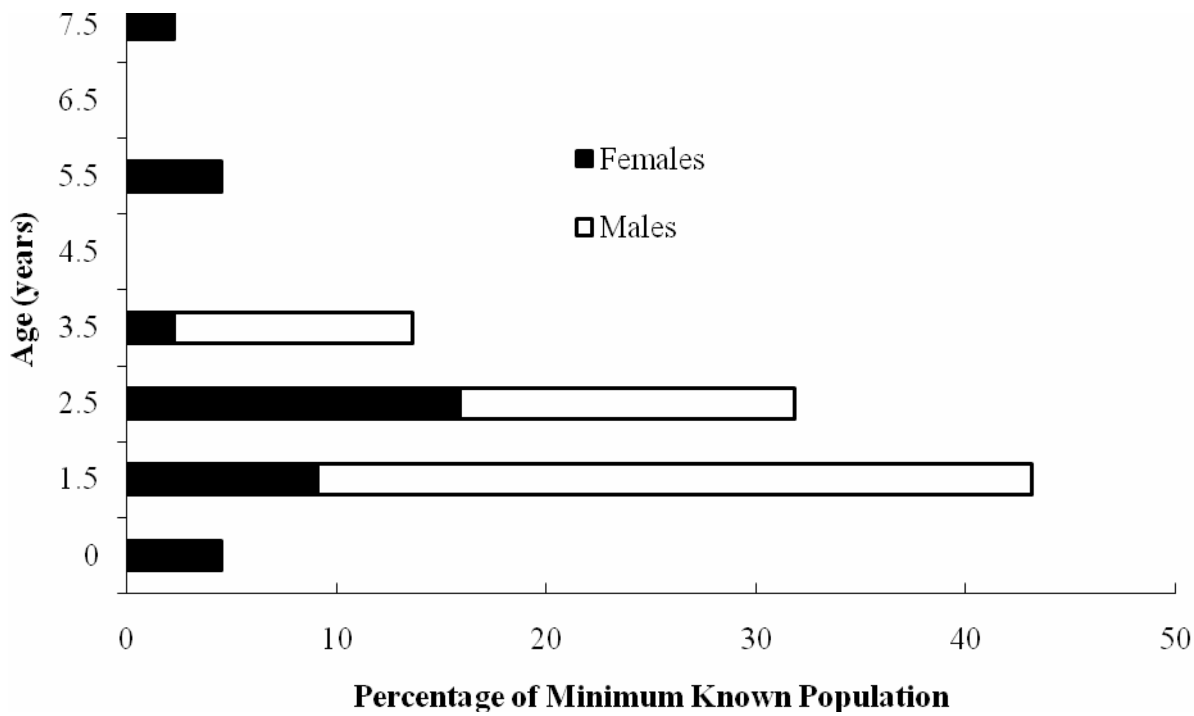

Figure 17: Age Distribution of 2006 Population

Total harvest data were divided into male and female percentages and graphed. Observed was the percentage of various age classes that made up the current 2006 minimum known population.

Preparations for Stepwise Regressions

Normality Test Results

For all data except snow depth, the Shapiro-Wilk statistics were between 0.9 and 1.0 and the Fisher kurtosis statistics fell between -3.0 and 3.0 (Appendix A.1, A.2), both of which indicated that the data were normally distributed (Garson, 2010). Because the Shapiro-Wilk statistic for snow depth (0.601) was significant (p <0.05), the data for that variable were non-normal. Because the skew was positive, a log transformation was performed (Norusis, 1982). The transformed log of snow depth values were tested for normality and the data were normally distributed (Appendix A.3).

Correlations for Indices of Abundance

The indices of abundance were run through a Pearson correlation matrix and each was strongly correlated with at least one other index (Appendix B.1). The reconstructed population size is strongly correlated (0.538) with the total buck killed during the hunting season. The buck harvest is also correlated strongly with deer per square mile (0.762) and hunter success rate (0.856). Deer per mile is correlated strongly (0.625) with deer per square mile. Because no particular index of abundance was not correlated with any other indices, all five were used for the next analysis, the stepwise regression.

Stepwise Regressions

Zero Time Lag

For deer per mile, total acorns were the first data entered into the stepwise regression. The significant correlation between these variables (0.670, p-value < 0.05) resulted in an R-squared value of 0.448 and adjusted R-squared of 0.370. The second and last variable entered into the equation for deer per mile and total acorns was snow depth. Snow depth had a -0.505 correlation with deer per mile and the addition of snow depth to the stepwise equation of deer per mile and total acorns resulted in an R-squared value of 0.799 and an adjusted R-squared value of 0.732.

For buck take, total take of bucks and does was the first variable entered into the regression equation. This total take was significantly positively correlated (0.802, *p*-value < 0.01) with buck take. This resulted in an R-squared value of 0.643 with an adjusted R-squared value of 0.592. The second and last variable entered into the stepwise regression equation, doe take, had a 0.396 correlation with buck take. After doe take was entered into the equation, the R-squared and adjusted R-squared values were both 1.000.

The only variable entered into the stepwise regression equation with hunter success rate was total take of bucks and does. These significantly correlated data (0.855, *p*-value < 0.005) produced an R-squared value of 0.731 and an adjusted R-squared value of 0.692.

No variables were entered into the stepwise equation for deer per square mile or for reconstructed population size.

One-Year Time Lag

Two variables were entered into the stepwise regression equation for deer per mile. The first variable, with a significant negative correlation with deer per mile (-0.870, *p*-value < 0.005), was the previous year's buck take. This resulted in a high R-squared value (0.756) and adjusted R-squared value (0.715). The second variable entered into the equation with deer per mile and the previous year's buck take was snow depth. Snow depth was weakly correlated with deer per mile (-0.261) but its addition into the equation resulted in an R-squared value of 0.927 and an adjusted R-squared value of 0.898.

One variable, snow depth, was entered into the equation for buck take. These variables were significantly negatively correlated (-0.708, p-value < 0.05). The R-squared value for these variables was 0.501 and the adjusted R-squared value was 0.418.

For deer per square mile, doe take had a significant, strong, negative correlation (-0.785, p-value < 0.05) and was the only variable entered into the stepwise regression equation. The resulting R-squared value was 0.616 and the adjusted R-squared value was 0.552.

No variables were entered into the stepwise regression equation for hunter success rate or for reconstructed population size.

Two-Year Time Lag

For deer per mile, the significantly, strongly, negatively correlated (-0.816, p-value < 0.05) previous year's buck take was first entered into the regression equation. The resulting equation had an R-squared value of 0.667 and a high adjusted R-squared value of 0.600. The second and last variable entered into the equation with deer per mile and the previous year's buck take was snow depth. Snow depth had a -0.376 correlation with deer per mile and after it was added into the equation, the R-squared value was 0.948 with an adjusted R-squared value of 0.921.

Snow depth was the only variable entered into the equation for buck take. These variables had a significant, negative correlation (-0.761, p-value < 0.05) and the equation had an R-squared value of 0.579 and an adjusted R-squared value of 0.494.

Hunter success rate had one variable entered into the regression equation. This variable, April through July precipitation, was significantly negatively correlated with hunter success rate (-0.768, p-value < 0.05). The resulting R-squared value was 0.589 and the adjusted R-squared value was 0.507.

Deer per square mile and doe take were significantly negatively correlated (-0.880, p-value < 0.01). Doe take was the only variable entered into the equation for this index of abundance. This equation had a high R-squared value (0.775) and a high adjusted R-squared value (0.730).

No variables were entered into the regression equation for reconstructed population size.

Three-Year Time Lag

Out of all five indices of abundance, reconstructed population size was the only one for which a variable was entered into the stepwise regression equation. The previous year's reconstructed population size was entered into the equation for reconstructed population size. These two variables had a strong correlation (0.851) and the equation produced an R-squared value of 0.724 and an adjusted R-squared value of 0.656.

Discussion

Given that the strongest correlations involved deer per mile, this is the index of abundance that will receive a lengthy description. At zero time lag deer per mile has a positive correlation with total acorns and a negative correlation with snow depth. The stepwise regression analysis indicated that the combination of total acorns and snow depth had the greatest influence on deer per mile with no time lag. Since the highest number of deer per mile was in 1997, and the lowest in 2008, the 1997 and 2008 data for snow depth and acorn abundance should follow this trend in density accordingly. Deer per mile was lowest in 2008. A drop in acorn abundance from 25,000 acorns per acre in 2007 to 5,000 acorns in 2008 is observed. This seems to support the direct correlation between total acorn abundance and density of deer per mile. In 1996, there was a snow storm with over 108 inches of snow and 84 days of 12 inches of snow depth or more. It is possible that this severe winter resulted in high mortality and continued until the spring months. Both the reduced reproduction and individual survival are the conditions in which the population entered into the winter of 1997, which had 3 days of snow depth greater than 12 inches. It is believed that populations decrease after severe winters, which appears to be supported by the results of the stepwise regression (Severinghaus, 1972). However, the same trend of over three days of snow depth greater than 12 inches can be seen in 2008, which is the year with the lowest deer per mile. Although 1997 and 2008 had similar trends in regards to snow depth data, it is the acorn abundance data that vary for these two years. In 1997, despite the reduced health and increased mortality of the population due to severe winters, the acorn crop was abundant and the deer density or deer per mile was highest. On the other hand, in 2008 when winter weather was the same as the winter of 1997 alone, there were few acorns available for the deer and the density that year was the lowest of all years. McShea and Schwede assert that deer are not a mast-dependent species (1993). The results of this study indicate that acorn mast is influential in deer density of that year but it is not the only factor that independently most influences relative abundance of deer per mile. However, it is the combination of snow depth and acorn abundance that most influences density.

Since the previous year's buck take showed a strong negative correlation with deer per mile with a one-year time lag, it is similar to say that buck take has a two-year time lag with deer per mile. This trend can be observed for the years 1991 and 1994 (Figure 15). From 1991 to 1992, buck take decreased from 52 to 34. Two years later, there is a sharp decrease in deer per mile, from 7.7 deer per mile in 1993 to 4.9 deer per mile in 1994. The addition of snow depth to the equation of previous year's buck take and deer per mile at a one-year time lag did increase the adjusted R-squared value by more than 0.3 and the R-squared value by slightly less than 0.3. A very similar relationship between deer per mile, previous year's buck take, and snow depth is observed with a two-year time lag.

Age class distributions for 1995 and 2006 (Figures 16 and 17) suggest a future increase in the population size (Odum and Barrett, 2005). There are a larger percentage of younger age classes than older age classes for each year. The relative population abundance for 1995 to 1997 supports this with an average rate of increase in the variables of deer per square mile, hunter success rate, and total buck take. For deer per mile, there is a 0.2 decrease in density from 1995 to 1996 and then a drastic jump to 8.7 deer per mile in 1997. The reconstructed population size is more variable from the trend of the other indices of abundance during this time period. The reconstructed population size changes from 34 to 46 between 1995 and 1996 and then to 39 in 1997. There is no complete data for reconstructed population size for 2006 to today but the other indices do not increase as the age distribution suggests would happen as described by Odum and Barrett (2005). Deer per mile gradually decreases from 7.5 to 3.0 in 2006 to 2008. Buck take gradually increases during that time from 27 to 34 individuals. This could have been expected though because of the aforementioned strong negative correlation between buck take and deer per mile. Hunter success rate, on the other hand, increases from 2006 to 2007 and then decreases from 2007 to 2008. Assuming there is not a lot of information lost to error, which will be addressed shortly, the data for this population do not support the concept that a larger percentage of younger individuals that older will lead to an increase in the population size.

Possibly, the female to male ratio could account for the population trend unaccounted for in the percentage of age classes in the population. It is common in herds subject to sport hunting for there to be more females than males. This has been observed in deer herds at other locations because of depleted fat reserves in males during the rut, which results in their mortality during the winter months. However, an explanation for another regularly hunted herd but with an equal ratio of females to males is that the acorn supply is sufficient enough to provide nutrition throughout the winter (Kie and White, 1985). From this train of thought, it should be expected that any annually hunted deer population will have an equal female to male ratio if it has abundant fat reserves to last the winter months. The average population at Black Rock Forest from 1970 to 2008 has a female to male ratio of 0.6, indicating almost double the amount of males in the population than females. This does not support the findings of Kie and White (1985). This leads to the idea that the quality management approach seeking to reduce the number of males in the population may be necessary at Black Rock Forest.

Halls (1984) suggests that the majority of twins or triplets birthed by well-nourished females is male. These is not enough evidence given by the age class distributions to support or reject this statement directly but the percentage of males making up the age classes of yearling, 2.5, and 3.5, is more than that of females for 1995 and 2006. This could be the result of females haven given birth to more males but there could be other reasons explaining this phenomenon.

One explanation is that the data used to construct the age class distributions was the reconstructed population size inferred from harvest data. However, the hunting data are biased in two ways. Buck take is biased because most hunters prefer male deer with antlers; antler size represents the achievement of the hunter (Connelly and Decker, 1989). Antlerless and doe take is biased because federal regulations regarding the number of doe a hunter can legally shoot changes over the years. Some years hunters must shoot a doe before shooting anything else and other years hunters are not allowed to shoot doe. Buck yearling weight because has been proven to be a good predictor of deer density for certain populations (Guynn *et al.*, 2005). However, the results of this study suggest that buck yearling weight is not a good indicator or predictor of deer density at Black Rock Forest (Table B.3).

The conditions associated with the largest success rate in 2007 compared with conditions related to the smallest success rate in 1995, indicate that the success rate does not increase with more hunters but with more bucks, antlerless, and does taken during the hunting season. This suggests, because more of all three were killed during the 2007 hunting season than in the 1995 season, either that the population size may have been larger in 2007 than in 1995 or that the density was larger in the areas where hunters were situated during 2007 hunting season than that of 1995. Fewer hunters participated in the 2007 hunting season but each hunter visited the forest about once more in 2007 than in 1995. The higher hunter success rate in 2007 could be contributed to an increase in hunter accuracy in killing deer between 1995 and 2007 or an abundance of deer killed during that one extra visit by each hunter in 2007. It is possible that none or both of these suggestions are the reasons for the difference in hunter success rates for the two hunting seasons. A further concentration on hunter accuracy and take per day at Black Rock Forest should be investigated in order to discern which of these explanations explains the difference in hunter success rates particularly of the 1995 and 2007 hunting seasons and the yearly difference in hunter success rates in general.

Additional sources of error involve harvest data. Harvest data theoretically includes any deer that a hunter brings out of Black Rock Forest without checking in at the deer check station. Compliance with this rule is thought to be 100% (Roseberry and Woolf, 1991). At Black Rock Forest, there is only one deer check station and hunters have to enter and exit the hunting zones in the forest through this point. There is always someone at the check station during hunting hours and the one-way road leading past the station inhibits anyone from entering if the person at the check station is busy recording data or talking with other hunters. These facts as well as the personal relationships gained between the same hunters and the forest staff over the years lead to the conclusion that although there is a chance of some unrecorded harvest data, this chance is highly unlikely.

Conclusions

Hunting and natural events have an influence on this particular population of white-tail deer. However, there does not appear to be any consistent time lag that can be applied to all of the data over the years. The number of days snow depth is greater than 12 inches is the only variable that can predict or reflect the trend in the white-tail density in the forest for all of the time lags tested. Findings indicate that the current year's overwintering deer density can be estimated by observing the trend in snow depth during the winter and the total number of acorns per acre during the fall of the same year. Findings suggest that the relative abundance of the white-tail deer population can be estimated or predicted in several ways. The snow depth and the total buck take of a certain year could explain the trend in the deer density the next winter and the winter in two years. Findings also suggest that snow depth can predict the trend in the deer density in two years and also that the buck take can be used to predict the trend in deer density in three years.

Recommendations

Two main recommendations can be taken from these analyses. Since the strongest correlations were observed with the index of abundance, deer per mile, that may be the best relative estimate of deer density in the forest and should be continued to be calculated and interpreted annually. Lastly, the continuation of regulated hunting, recording of total take and doe take harvest data, and monitoring of snow depth and acorn abundance are necessary in order to predict and manage deer density particularly at Black Rock Forest and possibly at other areas in need of deer management.

Acknowledgements

I would like to thank my mentors and thesis advisor for the countless hours they set aside to help me in any way possible while performing the research and analysis for this study. This communication with my mentors on-site could not be possible without the travel grant offered to me by Columbia University's Earth Institute. A special thank you also to the staff at Black Rock Forest, the staff at The Grail, Duane Diefenbach, William Porter, all of whom devoted time to discuss with me the issues pertaining to this study. Additional support was offered by Martin Stute, Alison Seigel, Angelica Patterson, Kamini Doobay, and Carolyn Popplewell.

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Appendix A: Assessing Malnutrition with Bone Marrow

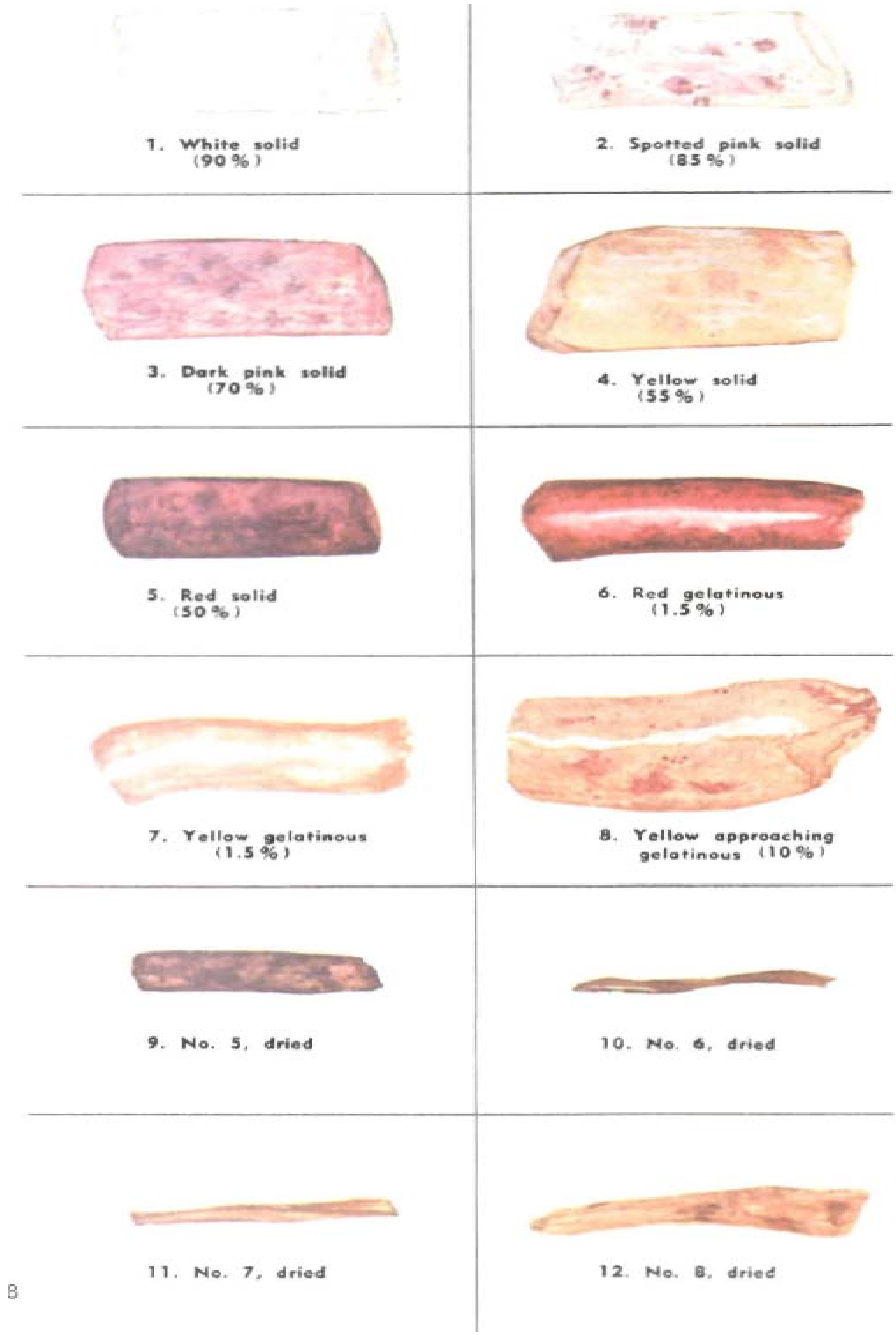

Figure A.1: Malnutrition and Bone Marrow

The bone marrow inside white-tail deer femur bones is pictured above. Characteristics of bone marrow can be used to assess relative nutrition of the deer at death. Numbers in parentheses indicate fat content of the bone marrow. The fatty bone marrow of well-nourished deer is at the top of the chart and the driest bone marrow of malnourished deer is at the bottom of the chart.

Appendix B: Normality Test Results

Dependent Variable	Deer/mi	Deer/sqmi	Reconstructed Population Size	Buck Take	Hunter Success Rate
Shapiro-Wilk statistic	.909	.964	.990	.952	.959
Fisher Kurtosis statistic	.032	-.927	.506	.862	-.313

Table B.1: Normality Test Results for Dependent Variables

All of the original data for each of the dependent variables had a Shapiro-Wilk statistic of between 0.9 and 1.0. The Fisher Kurtosis statistic for each was between -1.0 and 1.0. All data were normally distributed.

Independent Variable	Shapiro-Wilk Statistic	Sig. of Shapiro-Wilk	Fisher Kurtosis Statistic
Snow Depth (#days > 12 in)	**0.601**	**0**	**4.485**
Dec-Mar Temp (C)	0.958	0.759	-.728

Total Acorns (per acre)	0.93	0.375	-1.458
Total Viable Acorns (per acre)	0.95	0.633	-.563
Doe Take	0.96	0.789	-1.045
Total Take (buck + antlerless)	0.946	0.578	-1.097
Total Take (buck + doe)	0.927	0.353	-1.019
Apr-Jul Precipitation (mm)	0.941	0.51	.861
Apr Precipitation (mm)	0.923	0.314	1.214

Table B.2: Normality Test Results for Independent Variables

All data resulted in a Shapiro-Wilk statistic of between 0.9 and 1.0, except for the variable snow depth. All Fisher Kurtosis statistics generated were between -3.0 and 3.0 except for the snow depth data. The independent variables were normally distributed with the exception of snow depth, which had significant skew.

	Shapiro-Wilk Statistic	Sig. of Shapiro-Wilk	Fisher Kurtosis Statistic
Log Snow Depth	0.914	0.379	-0.678

Table B.3: Normality Test Results for Log Transformation of Snow Depth

The Shapiro-Wilk statistic was between 0.9 and 1.0 and the Fisher Kurtosis statistic was between 1.0 and -1.0 for the log transformed snow depth data. These transformed data were normally distributed.

Appendix C: Pearson Correlation Results

		Reconstructed	Buck Take	Deer/mi	Deer/sqmi	Success Rate
Reconstructed	Correlation	1	.538*	.169	.190	.427
	Sig.		.012	.517	.599	.146
Buck Take	Correlation	**.538***	1	.161	.762*	.856**
	Sig.	**.012**		.537	.010	.000
Deer/mi	Correlation	.169	.161	1	.625*	-.257
	Sig.	.517	.537		.017	.318
Deer/sqmi	Correlation	.190	**.762***	**.625***	1	.396

	Sig.	.599	**.010**	**.017**		.161
Success Rate	Correlation	.427	**.856****	-.257	.396	1
	Sig.	.146	**.000**	.318	.161	

Table C.1: Correlation Matrix for Indices of Abundance

This Pearson correlation matrix shows the strength of the correlation for each combination of two indices of abundance and also the significance of that correlation.

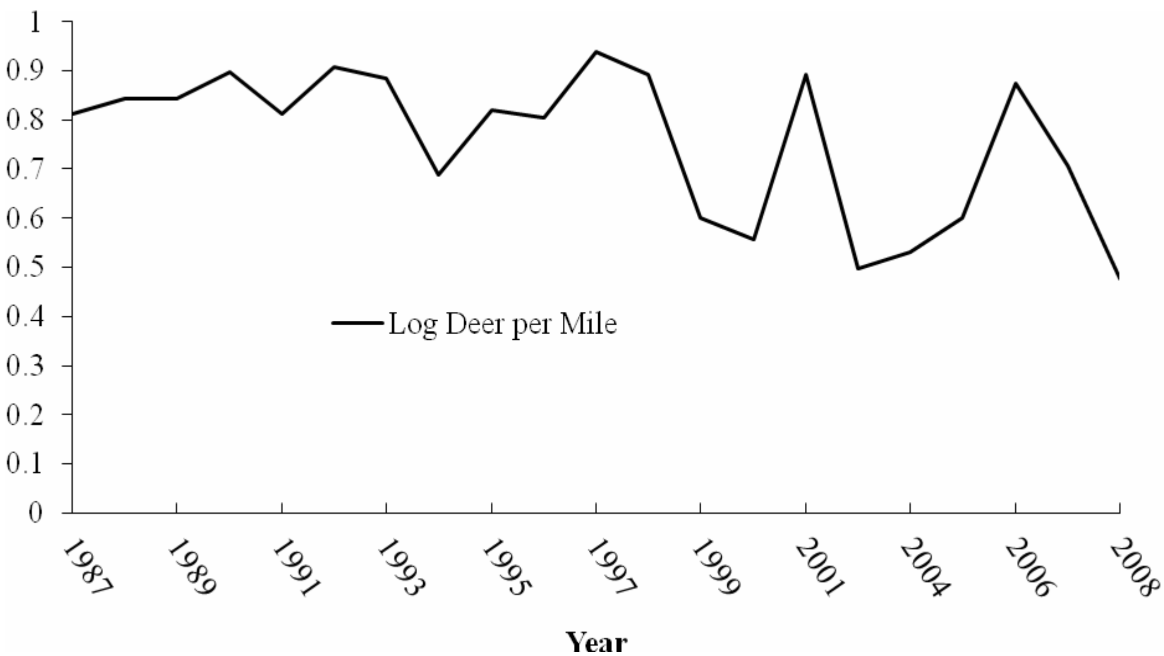

Figure C.1: Correlation for Deer per Mile and Exponential Growth

The log of the index deer per mile was taken and graphed against time. If the log of the population size was a straight line then the population followed exponential growth (Odum and Barrett, 2005).

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
r	1.191	1.204	-1.459	3.841
a	.047	1.478	-3.206	3.299
K	19.208	.629	17.825	20.592

R-squared value = .321

Table C.2: Correlation for Deer per Square Mile and Logistic Growth

Deer per square mile was put into a logistic growth equation in SPSS. The carrying capacity (K) is about 19 deer per square mile and the R-squared value is .321.

Time Lag (years)	Pearson Correlation
0	-0.109
1	-0.617
2	0.395
3	0.394
4	0.433

Table C.3: Correlation for Buck Yearling Weight and Density

Pearson Correlations were run for buck yearling dressed weight and density estimate of deer per square mile at time lags of 0, 1, 2, 3, and 4 years. Dressed weight refers to the weight of the body without the organs inside.